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Author:
Hattersley, R. T.; Yong, K. C.

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HYDRAULIC INVESTIGATION OF CRITICAL GRADIENTS FOR APPROACHES TO FARM WATER STORAGES

by

R.T. Hattersley and K.C. Yong

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Key Words

Design Criteria
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Preface

In Australia the storage of water in small, artificially created ponds is economic practically to the point of creating unit volume of water storage per unit volume of excavation. Such storages are frequently used on pastoral properties and for small irrigation projects.

The loss of such expensive water storage by siltation becomes a significant problem, moreso when it is recognised that the watersheds of many of these storages are not adequately protected by vegetation, and in some areas soil erosion is a problem.

The prevention of the ingress of the erosion products into water storages has been critically reviewed in a previous report of this Laboratory (Report No. 114), and as a result it would appear that further investigation is warranted into the improvement of drainage systems feeding rural storages and also in the relevant matters of selection of site and arrangement of control features. In this report, which is of a preliminary nature, an investigation has been carried out to establish the feasibility of designing the feeding drain system just upstream of the dam in such a way as to prevent ingress of all but the finest of the suspended soil carried by the water from erosion of upland surfaces.

It is hoped that this work may be followed by additional investigations along the same lines and ultimately expanded to set down the design criteria to guide rural landholders in the prevention of any avoidable siltation of their storages.

The present work was made possible by a research grant by the Rural Credits Development Fund of the Reserve Bank of Australia and with the assistance of the Soil Conservation Service of N.S.W. and the Water Conservation and Irrigation Commission who were responsible for supplying field data used in the investigation.

R. T. Hattersley,
Associate Professor of Civil Engineering,
Officer-in-Charge.

Summary

Laboratory flume tests have been carried out for three types of soil, namely Condobolin soils, a loose alluvium from natural deposit and a representative sand of uniform grain size to evaluate the limiting gradients under the condition of incipient motion.

The results can be used to establish design slopes for approaches to farm dams such that only the finest material is carried into the farm storage. These results are only applicable to soils having similar properties as tested.

Table of Contents

List of Figures.

1. Introduction

Previously the co-author reported on the mitigation of siltation in farm water storages (Ref. 1) covering current practices and a section of the work related to field inspections and an examination of storages which had shown by their history relative freedom from siltation over periods of 20 years or more.

The suggestion arising from examination of these cases was that by prescription of the gradient of the feeding drains of such storages a large part of the silt fraction could be deposited upstream of the storage leaving only the clay fractions of the soil constituents for terminal deposition in the storage.

Because of the wide variety of soils forming the watersheds or catchments of rural storages, it would seem that prior specification of the erosion product would be a difficult task indeed except that when the natural sorting of erosion products in a drainage system is considered. It is clear that erodibility of soil ceases to be a significant factor in the design of a siltation prevention scheme if the transport capacity of the drainage system is designed to limit the size of particles ultimately entering the storage.

The idea is not new as is evidenced by the American idea of brush screens but what has apparently not been recognised is that in the case of relatively small catchments and storages such as are met with on rural dams in Australia, the limitation of gradient in the drainage channels immediately upstream of a dam is not so critical that relatively large pre-entry storage for trapping silt and sand can be provided by suitably positioning the water storage pit. Setting the gradient of the approach stream to cause deposition of grains in excess of the clay fractions, moreover, as found in brush barriers overseas, growth of grasses or other cover in the deposited alluvium enhances the efficacy of the trapping system. (See Ref. 4).

Because of the ease of access to such a drain system, it is a simple matter, although not likely to be necessary except in extreme cases, for the deposited soil to be recovered from the drain system by ordinary farm machinery.

With the object of confirming what was observed in a practical fashion in the field, an attempt has been made to confirm by laboratory tests, the range of critical gradients which would suffice to trap all but the finest sediments in water approaching a rural storage.

Soil Products

The natural process of erosion tends to segregate the soil particles although in an alluvial bed there is inevitably a percentage of fine material entrained in the moving "carpet" of stream transporting sediment of heterogeneous composition. The series of tests would be effective for the purpose in view if a limited range of sediments were tested, at least initially within the scope of establishing the validity of the concept of a limiting gradient. The sediments in question range from a "washed down" sample of a typical soil taken from the area in which the field observations were made, a typical loose alluvium from a natural deposit and a representative sand of uniform grain size.

Without experimental verification the results of sediment transport experiments for sediments of non-cohesive types and uniform grain size reported widely in the literature of sediment transport (see Figure 6) can only be used as a rough guide to the critical gradients applicable to washed down soils.

The direct use of the Shields plot (Ref. 5) for the design of approach channels to farm dams leaves a degree of uncertainty in determining the range of critical gradient since the specification of critical stress is subjective and the data used are from sands of uniform grain size. Figure 6 illustrates the comparison of the results of this series of experiments with the Shields curve and it is noted that the range of gradients (bed shear) corresponds to the single parameter curves for representative grain size proposed by Yalin (Ref. 3). The intersection of these curves with the Shields line can be used as a determination of the critical gradient for design purposes.

2. Properties of Soils chosen for Experiment

2.1 Condobolin Soils

2.11 General

Condobolin soils can be described as red brown earth. The soils are supplied by the Soil Conservation Service of New South Wales. Its particle size distribution is given in Figure 1. Profile description of Condobolin soils is given below.

2.12 Profile Description

(i) Location: Condobolin Region, N.S.W. 33° 02'S, 147° 16' E; 700 ft. (210m).

(ii) Topography: On level to slightly undulating plain with very gently undulating rises.

(iii) Climate: Condobolin, 33° 05'5, S147°07' E; 650 ft. (200m) Evaporation 65 in (1650mm) Rainfall: 16.5 in. (420 mm); uniform distribution.
Temperature: Jan. 94°F, 65°F, (34°C, 18°C) July 60°F, 38°F (16°C, 3°C)

(iv) Parent Material: Recent aeolian and fluviatile materials.
(v) Profile Drainage: Fair, restricted in clay subsoil.
(vi) Native Vegetation: Savannah woodland cleared, Eucalyptus populnea and Callitris collumellaris association. Chloris, Danthonia and Eragrostis grass species.

(vii) Land Use: A travelling stock route. Surrounding country has sheep grazing and wheat cultivation.

(viii) Morphology:

Depth (cm)	Description
5	Dark reddish brown (5 yr. 3/6 moist), fine sandy loam to loam, fine sandy; weak subangular blacky: moderately hard (dry), friable (moist); pH 6 (Raupach indicator); slight gravel inclusions.
15	Same as above; (5 yr 4/6 dry); clear to -
30	Dark reddish brown (2.5 yr. 3/6m); light clay; weak sub-angular ped breaking to strong crumb; moderately hard (dry); friable (moist); pH $8\frac{1}{2}$, calcareous. Abrupt to -
45	Dark reddish brown (2.5 yr 3/6 moist); light medium clay; strong angular blocky ped (3 cm) breaking to finer ped (0.5 cm), clay skins common, hard (dry), plastic (moist); pH 9; calcareous. gradual to -
70	Dark reddish brown (5 yr 3/6 moist), same as above. Gradual to -

Depth (cm)	Description
120	Mottled, dark reddish brown (2.5 yr 3/6 moist) and brown (7.5 yr 4.6 moist); medium clay; strong blocky peds (3.5cm) breaking to crumb, hard (dry), tough (moist); pH $8\frac{1}{2}$, calcareous. No salt accumulation present.

2.2 Sandy Loams

The material was obtained locally and is widely used as topsoil for gardening purposes. It's description fits into that of alluvial soils commonly found in all parts of Australia. The sandy loam as tested consists of 80 per cent fine sand and about 20 per cent of silts mixed with some organic matter. Figure 1 gives its size distribution.

2.3 Processed Sand

This material is selected to serve as a standard for which future tests on a wider range of soils can be referred to. The material is locally available and its particle size distribution falls within the range of fine sand (see Figure 1).

3. Program of Tests

3.1 Equipment

A tilting flume 10 inches wide and about 30 feet long was used for the experimental tests. The rate of flow of water through the flume was measured by means of a 90^{o} V-notch weir located at the downstream end of the flume. The bed slope was set by automatic level whereas the water surface slope at the test section was measured by means of micrometer gauges. The surface velocity for each test was measured by timing confetti over a specific distance.

3.2 Method of Preparing Test Bed

A test bed for each material was prepared by washing the material down the flume by running water and allowing the material to settle on the flume forming a uniform bed. The main reason for using this method for preparing the test bed was to break down the soil particles in such a way that composition of each soil in the tests was similar to that found in the field. This is to simulate the field conditions in which soils were washed down from a steeper slope to deposit on a milder slope. For each test bed, two soil samples were taken for particle size analysis; one before it was washed and one after it was washed at the test section in the flume.

3.3 Test Procedure

For each type of soil, a series of tests was carried out to determine the uniform flow rate required for the water surface slope (approximately the same as the bed slope) at which the condition of incipient motion of sediments was reached. The recognition of the condition of incipient motion was subjective, but consistency in the results was maintained by using a grid system consisting of 18 - 3-inch square mesh, 10 inches wide and 18 inches long placed over the test section slightly above the water surface to observe sand grain movement in every square. For each test, the following measurements were made:-

(i) Discharge (Q) c.f.s. by V-notch weir
(ii) Water surface slope (S) in percent by micrometer gauges
(iii) Mean velocity (V) f.p.s. by timing a surface float over a specific distance. The mean velocity was only used to check the depth of flow at the test section.

4. Test Results

All results are summarised in Table 1 and plotted in Figure 2 for the three soils tested for purposes of comparison. The results for each individual type of soils are given in Figures 3, 4 and 5 respectively for Condobolin soil, sandy loam and processed sand. These results are plotted in terms of flow rate per ft. width of channel versus the corresponding water surface slope (can be used as for bed slope). The results for three types of soil are also plotted on Shield's diagram given in Figure 6. All results are for sediments in flowing water at the point of incipient motion.

Table 1: Summary of Results

Soil type	Condobolin Soils	Sandy Loam	Processed Sand
q(cfs/ft)	0.001 to 0.03	0.002 to 0.02	0.003 to 0.02
V(fps)	0.6 to 1.0	0.6 to 0.9	0.7 to 0.95
Depth of flow	0.25" to 1/32"	0.26" to 1/32"	0.35" to 1/32"
Water surface slope (%)	0.06 to 2.3	0.05 to 1.8	0.09 to 2.0

5. Discussion of Results

The results as reported here were conducted under laboratory conditions in that the effects of rainfall, wind waves, vegetation etc. were excluded. The effect of surface disturbances will probably decrease the critical slope for initiation of particle movement, but then the effect of rainfall will probably damp out wave disturbances. Exactly how much the above factors will affect the results is difficult to estimate without recourse to further tests on a wider range of soils with some of the factors included in the test programme.

It is of interest to note that critical flow rate was much different for a uniform bed than a rippled bed. A flow rate of as much as half that for a rippled bed than for a uniform bed was noted.

For use in design, the intersection of the lines for a given grain size and soil (see Figure 6) may be used to determine the critical bed shear stress at incipient motion. This is equal to the triple product of specific weight of water depth of flow and stream slope.

The specific weight of water is assumed constant and Table 2 gives gradients corresponding to depths ranging 2 inches down to 1/8 inch.

Table 2:

Materials	y.S	S in per cent				
		y = 2"	y = 1"	$y=\frac{1}{2}$"	$y=\frac{1}{4}$"	y=1/8"
Processed Sand	5.76×10^{-5}	0.035	0.069	0.138	0.276	0.552
Sandy Loam	5.76×10^{-5}	0.035	0.069	0.138	0.276	0.552
Condobolin red earth	4.33×10^{-5}	0.026	0.052	0.104	0.208	0.416

The depth of flow will depend on the width of drain system for aquifer discharge and on the curvature of ground contours.

The drain width is therefore dependent on the form of the ground contours and an estimate of the design discharge.

However, it is clear from Table 2 that the difference in gradient between the uniform grain processed sand, the alluvial loam and the erosion product of Condobolin red earth for a given depth of flow is slight.

The choice of a design gradient to limit silt carried into a dam would not be critically determined by the soil type of the watershed.

6. Concluding Remarks

Results of this investigation provide encouragement towards the establishment of rational design criteria for farm dam approaches for mitigating siltation in farm water storages within the range of the types of soil tested. The results provide a guide for preliminary design of slope for farm dam approaches for a limited number of soils. To provide design criteria for a wider range of soils and to incorporate the effects of rainfall, wind waves, vegetation etc., further experimental research is suggested.

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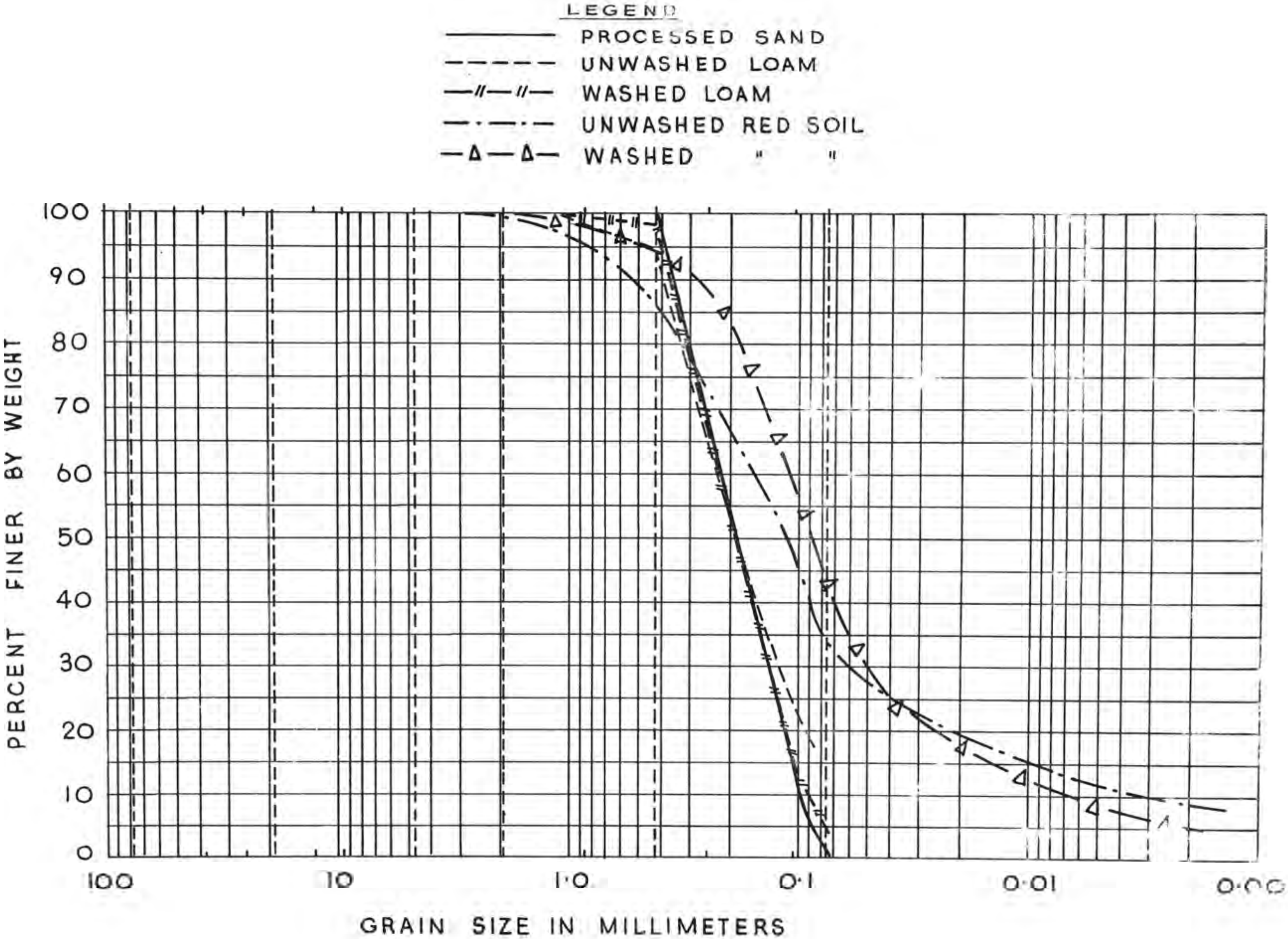

Fig 1: Particle size distribution curves.

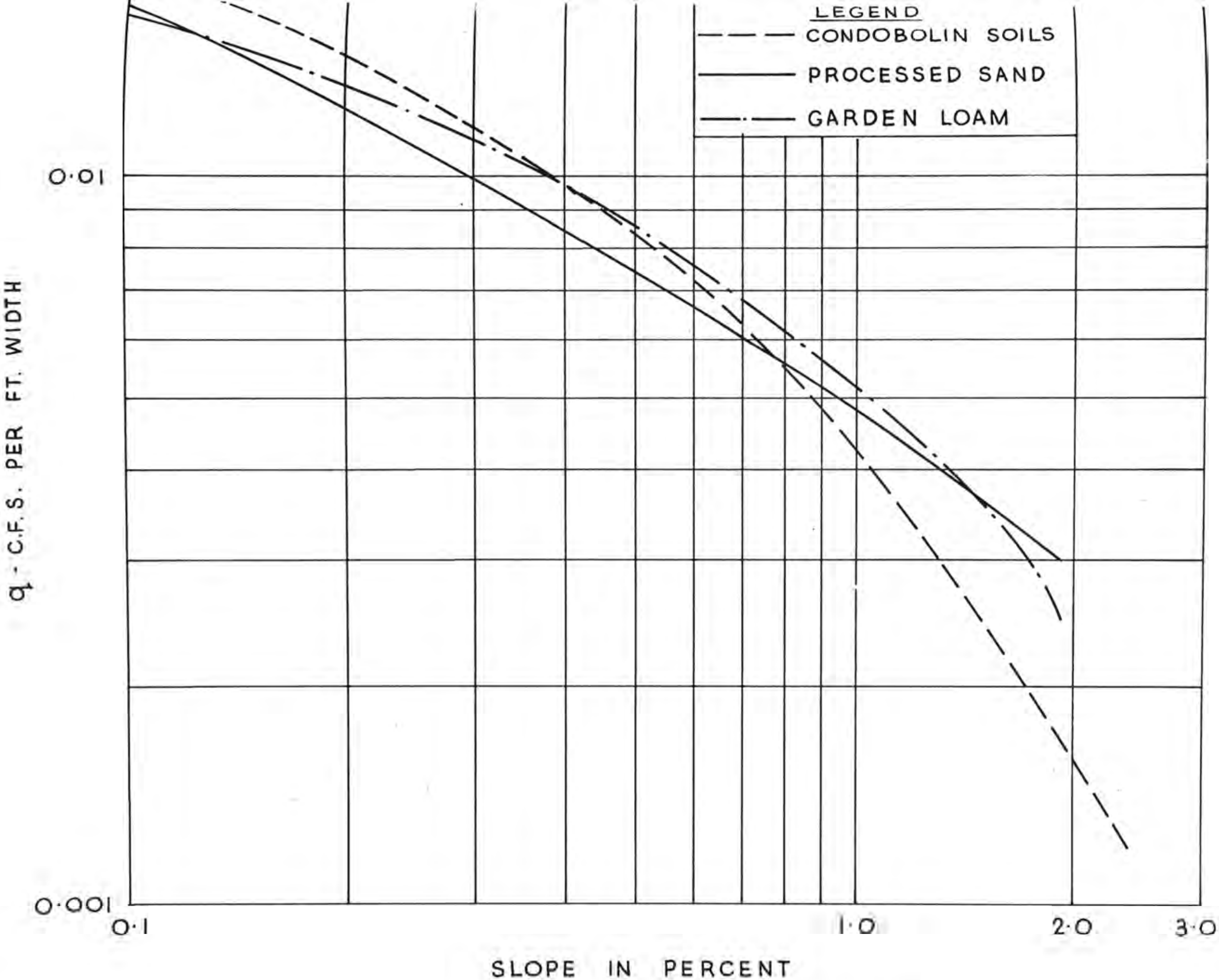

Fig. 2: Summary of Test Results.

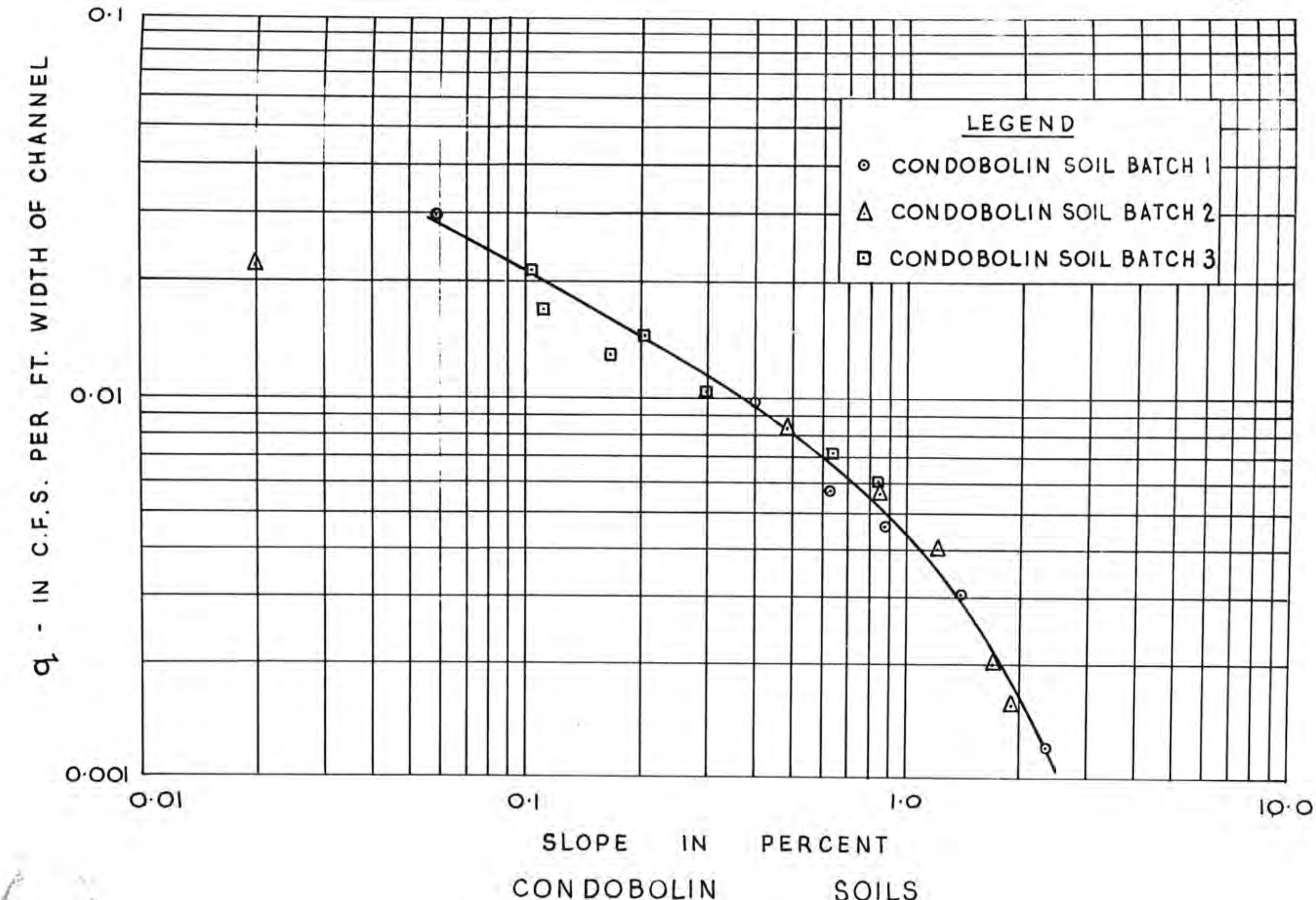

Fig. 3: Test Results for Condobolin Soils.

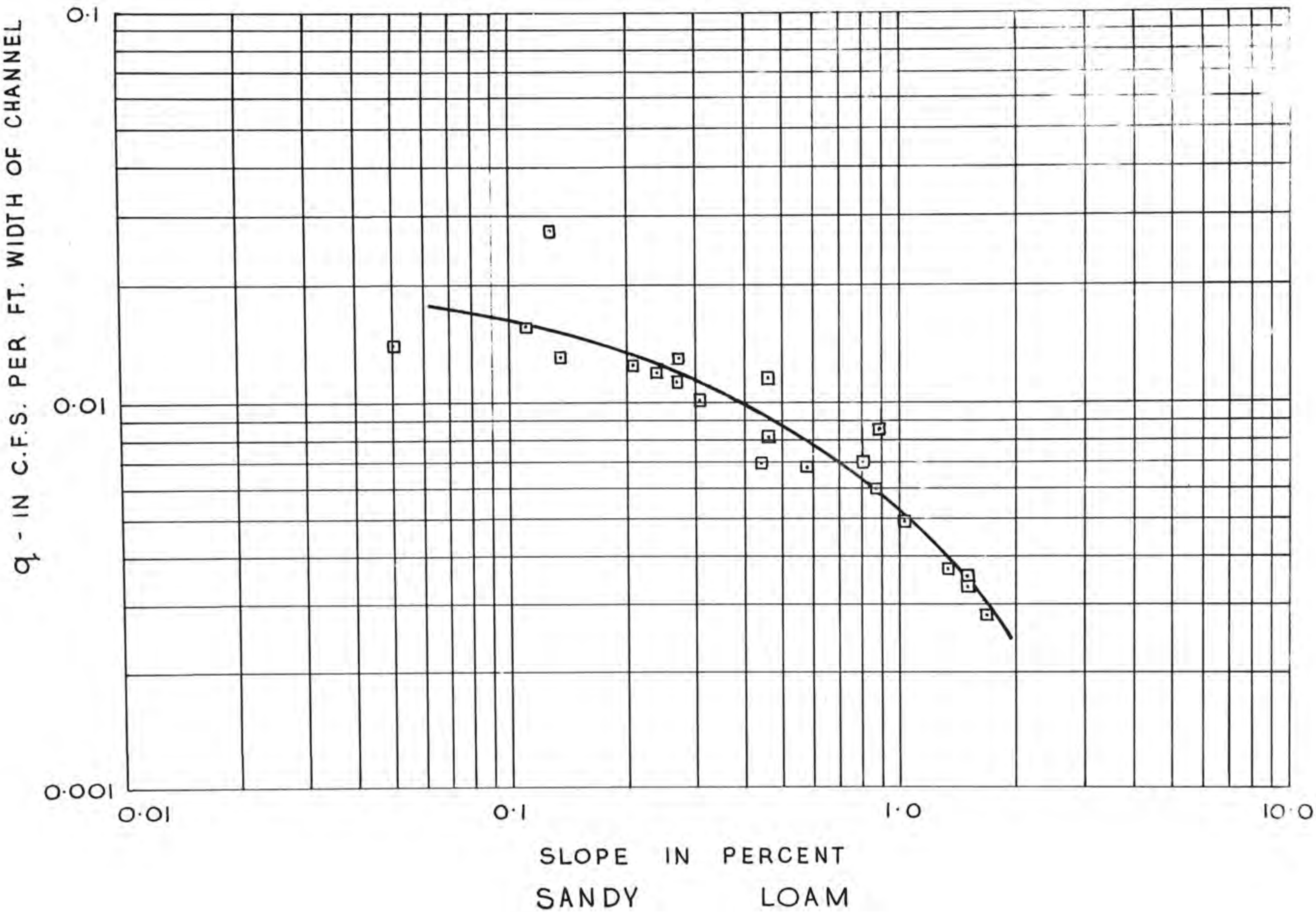

Fig. 4: Test results for sandy loam.

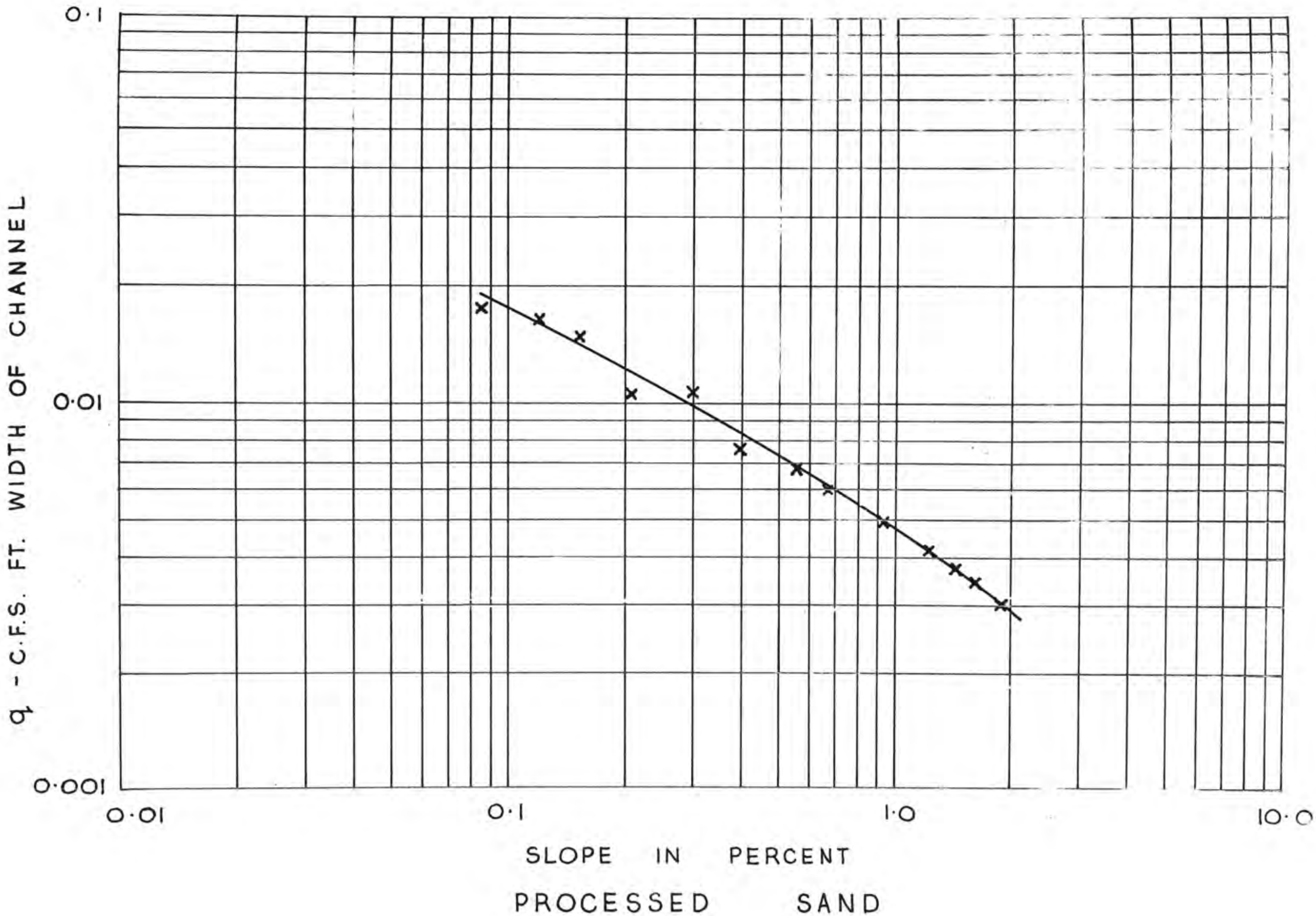

Fig. 5: Test results for processed sand.

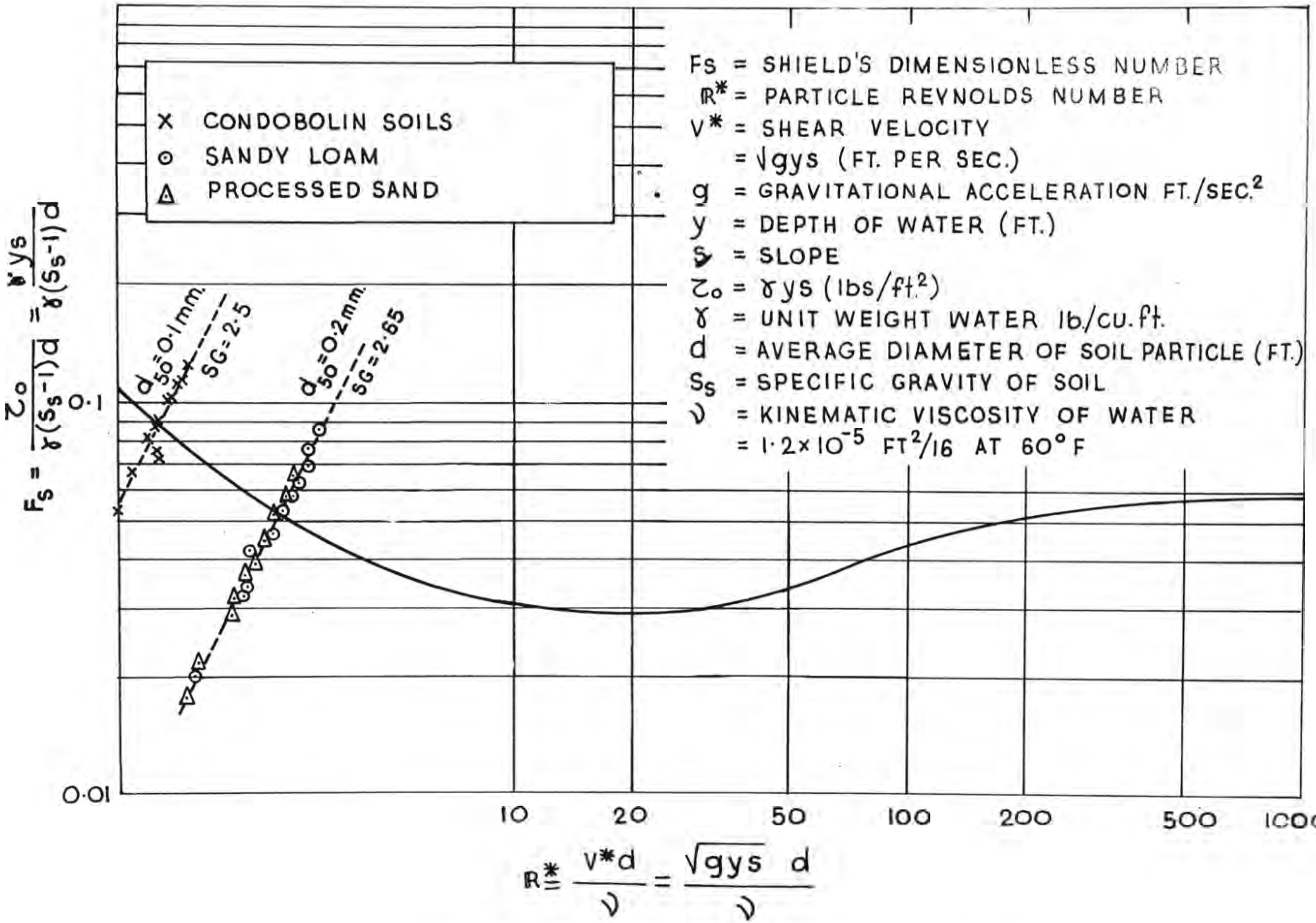

Fig. 6: Shields' sediment transport function.