UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

REMOVAL OF CONTAMINATED SEDIMENT FROM ROOF SURFACES BY SHEET FLOW

Hydraulics Branch Report No. Hyd-501

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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FOREWORD

The study described in this report was conducted by the Sediment Investigations Unit of the Hydraulics Branch. The tests were made in the Hydraulic Laboratory by P. F. Enger, E. R. Zeigler, and R. A. Dodge, Jr., under the supervision of E. J. Carlson. Several engineers from the Structural and Architectural Branch and other design branches visited the laboratory during the tests to observe the results and apply them to designs in progress. Design personnel made suggestions which were very helpful in conducting the study and obtaining applicable results.

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Division of Research
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Special Investigations Section
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Laboratory Report No. Hyd-501
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REMOVAL OF CONTAMINATED SEDIMENT FROM ROOF SURFACES BY SHEET FLOW

SUMMARY

An investigation was conducted to study the possibility of utilizing water to flush (contaminated fallout) sediments, average diameter 200 microns (0.2 mm) from a flat roof surface. Preliminary tests using a half-round pressure conduit discharging on a level smooth floor, Figures 1 and 2, indicated that good results may be obtained on a troweled concrete surface. To extend the range of data, a 30-foot-long by 40-inch-wide tilting flume, Figures 3 and 4, was constructed and used to determine flow and sediment movement characteristics on painted concrete, asphalt and gravel and plastic sheet surfaces. Flume slopes and discharges were varied, and hydraulic characteristics and the velocity of movement of a 200-micron average-diameter sediment were determined for both a painted and concrete surface. Flume slopes were varied from near zero to approximately 0.2-foot per foot and discharges from approximately 0.03- to 0.36-cubic-foot-per-second per foot of width. Graphs of the velocity of fine sand movement in terms of discharge and slope for the two surfaces are shown in Figures 6 and 8, and graphs of the hydraulic characteristics of the painted and concrete surfaces are shown in Figures 5 and 7.

An asphalt-gravel surface was then constructed in the flume, and hydraulic characteristics were determined and are shown in Figure 9. The percent of fine sand which was washed from the asphalt-gravel surface, for various discharges and slopes, was determined, and a plot of the d ta is shown in Figure 10. The percentage of fine sand which could be washed from the surface was relatively small, reaching a maximum value of approximately 27 percent. This small percentage would make flushing contaminated sediment from rough surfaces by open channel flow impractical.

To determine if flushing an irregular surface could be made practical and inexpensive, a plastic cover was placed over the asphalt-gravel surface. The plastic material used was 10 mils thick and successfully bridged the voids in the uneven surface. Sediment was readily flushed from the plastic surface, indicating asphalt-gravel surfaces could rapidly and inexpensively be made satisfactory for cleaning by flushing with water. The curves shown in Figures 7 and 8 may be used for design purposes.

INTRODUCTION

Modern times presents us with the possible problem of contaminated fallout depositing on the roof of a structure and thereby creating a serious health hazard. The fallout material actually consists of sand or sediment of a particular size range and can be represented by ordinary sand. The early removal of the contaminated sediment from the affected area may be of utmost importance to the occupants. One method of removing the contamination may be to utilize a clean water source to wash the sediment from the affected area. Removal by this method is not overly difficult if the affected area is on a favorable slope and has a relatively smooth and dense surface. On the other hand, removal of the sediment from a rough surface, such as an asphalt-gravel roof, presents a difficult problem, and 100 percent removal cannot be assured.

In new construction, smooth, dense roofs set at the proper slope to assure sediment removal with minimum waterflow may be specified. However, it would be necessary to treat existing asphalt-gravel roofs in some manner to render their surfaces smooth before flushing methods could be used effectively. In the case of an existing roof having a smooth, dense surface, but having an adverse or insufficient slope, hydraulic model studies are recommended to assure that sufficient removal could be obtained by flushing with water.

This model study was conducted to obtain data to assist in the design of roof flushing systems.

THE INVESTIGATIONS

Preliminary Tests

To study the possibility of utilizing water to flush sediment of 200-micron average diameter from smooth, dense surfaces, brief preliminary tests were made in existing flumes to determine the effectiveness of tranquil flow (low velocity) and shooting flow (high velocity) in moving sediment on horizontal surfaces. The tranquil flow moved the sediment very slowly--approximately 0.01 to 0.02 foot per second when the water depth and velocity were 0.3 and 1.0 foot per second, respectively. However, the preliminary tests indicated that higher velocity flow would rapidly move the sediment. Additional tests with higher velocity flow were therefore conducted.

Tests Conducted on a Flat Concrete Surface

To study higher velocity flow a half-round pressure conduit 8 feet long, Figures 1 and 2, was constructed. The conduit contained a slot adjustable in vertical opening from which water could be discharged onto a smooth, flat, 40-foot-long, concrete surface. Preliminary tests indicated that normal pressure differences which occurred along the conduit produced unequal longitudinal velocity distribution in the flow issuing from the slot. However, at pressures of approximately 2.2 pounds per square inch in the conduit (5.1 feet of water) and with resulting discharges from the slot of approximately 0.45-cubic-foot-per-second per foot of width, the test sediment could readily be flushed from the 40-foot-long concrete surface. Because of the pressure differences found to occur along the conduit and which resulted in a nonuniform discharge per foot of length along the slot, it might be desirable to make model studies of any manifold used for a pressure system. This would assure sufficient washoff of sediment with the minimum quantity of water. To extend the range of data, additional tests were performed in a tilting flume.

Tests Conducted on a Tilting Flume with a Painted Surface

Because preliminary tests had indicated that fine sand could be readily flushed from a smooth, dense surface, a tilting flume was designed to study the characteristics of sediment moving over different surfaces at various slopes and discharges, Figure 3. The flume was 30 feet long by 40 inches wide by 6 inches deep. The bottom was constructed of 3/4-inch plywood attached to three 2- by 8-inch longitudinal wooden beams. Sidewalls were constructed 6 inches high of 3/4-inch plywood. A pulley arrangement, Figure 4, was attached to the flume 18 feet from the upstream end and was used to change the slope of the flume from zero to approximately a 6-foot drop in 30 feet. The plywood bottom and sides of the flume were painted with an industrial oil-base enamel paint containing approximately, by weight, 30 percent titanium dioxide pigment, 31 percent soya alkyd resin, and 39 percent mineral spirits. The resulting surface appeared smooth and dense and was used for the painted surface tests.

In conducting a test, the slope of the flume was first established with an engineer's level and rod. Numerous points along the flume were checked for elevation, and if the flume bottom was found to be out of level or to deviate from the general slope, temporary braces were attached to the bottom beams, and the flume was forced into the desired alinement. The test discharge was then established in the flume, and a movable point gage on a movable aluminum channel was used to determine the boundary location and average water surface elevations at stations 2, 6, 10, 14, 20, 24, 26, 28, and 29 feet from the upstream end. After the flow characteristics had been recorded, 100 cc of fine sand of approximately 200-micron average diameter was rapidly dumped into the flume at a point 2 feet from the upstream end. The length of time required for the sediment cloud to travel over a given distance was recorded with a stopwatch. Photographs were made to help interpret data.

Plots of measured depth versus the distance from the upstream end of the flume indicated a near constant depth along most of the flume for most discharge slope conditions tested. Because only shallow depths were used in the flume (average approximately 0.05 foot), the constant depth reach was very long relative to the 30-foot flume length. For example, at most flow conditions the flume length was over 500 times the depth.

Normal depths plotted against the discharge, for the slopes tested, are shown in Figure 5. To establish the consistency of the data, which was difficult to obtain, Manning's equation was investigated to see if it applied to the flow conditions described. To establish a Manning's n value for the flume flow surface, Mannings's equation was used in the form:

$$n = \frac{1.49\, d^{5/3}\, S^{1/2}}{q}$$

where:

- q = the discharge ft^3/sec per foot of width
- d = the normal depth measured--feet
- S = the slope of the flume in ft/ft

The depth was used in place of the hydraulic radius because the depth of flow is small compared to the width of the flume.

An n value was calculated for each slope tested using a discharge of 0.2-cubic-foot-per-second per foot of width. The resulting n values were closely comparable and averaged 0.0098. Using this n value as a constant, Manning's equation was used to calculate the depths for the slopes tested. The equation was written in the following form:

$$d = \left[\frac{q\,n}{1.49\,S^{1/2}} \right]^{3/5}$$

The units are as previously defined.

Although the flume slopes were steep, the water depths were small, and the flow was usually supercritical, there was excellent agreement between the calculated and the measured depths, indicating that Manning's equation was applicable to the flow condition in the flume. A plot of the calculated results is superimposed on the plot of the measured depths and shown on Figure 5. For the steepest slopes, and lowest discharges, slug flow or roll waves occurred, and if the top of the wave was recorded to establish the depth, the flow was deeper than indicated by the equation. With this exception, the data indicate that if the correct Manning's n value can be determined for a smooth, dense, steep surface, the depths predicted by the Manning's equation will be quite accurate.

The velocity at which the sediment cloud moved along the painted slope is shown in Figure 6. This figure also includes a gradation analysis curve of the sand used. It may be noticed that the sand particles are quite uniform and are of approximately 200-micron average diameter. Slopes and discharges which permit flushing this material from a roof should certainly be suitable for flushing smaller grain sizes if the water is flowing when the material is being deposited. The curves of Figure 6 should be useful in the design of roof flushing systems.

Tests Conducted on a Tilting Flume with a Concrete Surface

Metal lath was tacked to the plywood bottom of the flume, and a layer of concrete approximately one-fourth inch thick was placed over the metal lath, Figure 3. The concrete was troweled smooth and a series of tests conducted, similar to those on the painted surface.

The normal depths for the concrete surface plotted against discharge for the various slopes tested are shown in Figure 7, as are the depths calculated from Manning's equation. It is interesting to note that Manning's n value for the concrete was 0.0081, which is (smoother) than the value of 0.0098 established for the painted surface. In general, the use of Manning's equation would have resulted in an excellent prediction of depths for the range of discharges and slopes investigated. One exception appears to be at the slope of 0.0117 ft/ft. Considerable wave action was apparent in the flume for this slope, making water surface readings difficult to obtain. This may explain why the observed depths were greater than the predicted depths.

The velocity at which the sediment cloud moved along the concrete slope is shown in Figure 8. The gradation analysis curve is also included on this figure for easy reference. Movement of sand on the concrete surface was similar to that for the painted surface. The curves of Figure 8 should be useful for design purposes.

Test Conducted on Tilting Flume with an Asphalt-gravel Surface

A 1/4-inch layer of a cold-ply asphalt, Figure 3, was applied to the flume bottom, and a uniformly graded gravel cover, between one-fourth and three-fourths inch in size, was placed on the asphalt in a quantity approximating 550 pounds per 100 square feet. After allowing the asphalt to set, a series of tests to determine the hydraulic characteristics of the surface were conducted as on the previous surfaces.

The resulting asphalt-gravel surface was rough, with many particles protruding from the asphalt. As depths for the small discharges and steep slopes were small, these particles often protruded a distance equivalent to a large percentage of the depth. It was not clear therefore where to locate the mean horizontal boundary of this surface from which the depths could be measured. To establish the horizontal location of the mean boundary at the stations used for depth measurements (2, 6, 10, 14, 20, 24, 26, 28, and 29 feet from the upstream end of the flume) a sample of 30 random readings of the boundary was obtained in the immediate vicinity of each station by means of the movable point gage. It was attempted to make the readings completely random, and their mean (which was closely reproducible by taking another group of 30 readings) was used as the location of the mean boundary for the point. As the water surface in the flume was quite rough for most slope discharge conditions, at least six random point gage readings of the water surface were taken at each section, and their average was used with the mean boundary location to establish the water depth at the section.

The normal depths plotted against discharge for the various slopes tested, with the asphalt-gravel surface in place, are shown in Figure 9. Because the projections from the asphalt-gravel surface were a large percentage of the flow depth for the discharges tested, Manning's n value varied with the discharge and slope. No plottings using a constant n value were therefore made. In general n values varied from approximately 0.023 at the largest depths to 0.040 at the smallest depths.

Because the sediment cloud became so dispersed on the rough surface that it could not be timed, and becuase it was obvious that a portion of the sand was deposited in protected areas on the rough surface, no attempts were made to determine the velocity of movement on the asphalt-gravel surface. However, to obtain data regarding the percent of sediment which moved from the surface in a given time, a catch basin was designed, Figure 3. The catch basin was proportioned so that when the discharge from the end of the flume spilled into it, the average horizontal velocity in the catch basin was reduced sufficiently to allow sand particles to settle to the floor. Following a run, the model was turned off, the water was slowly drained from the catch, and the sand was flushed to a small collector in one corner of the catch basin by means of a hose and nozzle. Sediment from the small collector was drained into a graduated cylinder for measurement.

Tests were conducted to determine the percentage of sediment recovered in the catch basin. These tests were performed by first setting a discharge through the flume into the catch basin, then introducing a known amount of material into the water nappe entering the catch basin. After 15 minutes of operation, the model was turned off and the sand collected and measured. Recovery was found to vary from 90 percent at a discharge of 0.75 cubic foot per second to 97.5 percent at a discharge of 0.25 cubic foot per second.

To determine the percentage of sediment which would move from the asphalt-gravel surface for various slope discharge conditions, the following test procedure was established. A slope was established and the maximum discharge to be tested was set in the model. Two hundred cc of the sediment being tested was then introduced into the flume 2 feet from its upstream end. The sediment was sprinkled into the flume during an approximate 1-minute period, and the flume was allowed to continue in operation for 15 minutes. After the allotted time interval, the flow was stopped and the sediment which had entered the catch basin was measured. The next largest discharge was then set and the procedure repeated.

After the tests using a given slope were completed, the remaining sediment was flushed from the flume by passing a large discharge through the flume and by cleaning the surface by means of a hose with a nozzle attached. This method was quite successful in that approximately 80 percent of the sediment which remained on the slope following a test series could be washed from the slope and collected in the catch. However, considerable effort was required to remove the sand from the slope.

The percentages of material removed from the asphalt-gravel surface for various slope discharge conditions are shown in the curves of Figure 10. Significant is the fact that the percentage is relatively small, reaching a maximum of approximaely 27 percent. Flushing contaminated sediment from an asphalt-gravel roof is therefore considered to be impractical.

To determine whether this flushing could be made practical in an inexpensive manner, a plastic cover was placed over the asphalt-gravel surface and the tests were repeated. The plastic sheet material was 10 mils thick, and was placed so that water and sediment could not flow beneath it. Photographs of the flume, with the asphalt-gravel surface in place before and after the plastic cover was placed are shown in Figure 11. The sediment was quite readily washed from the plastic surface in a manner similar to that for the painted and concrete surfaces, indicating that most sloping asphalt-gravel roof surfaces could be rapidly and inexpensively made satisfactory for cleaning by flushing.

Discussion of Results and Suggestions

Sediment removal by flushing from relatively smooth, dense surfaces is not difficult. Figures 6 and 8 give the rate of movement of 200-micron sand on a painted and a smooth concrete surface for various slopes and discharges. In new construction, smooth dense roofs set at the proper slope to assure sediment removal with minimum water discharge could be specified. However, in the case of an existing roof with a smooth, dense surface, but with insufficient or no slope, model studies are advisable to assure sufficient washoff by a pressure flushing system.

In the U.S. Naval Radiological Defense Laboratory Report, USNRDL-467, titled "Radiological Protective Construction" published January 8, 1962, it is stated on page 114: "One distribution system that has proved successful consists of a water delivery manifold suspended 6 to 12 inches above the roof and parallel to the roof ridge. Commercial nozzles that furnish a fan-shaped water jet are spaced along the manifold at 2-foot intervals. This arrangement will provide cleaning action approximately 50 feet down slope for most roof surfaces, tar and gravel roofing being the main exception.

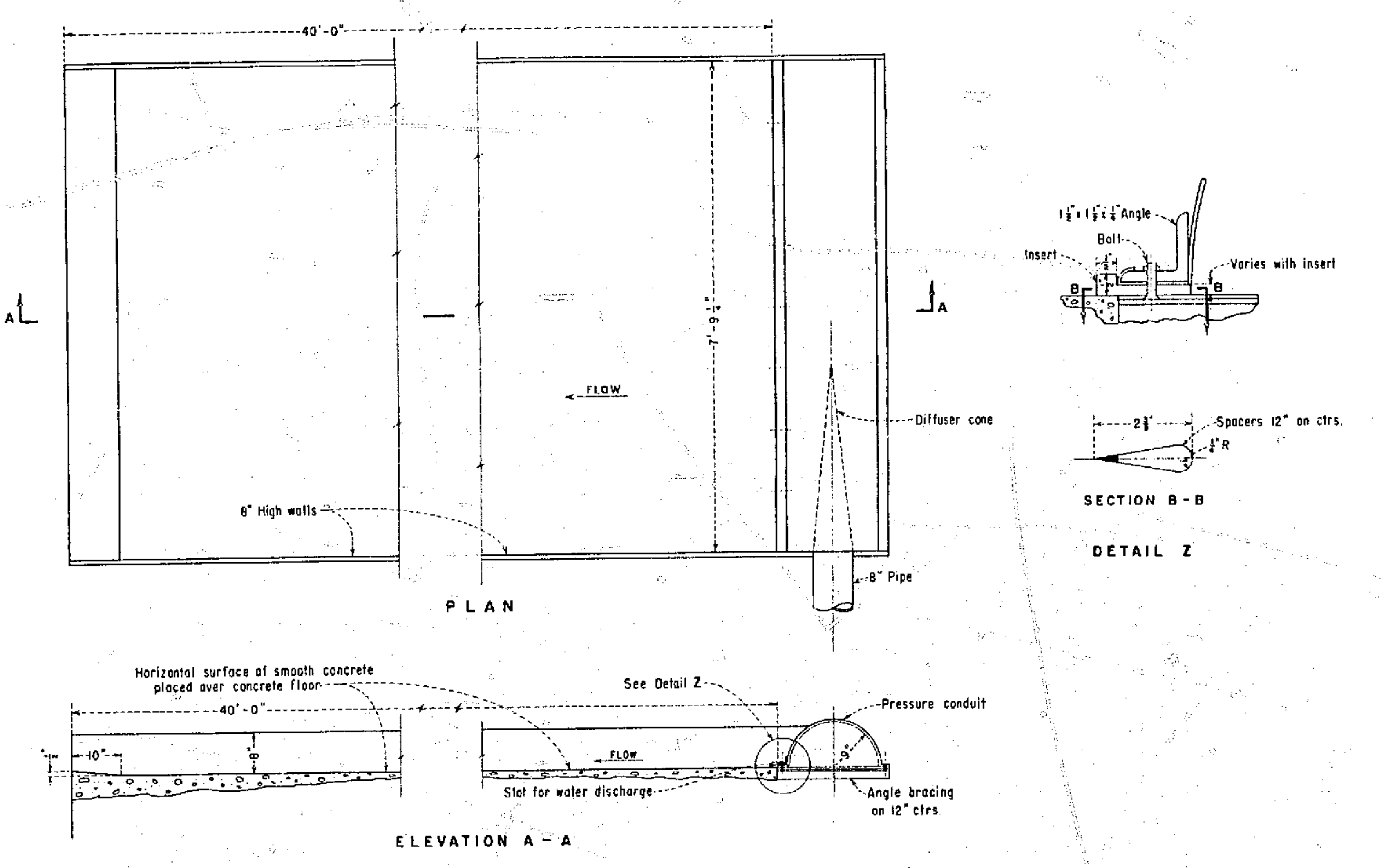
"The removal capability of this distribution system can be improved by the introduction of turbulences in the flowing water film. This may be accomplished by interspersing oscillating sprinklers along the manifold. The impact of the rain-like droplets will create the agitation required to resuspend the more sluggish soil particles for continued transport down slope."

In the same report (pages 113 and 114) a storage sump with a fiberglas filter system to allow recirculation of the water is suggested. A system of this type would allow a relatively small volume of water to be used several times. The report states, page 114: "The water storage capacity should be at least 10 times the volume circulating at full operation. Such a volume would allow for detention time, evaporation, and spray losses during operation. The storage pool should be subsurface to facilitate gravity return and to provide shielding against the trapped fallout. Water in the pool itself will constitute an excellent shield against any radiation from fallout material that has settled along the bottom. The pool also could provide emergency fire fighting or process water during domestic emergencies."

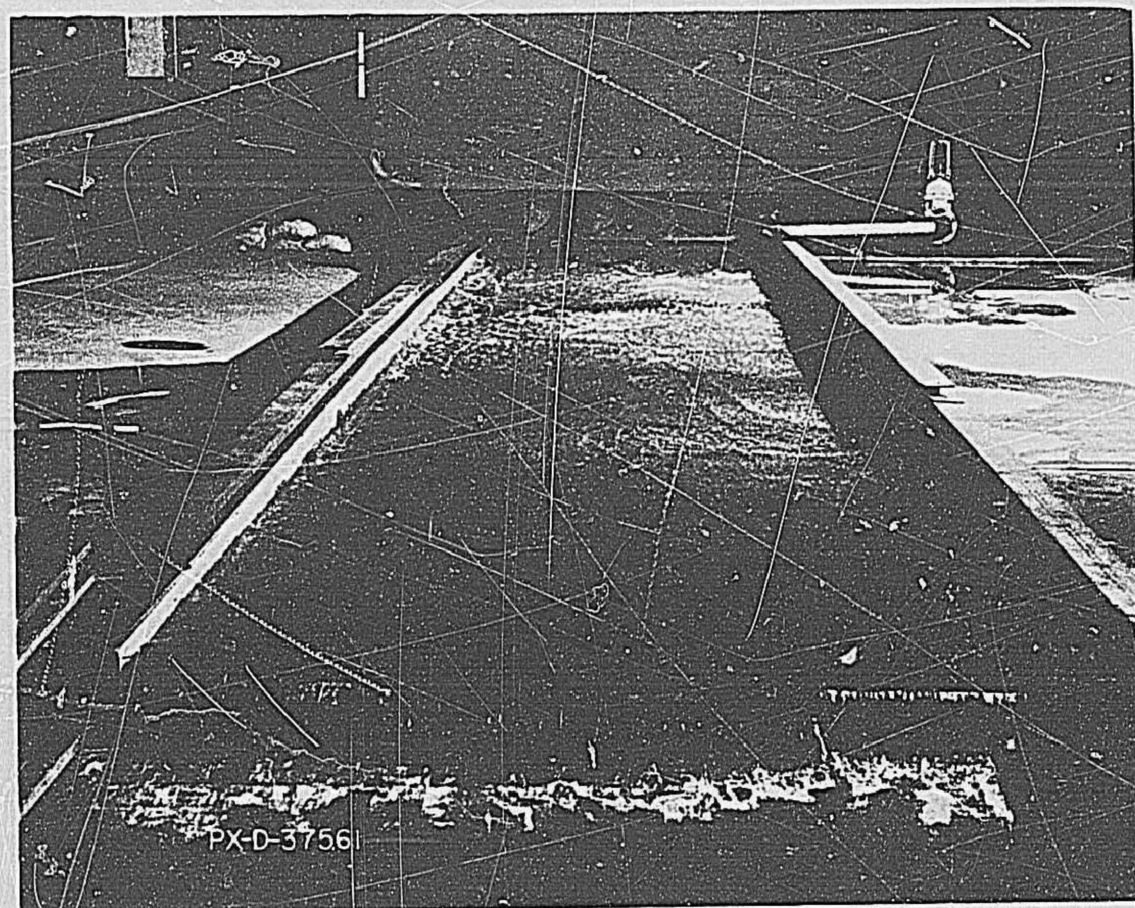
The results of this study (as did the Navy study) indicate that uneven roof surfaces, such as an asphalt-gravel roof, permit the accumulation of fine particles which defy flushing with water. The obvious method to make this type of roof satisfactory for cleaning by flushing with water is to convert the rough surface to a smooth, dense surface by the application of some material capable of filling the voids in the surface. Surface irregularities, including joints, cracks and holes, act as catches for fine particles and these should be filled. The roof should then be inspected periodically to prevent the reoccurrence of any voids.

Another method, which is in many ways simpler, is to cover the roof with sheet plastic so that the sediment can be flushed off the plastic surface. Plastic sheets, large enough to cover the roof, could be stored in rolls in weathertight containers attached to the flushing system. In event their use was desired, the plastic sheets could be rapidly unrolled and the flushing system turned on. A plastic material approximately 8 to 10 mils thick will bridge the voids of an uneven surface and allow the sediments to be washed from the roof. After these sheets have served their purpose, they may be rolled up for further use or disposed of.

In the design of a system using plastic sheets over a large uneven surface, the surface should be carefully inspected to determine the maximum values of high points and valleys. These values should be noted when establishing a depth for design so that flow will cover the entire roof area. On very uneven surfaces, small guide walls may be of aid in helping to establish more uniform flow conditions over the area. A Manning's n value of 0.008 may be used for the plastic material, and the curves shown in Figures 7 and 8 used for design purposes.

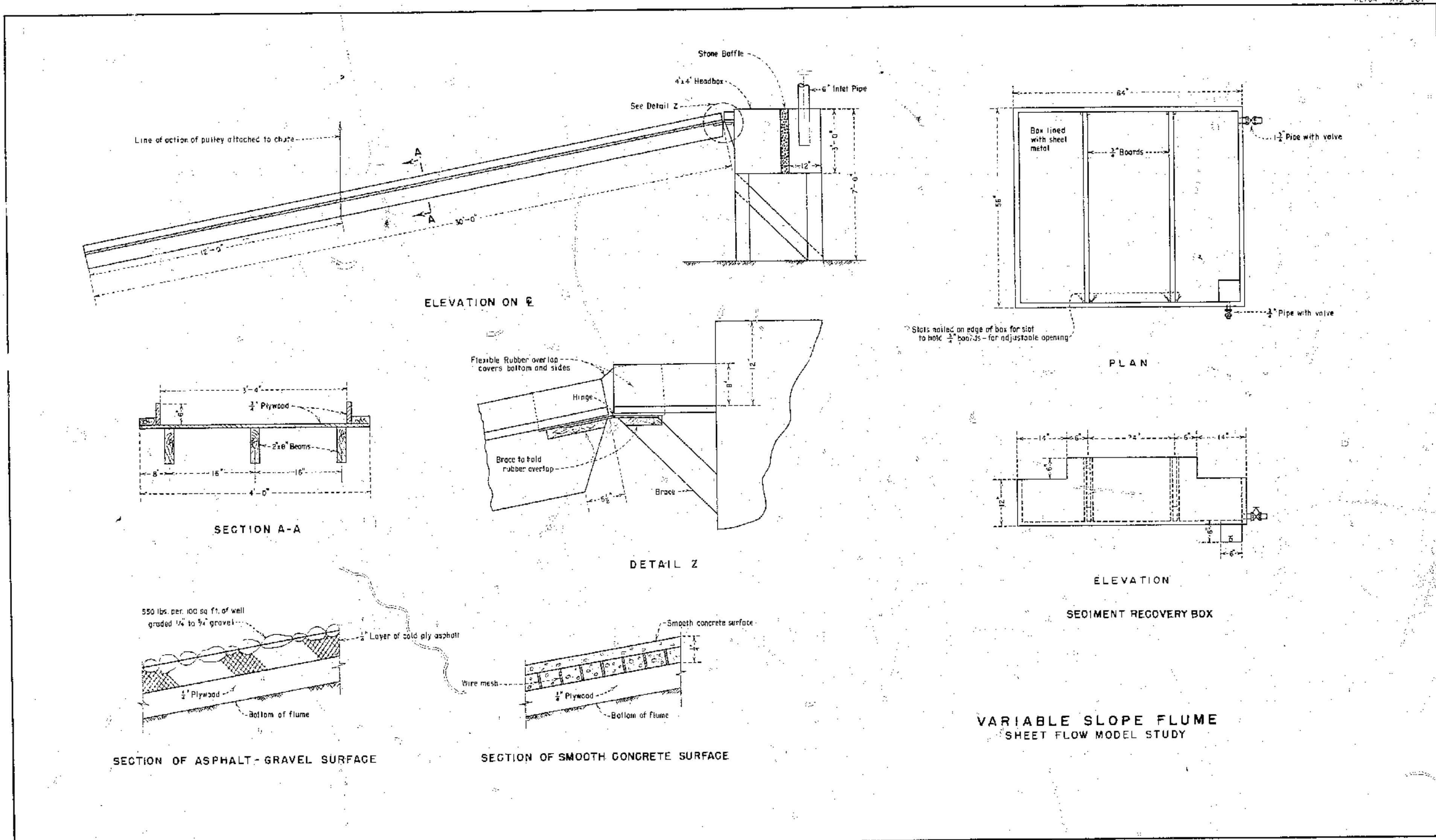


MODEL USED FOR PRELIMINARY STUDY
SHEET FLOW MODEL STUDY

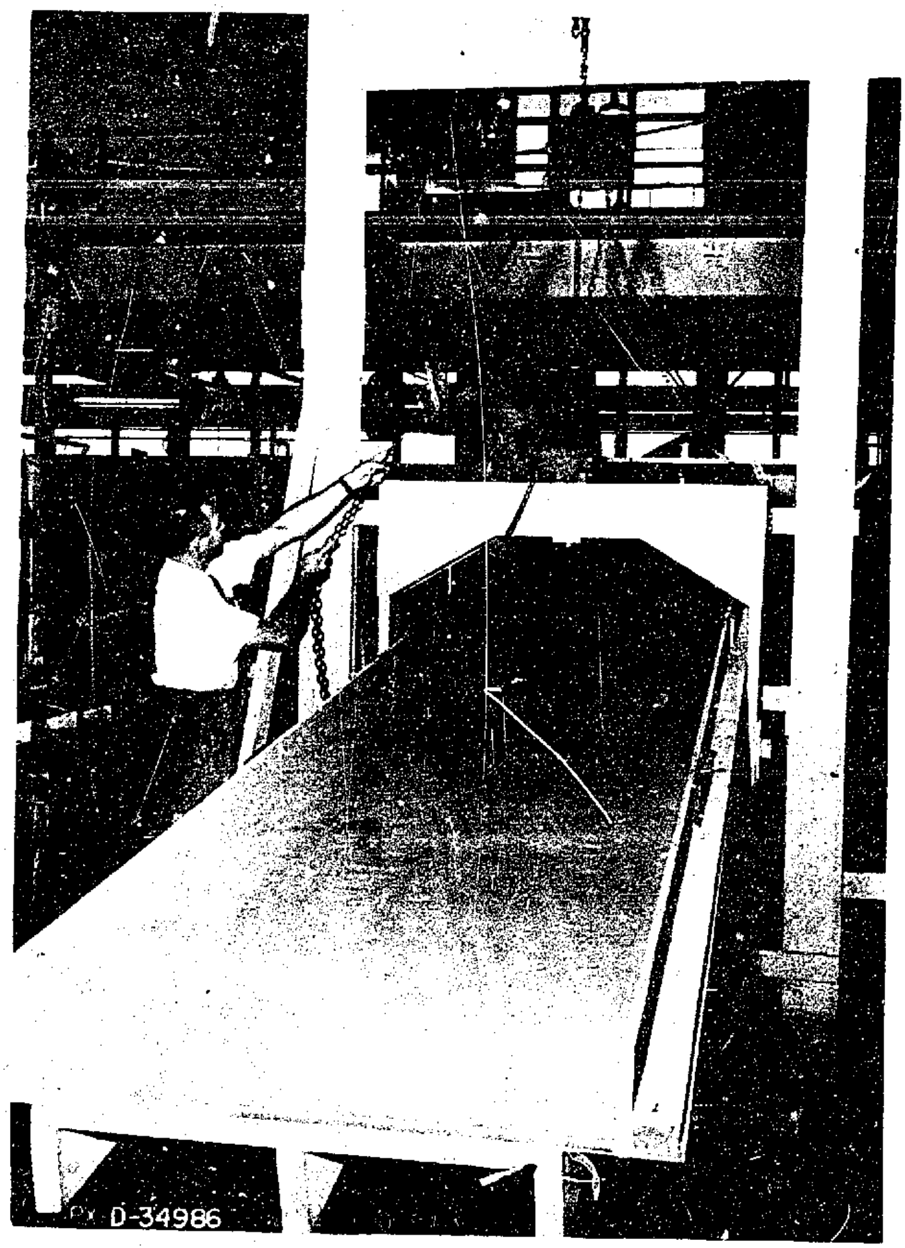


PRELIMINARY MODEL IN OPERATION
At a discharge of approximately 0.45 cubic feet per second per foot of width.

Sheet Flow Model Study

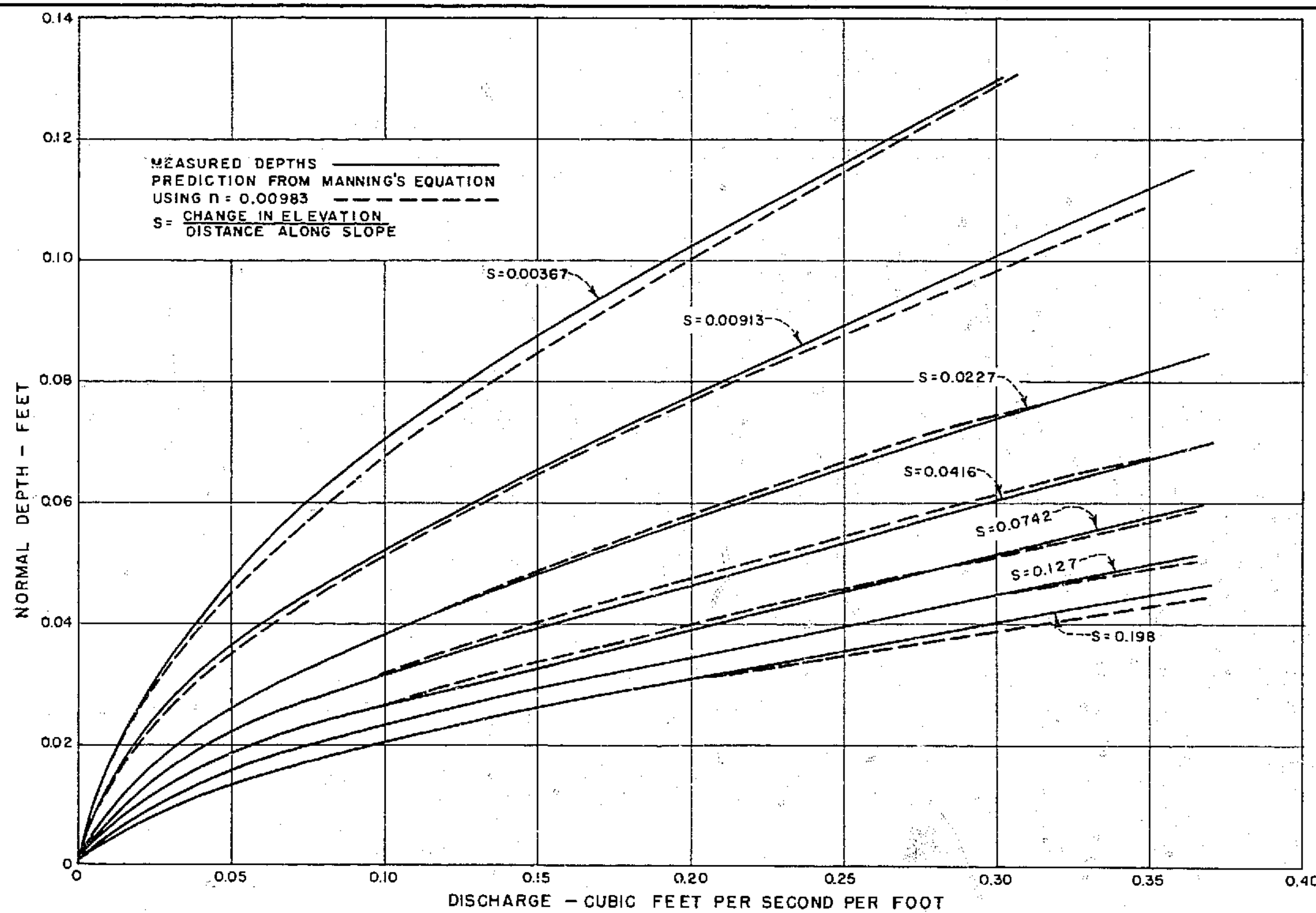


VARIABLE SLOPE FLUME
SHEET FLOW MODEL STUDY



OPERATING PULLEY ARRANGEMENT ON
VARIABLE SLOPE FLUME

Sheet Flow Model Study



NORMAL DEPTHS FOR SMOOTH PAINTED SURFACE
SHEET FLOW MODEL STUDY

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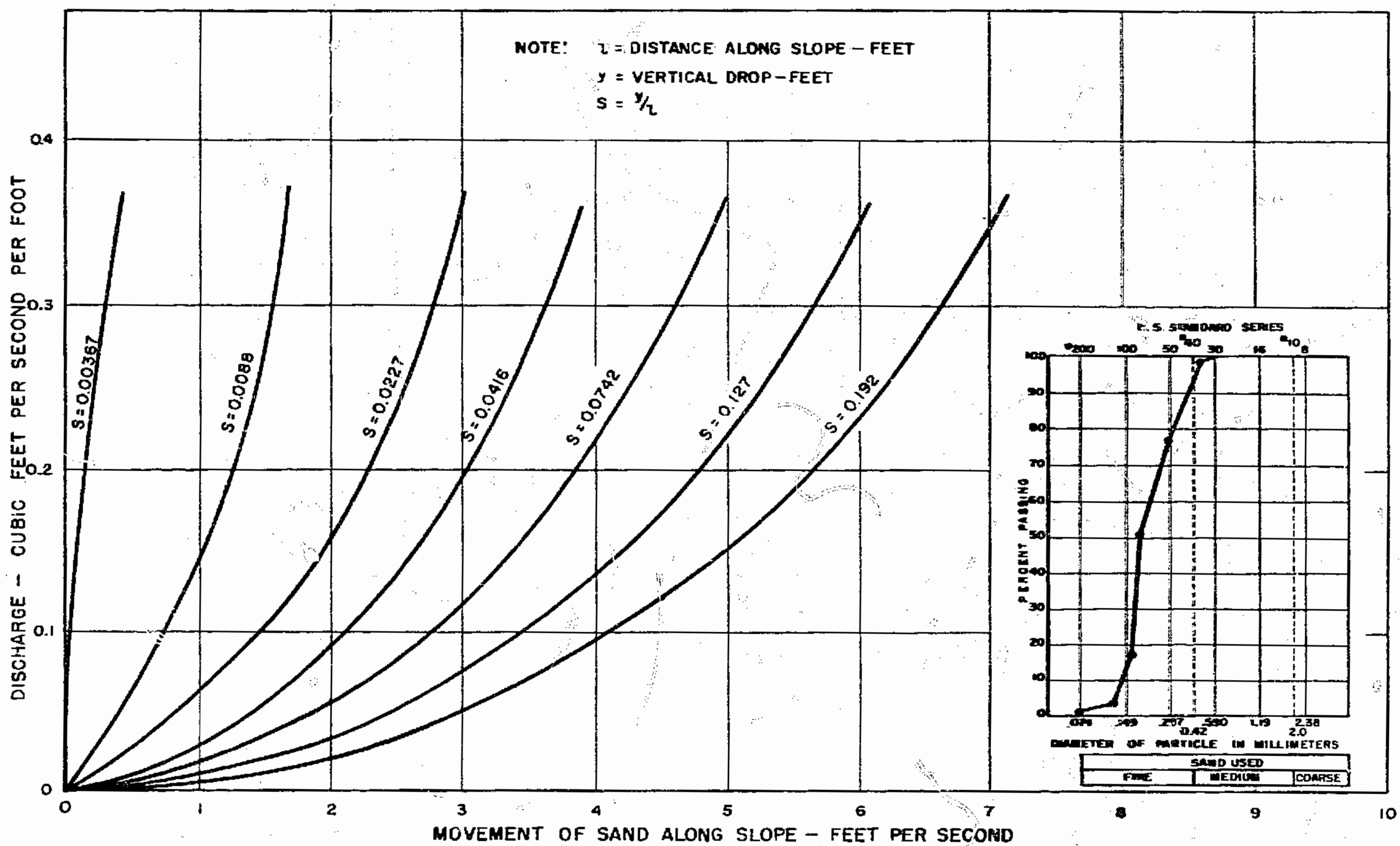
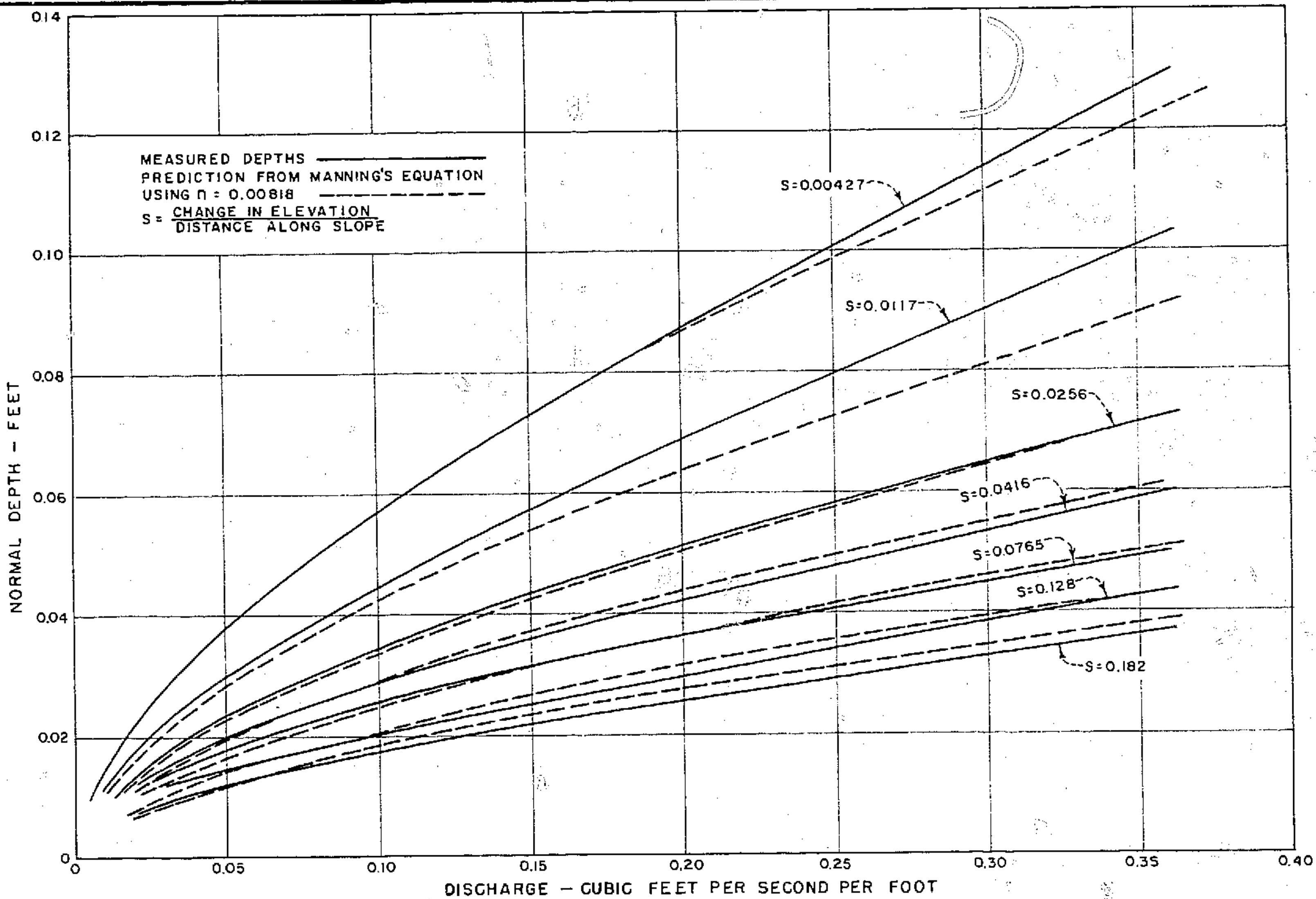


RATE OF SAND MOVEMENT ON SMOOTH PAINTED SURFACE
SHEET FLOW MODEL STUDY



NORMAL DEPTHS FOR SMOOTH CONCRETE SURFACE
SHEET FLOW MODEL STUDY

FIGURE 7
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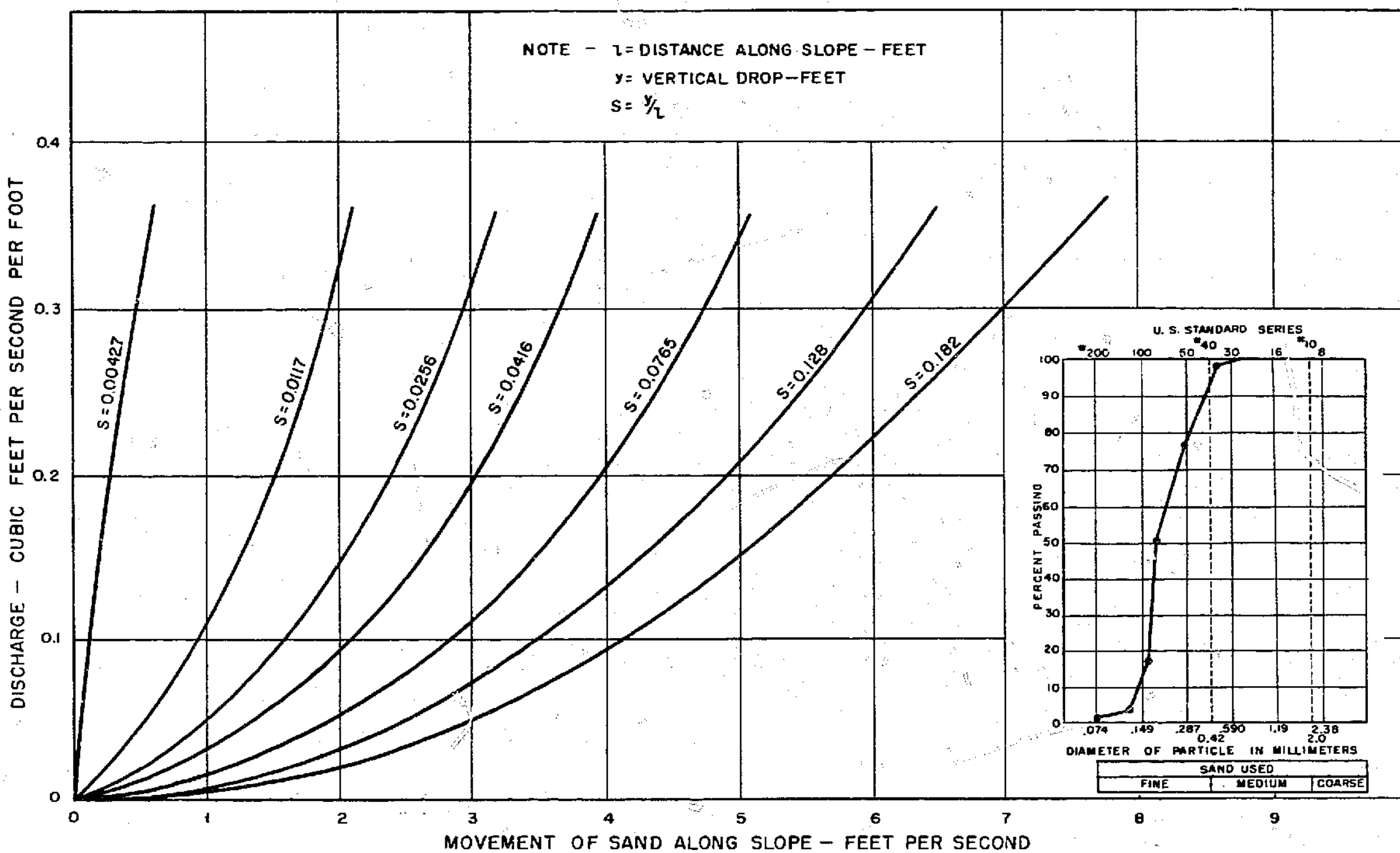
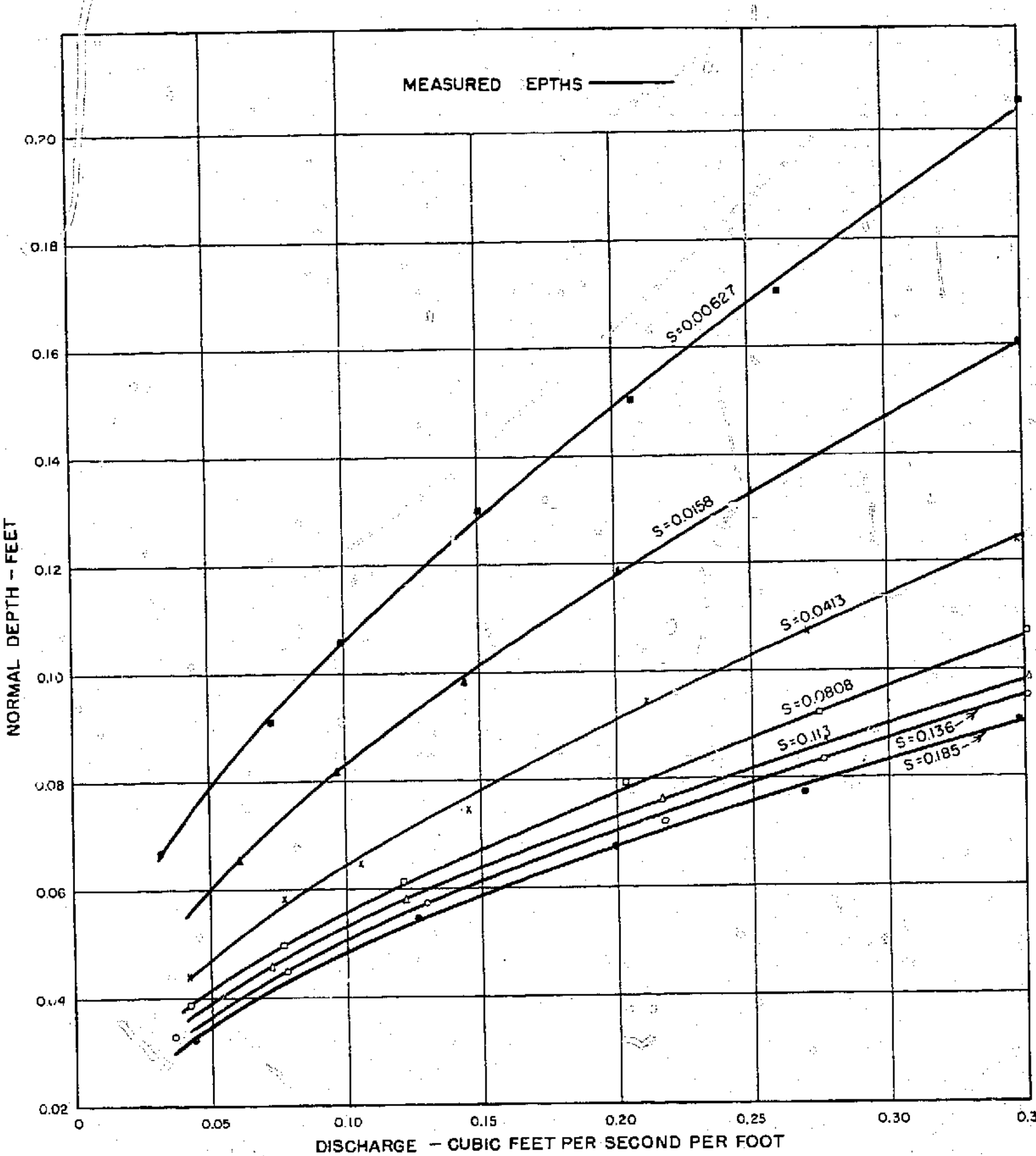
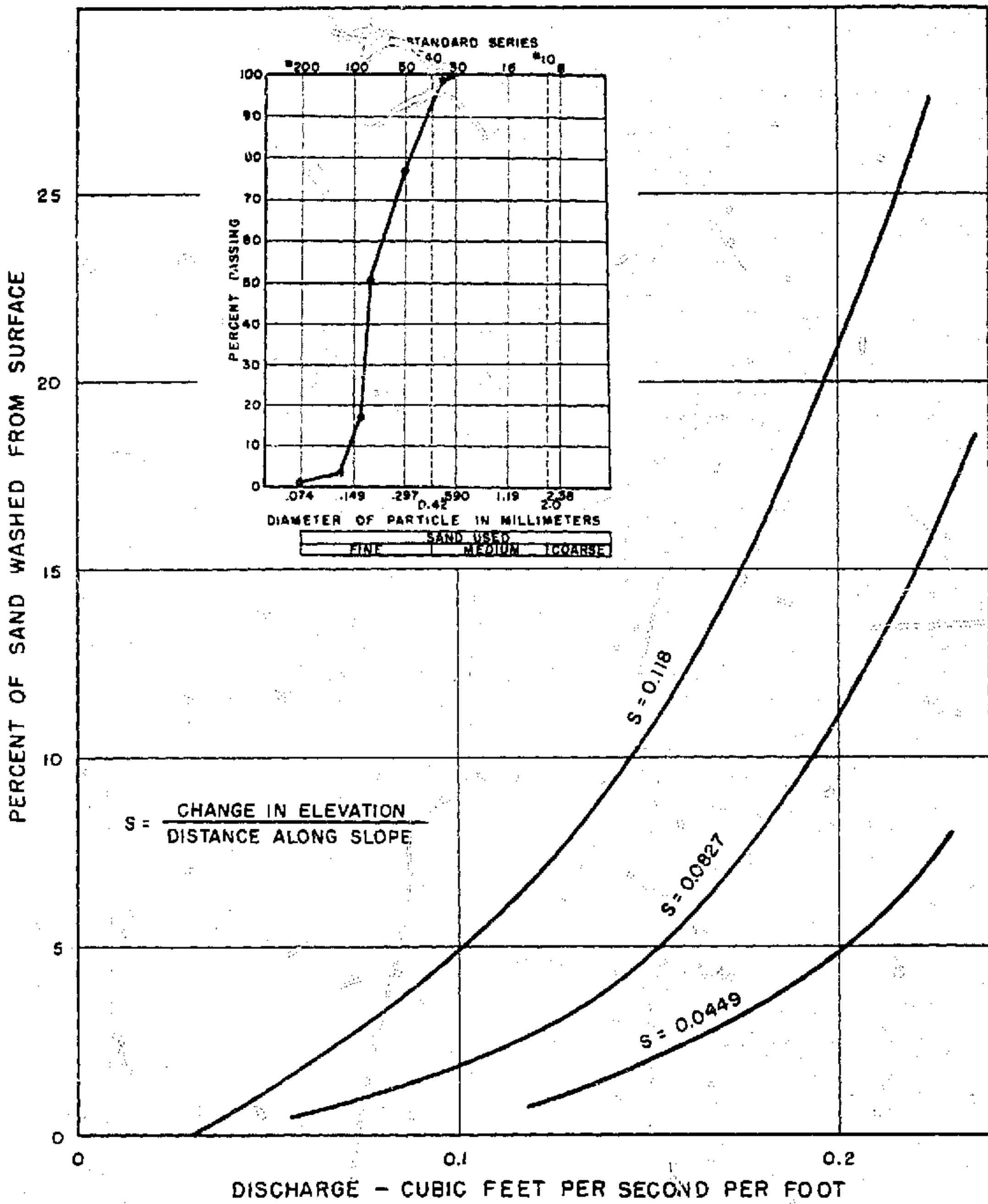


RATE OF SAND MOVEMENT ON SMOOTH CONCRETE SURFACE
SHEET FLOW MODEL STUDY



NORMAL DEPTHS FOR ASPHALT - GRAVEL SURFACE
SHEET FLOW MODEL STUDY

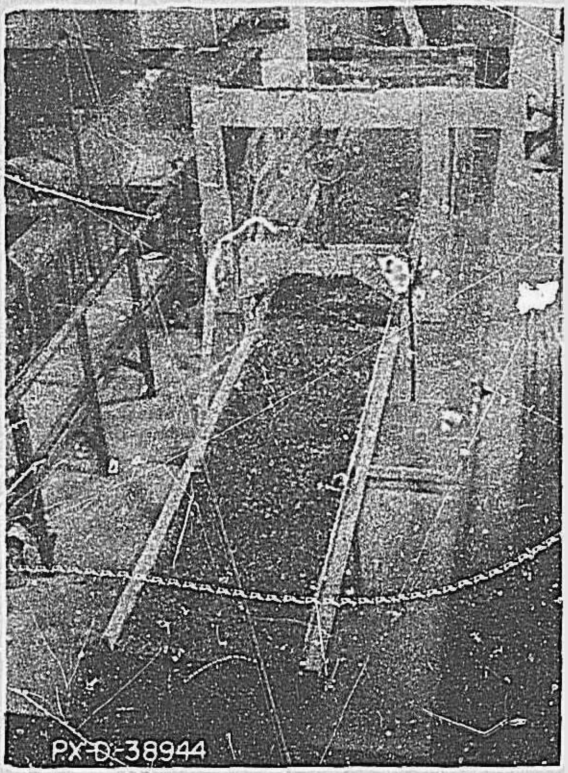
FIGURE 10
REPORT HYD. 501



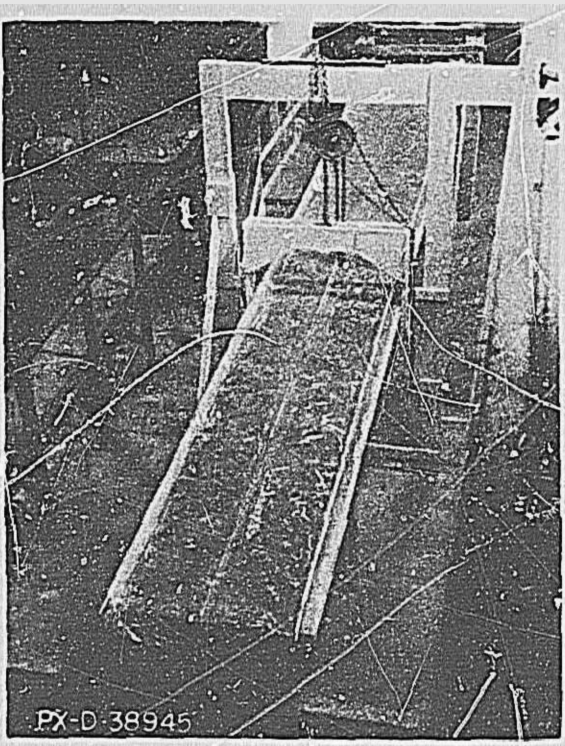
SAND WASHED FROM ASPHALT - GRAVEL SURFACE
SHEET FLOW MODEL STUDY

GPO 835-081

Figure 11
Hyd-501



(a) Flume with asphalt-gravel surface



(b) Plastic cover has been placed over asphalt-gravel surface

ASPHALT-GRAVEL SURFACE WITH AND WITHOUT PLASTIC COVER

Sheet Flow Model Study