T H E S I S

THEORY AND DESIGN OF STABLE CHANNELS IN ALLUVIAL MATERIALS

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DARYL B. SIMONS ENTITLED THEORY AND DESIGN OF STABLE CHANNELS IN ALLUVIAL MATERIALS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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(1) Data collected by Mr. D. L. Bender and the writer from stable irrigation canals during 1953 and 1954.

(2) Canal data taken from reports published by the Central Board of Irrigation, Simla, India and The Punjab Irrigation Research Institute.

(3) Data collected by the U. S. Bureau of Reclamation and other agencies from stable canals and rivers.

The collection of the original data was initiated as a result of conferences held by Professor Maurice L. Albertson, Civil Engineering Department, Colorado State College and the writer with Professor Thomas Blench, Civil Engineering Department, University of Alberta, Canada, on the need for information regarding side factors and bed factors for stable channels in the United States. The scope of the investigation was broadened considerably following consultation with Professor E. W. Lane, Civil Engineering Department, Colorado State University, Mr. Whitney M. Borland, and Mr. Kenneth B. Schroeder of the Bureau of Reclamation, Mr. Don C. Bondurant of the Corps of Engineers, and Mr. Paul C. Benedict of the U. S. Geological Survey.

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LIST OF SYMBOLS

Symbol	Dimensions	Definition or Description
a	L	Amplitude of waves
A	L^2	Area of water cross-section
b	L/T^2	Bed factor
B	L	Bed width of channel
B_k	--	A function of channel shape
C	F/L^3	Sediment concentration at D-y/y = 10
C_1	F/L^3	Sediment concentration
C	--	Constant when not designated otherwise
C	$L^{1/2}/T$	Chezy coefficient
C^1	--	Ratio of q_s/q_w
C_D	--	Discharge coefficient
d	L	Mean diameter
d_b	L	Mean diameter of bed material
d_s	L	Mean diameter of side material
d_{15}	L	Fifteen percent passing size
d_{75}	L	Seventy-five percent passing size
d_{85}	L	Eighty-five percent passing size
D	L	Average bed depth
E	--	Euler number
f	L/T^2	Lacey silt factor
f	--	Friction factor
h	L	Wave height
h_e	L	Head loss
i	--	Hydraulic gradient
J	--	A function of the roughness, K
k	--	Constant unless designated otherwise
K	--	Constant unless designated otherwise
K	--	Ratio of critical tractive force on the sides to that on the bed
K_1	L	Bed roughness assumed equal to the mean diameter of the bed material
L	L	Wave length
M	F	Weight of granular mass
n	--	Manning coefficient of roughness
n_a	--	Lacey coefficient of roughness
n_k	--	Kutter coefficient of roughness
N	--	Number of points involved
F_r	--	Froude number
R_e	--	Reynolds number
p	$1/T$	Frequency
p	F/L^2	Pressure
P	L	Wetted perimeter

LIST OF SYMBOLS, continued

Symbol	Dimensions	Definition or Description
q_s	F/T	Weight of sediment being transported per foot of width per second
q_w	F/T	Weight of water flowing per foot of width per second
Q	L^3/T	Discharge
Q_s	F/T	Weight of sediment being transported
r	--	$\left(\frac{10^{-5}}{\nu}\right)^{1/4}$
R	L	Hydraulic radius
R_i	--	Richardsons number
s	L^2/T^3	Side factor
S	--	Slope
T	T	Wave period
t	T	Time
U_o	L/T	Velocity of oscillation of a flat plate at time t = 0
U	L/T	Velocity of oscillation of a flat plate at time t
U_{max}	L/T	Velocity of water adjacent to the bed due to wave action
$U*$	L/T	Shear velocity
V_o	L/T	Kennedy non-silting velocity
V	L/T	Average velocity
V_1	L/T	Velocity at Y_1 above bed
V^2	L/T	Velocity at Y_2 above bed
V_s	L/T	Fall velocity
W	L	Average width of channel such that A = WD
W_T	L	Top width of channel at water surface
X	L	Distance from origin
X	--	Corrective parameter for the transition from smooth to rough
y	L	Distance from origin
Y	L	Thickness of permeable bed
Y_1	L	Distance above bed to point where V_1 is measured
Y_2	L	Distance above bed to point where V_2 is measured
B	degrees	Angle channel bed makes with horizontal
γ	F/L^3	Specific weight
Δ	--	Apparent surface roughness
δ	L	Thickness of laminar sub-layer
θ	degrees	Angle of repose

LIST OF SYMBOLS, continued

Symbol	Dimensions	Definition or Description
K	--	von Karman coefficient
μ	FT/L^2	Dynamic viscosity
ν	L^2/T	Kinematic viscosity
ρ	FT^2/L^4	Mass density
ρ_s	FT^2/L^4	Mass density of sediment
σ	L	Standard deviation
σ_1	--	Standard deviation in dimensionless form
τ	F/L^2	Tractive force or shear
τ_{bed}	F/L^2	Tractive force or the bed due to wave action
τ_c	F/L^2	Critical Tractive force
ϕ	degrees	Angle of side slope
Φ	--	Potential function
Ψ	--	Stream function

Chapter I

INTRODUCTION

The design of stable or regime channels has been the object of considerable research during the past four decades. It is known that any design theory must recognize the effect of the many variables involved. Originally only a single equation of the Chezy or Manning type was utilized. In recent years, however, various investigators have concluded that width, depth, and slope are all variable in alluvial channels and that this implies mathematically the necessity of at least three design equations. The problem appears even more complex when one recognizes that sediment transport also affects channel stability.

Recently two schools of thought, one empirical, the other primarily theoretical, have each evolved theories more capable of adequately predicting channel behavior than any heretofore. As yet, however, these theories are incomplete and should be subjected to further study and investigation in order to broaden their scope and possibly reduce them into one general comprehensive and complete theory.

Definition of a Stable Channel

An excellent definition of stable or regime channels was presented by Lane (35) in 1952 as follows.

> "A stable channel is an unlined earth canal for carrying water, the banks and bed of which are not scoured by the moving water and in which objectionable deposits of sediment do not occur".

The foregoing definition does not exclude minor erosion or accretion during the yearly cycle of flow. It does, however, require that these opposing effects should balance and cancel one another on an annual basis.

Application of Stable Channel Theory

Stable channel theory is widely applicable to many phases of work in the fields of civil and agricultural engineering, the major ones being the design and operation of drainage and waste water channels, the design of power canals, and scour prevention and control.

Satisfactory design of irrigation systems requires an intimate knowledge of channel design relationships. In fact considering the current quality of these relations considerable experience is necessary to bridge the existing gaps. Improper design may well introduce instability in the channels of such magnitude that it is not economically feasible to operate them.

Drainage and waste water channels constructed for the purpose of conveying drainage and waste water from given areas have been subjected to such gross neglect that they warrant special mention. Certainly lack of a suitable channel design theory or at least lack of application of it to problems falling in this group has caused loss of considerable tillable acreage, the loss of many hydraulic structures and the formation of unsightly scars on the earth's surface.

An adequate knowledge of the many variables influencing channel stability would make possible a more intelligent treatment of:

1. Bank scour problems caused by increasing normal flow in channels.

2. Evaluation of the effect of slope changes, due to the use of meander cut-offs, on channel stability.

3. Erosion problems above and below bridges and other types of hydraulic structures that constrict channels.

4. Stabilization of non-regime channels by armor-coating the banks with material more resistant to scour than the existing natural material and/or by introducing structures to control slope.

It is of particular importance to be able to design stable power canals in alluvial materials since the quantity of sediment being transported to the power plant penstocks must be controlled; in fact, for the most part, eliminated.

Proposed Research

Based on the inadequacy of current design methods and lack of understanding of the regime theory in a field study of stable canals was proposed in 1953 with the purpose in mind of attempting to clarify, expand, and perhaps combine the above theories. Specifically, the major objectives of this research are as follows.

1. To investigate the validity of the regime theories as developed in India.

2. To investigate, expand, and possibly improve the tractive force method of stable channel design.

3. To relate the regime theories to the tractive force insofar as possible.

A detailed discussion of the field phase of the research including a description of canals investigated, the data collected, and the equipment utilized is presented in Chapter V. As a prelude to this discussion the review of literature, factors influencing stability of canals and a theoretical analysis of the problem follows.

Chapter II

REVIEW OF LITERATURE

Reiterating, satisfactory design and construction of artificial channels in alluvial material is affected by many factors some of which are extremely complex and hence are only vaguely comprehended. A brief history of the development of currently used empirical rules and theories follow:

A survey of existing records, research reports, and texts reveals that the problem of determining a standard roughness for channels in alluvial material has been studied by many investigators. Most investigators in this field were concerned primarily with determining a roughness coefficient for canals and natural rivers.

One of the first open channel formulae of importance was proposed in 1775 by Chezy (23), a French engineer. His equation may be stated as:

$$Q = CA\sqrt{RS} \tag{1}$$

In 1891 the Manning formula (41) and (42) was developed. This formula;

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \tag{2}$$

is now more widely used than the Chezy formula, particularly in the United States. Terminology is the same as in Eq 1 with the exception that n, which is the Manning coefficient of resistance is introduced. This coefficient is considered to be characteristic of the boundary and to remain constant for particular types of material in a fixed condition.

Permissible maximum velocities were recommended by Etcheverry (19) and values of Manning's n for different types of materials were recommended by Lane (35) as follows:

Table 1. Values of n and Permissible Velocities for Different Types of Materials

Material	Value of Manning's n used	Velocity (ft/sec)
Very light pure sand of quick-sand character	0.020	0.75-1.00
Very light loose sand	.020	1.00-1.50
Coarse sand or light sandy soil	.020	1.50-2.00
Average sandy soil	.020	2.00-2.50
Sandy loam	.020	2.50-2.75
Average loam, alluvial soil, volcanic ash soil	.020	2.75-3.00
Firm loam, clay loam	.020	2.00-3.75
Stiff clay soil, ordinary gravel soil	.025	4.00-5.00
Coarse gravel, cobbles and shingles	.030	5.00-6.00
Conglomerate, cemented gravel soft slate, tough hardpan, soft sedimentary rock	.025	6.00-8.00

Scobey (59) summarized most of the studies on flow of water in open channels. In addition, he made a number of field studies for the purpose of determining resistance coefficients in several discharge formulae which would be applicable to the various conditions found in practice.

Fortier and Scobey (22) presented data on permissible canal velocities and Lane (35) gave corresponding values of Manning's n for different water conditions in straight channels after aging. Their recommended values are given as follows.

Table 2. Values of Manning's n and Permissible Velocities for Different Soil Types According to Fortier and Scobey & Lane

Material	Manning's n	For clear water velocity (ft/sec)	Water transporting colloidal silts velocity (ft/sec)
Fine sand colloidal	0.020	1.50	2.50
Sandy loam noncolloidal	.020	1.75	2.50
Silt loam noncolloidal	.020	2.00	3.00
Alluvial silts noncolloidal	.020	2.00	3.50
Ordinary firm loam	.020	2.50	3.50
Volcanic ash	.020	2.50	3.50
Stiff clay very colloidal	.025	3.75	5.00
Alluvial silts colloidal	.025	3.75	5.00
Shales and hardpans	.025	6.00	6.00
Fine gravel	.020	2.50	5.00
Graded loam to cobbles when noncolloidal	.030	3.75	5.00
Graded silts to cobbles when colloidal	.030	4.00	5.50
Coarse gravel noncolloidal	.025	4.00	6.00
Cobbles and shingles	.035	5.00	5.50

In keeping with the foregoing, the Union of Soviet Socialist Republics, as of 1936, published a code of rules to assist in the design of silt stable canals (37) and Lane (35). The interdependence of size of grain and average velocity is again illustrated.

Table 3. U.S.S.R. Permissible Velocities for Silt Stable Channels

Material	d (mm)	Mean Velocity (ft/sec)
Silt	0.005	0.49
Fine sand	0.05	0.66
Medium sand	0.25	0.98
Coarse sand	1.00	1.80
Fine gravel	2.50	2.13
Medium gravel	5.00	2.62
Coarse gravel	10.00	3.28
	15.00	3.94

Fine pebbles	15	3.94
Medium pebbles	25	4.59
Coarse pebbles	40	5.91
Large pebbles	75	7.87
Large pebbles	100	8.86
Large pebbles	150	10.83
	200	12.80

Velocities determined by this means are then modified by a correction factor which varies with depth as follows:

Depth, ft:	0.98	1.97	3.28	4.92	6.56	8.20	9.84
Correction factor:	0.80	0.90	1.00	1.10	1.15	1.20	1.25

For cohesive materials their code of practice related the effect of voids ratio or compactness of bed material to permissible average velocity and tractive force.

Table 4. U.S.S.R. Permissible Velocities and Tractive Forces (37) Considering Cohesive Soils and Various Degrees of Compaction

	Compactness of Bed Material							
	Loose		Fairly Compact		Compact		Very Compact	
Voids ratio	2.0-1.2		1.2-0.6		0.6-0.3		0.3-0.2	
	Limiting mean velocities in ft/sec and limiting tractive force in lb/sq ft							
	ft/sec	lb/sq ft	ft/sec	lb/sq ft	ft/sec	lb/sq ft	ft/sec	lb/sq ft
Sandy clays (sand content more than 50 per cent)	1.48	0.040	2.95	0.157	4.26	0.327	5.90	0.630
Heavy clayey soils	1.31	0.031	2.79	0.141	4.10	0.305	5.58	0.563
Clays	1.15	0.024	2.62	0.124	3.94	0.281	5.41	0.530
Lean clayey soils	1.05	0.020	2.30	0.096	3.44	0.214	4.43	0.354

As before a correction factor is applied to the foregoing velocities, its magnitude being a function of depth.

Depth, ft:	0.98	1.64	2.46	3.28	4.92	6.56	8.20	9.84
Correction factor:	0.8	0.9	0.95	1.0	1.1	1.1	1.2	1.2

The introduction of effect of voids ratio on bank and bed stability is a concept thus far omitted from other theories.

Rouse (54) discussed the relations between existing flow formulas and the boundary resistance. He stated that the standard flow equations do not apply in their present form because of the characteristics of the boundary layer which exerts a varied viscous effect depending on such variables as velocity, slope, cross-section, and bed material.

Barbarossa and Einstein (18) studied river channel roughness. They used the Manning and the Strickler (63) equations in the theoretical solutions because of their practical value. By using the shear theory and the formula for transportation of bed load developed by Einstein (17), they showed that the friction loss due to channel irregularities is a function of sediment transport. The assumptions and the conditions of this study were:

1. The grain roughness and irregularities were assumed to be uniformly distributed over the river boundary area.

2. The slope was calculated as the total drop over the total distance.

3. The water surface profile was assumed to be essentially a straight line in a long reach and to remain straight with unvarying slope as the discharge changed.

4. The average cross-section in a fairly long reach was ascertained not to change substantially in shape and size as discharge varied.

Many studies have been made on artificial roughness; the most complete one was that by Powell (46), (47) and (48). He made a series of experiments using square steel strips across the sides and bottom of a channel. Utilizing the fundamental formula given by Keulegen (30) he developed the equation:

$$C = 1.263J + 17.9\ B_k + 41.2\ \mathrm{Log}_{10} \frac{R}{K_1} \qquad (3)$$

where

C = Chezy coefficient

J = function of roughness K_1 which is the diameter of equivalent Nikuradse sand particles

B_k = function of the shape of the cross-section

R = hydraulic radius.

Robinson and Albertson (52) made a study of artificial roughness in open channels. In this study they showed that a standard of artificial roughness could be established similar to the roughness standard that exists for pipes. The coefficient of roughness C was expressed in terms of the ratio of depth of flow over the bed to height of artificial roughness.

During recent years growth of interest in the theory and design of stable canals in erodible material has been phenomenal. This increased interest has stimulated both laboratory and field research. As a consequence improved theories and methods of design have been developed. These design methods while neither uniform nor exact are based on fundamentals that can be at least partially explained in terms of the basic engineering sciences. The trend then is toward a better understanding of the complex factors involved and hence more exact design methods.

Present Methods of Design

A study of man-made alluvial channels suggests that they have three degrees of freedom, that is, channels are free to adjust in slope, depth, and width after construction. The concept of three degrees of freedom implies three unknowns which in turn requires three independent equations to obtain a satisfactory solution.

This explains in part the futility of attempting to design a stable channel based on a single equation of the Manning or Chezy type without supplementary knowledge and information. The average hydraulic engineer obtains the necessary additional information from rules of thumb, empirical relationships, and experience. In general this design procedure is more of an art than a science and consequently satisfactory designs based on this approach are not always attained. A sounder approach to the solution of stable channel design problems involves using some form of the Regime Theory as developed in India, the tractive force or drag theory which is currently gaining popularity in this country, or possibly a combination of both approaches.

Regime Theory

The regime theory of India was initiated by Kennedy in 1895 when he produced his classic empirical equation

$$Vo = C\ D^m \tag{4}$$

where C and m were thought to be constants and were originally assigned values of 0.84 and 0.64 respectively. Kennedy concluded that channels having velocities based on his formula would neither silt nor scour their beds. The equation was empirically formulated based on data collected on the Bari Doab canal system in the Punjab.

According to the above equation it is permissible to design a narrow deep channel or a wide shallow one to carry the same discharge. Actually this is far from the truth of the matter. As far as design is concerned the only time the Kennedy equation can possibly yield correct results is when shape is also properly selected, or when dealing with very stable materials.

Other investigators attempting to prove or disprove Eq 4 soon established that the constant C , and the exponent m , varied from system to system. In spite of this the Kennedy equation, in its original form, can still be found in many recent engineering texts and it was applied extensively in design as originally presented until about 1930.

A paper on "Regime Channels" was presented in 1919 by E. S. Lindley. In this paper he introduced the following regime equations:

$$V = 0.95\, D^{0.57} \tag{5}$$

$$V = 0.57\, B^{0.355} \tag{6}$$

$$B = 3.80\, D^{1.61} \tag{7}$$

These equations were derived by correlating data obtained from 786 observations in branch surveys of the Lower Chenab Canal. This was the first time that bed width and depth were introduced as regime variables. In his reply to the discussion on his paper he stated:

> "The existence of these relations meant that the dimensions width, depth, and gradient of a channel to carry a given supply loaded with a given silt discharge were all fixed by nature."

That is, W , D , and S are uniquely determined. The variables bed width, depth, and slope were observed. Velocities, however, were not observed. They were computed by means of the Kutter and Chezy equations, the Kutter equation being:

$$C = \frac{41.65 + \frac{0.00281}{S} + \frac{1.811}{n}}{1 + \frac{n}{\sqrt{R}}\left[41.65 + \frac{0.00281}{S}\right]} \ . \tag{8}$$

The value of n in this equation was assumed constant at 0.0225. The Lindley equations, although never popular in this country, were used extensively in India until about 1935.

In 1927 Gerald Lacey was commissioned by the Governments of England and India to systematize all data that had been collected relative to stable channels. A summary of the results of the study were published in 1929 and 1933 respectively, in the form of two papers entitled "Stable Channels in Alluvium" and "Uniform Flow in Alluvial Channels" (28). Lacey's original equations as presented in the first paper were:

$$V = 1.17\sqrt{fR} \qquad (9)$$

$$A f^2 = 3.8\ V^5 \qquad (10)$$

$$S = 0.000387\ f^{3/2}/Q^{1/9} \qquad (11)$$

$$P = 2.668\ Q^{1/2} \qquad (12)$$

where P = the wetted perimeter

f = the Lacey silt factor.

They were later modified to:

$$V = 1.155\ fR \qquad (13)$$

$$Af^2 = 4.0\ V^5 \qquad (14)$$

$$S = 0.000383\ f^{3/2}/R^{1/2} \qquad (15)$$

These equations can be restated in terms of discharge as follows:

$$P = 2.668\ Q^{1/2} \qquad (16)$$

$$A = 1.26\ Q^{5/6}/f^{1/3} \qquad (17)$$

$$R = 0.4725\ Q^{1/3}/f^{1/3} \qquad (18)$$

$$V = 0.794\ Q^{1/6}/f^{1/3} \qquad (19)$$

At the time of his reply to the discussion of his latter paper he added four other equations:

$$S = 0.000547\ f^{5/3}/Q^{1/6} \qquad (20)$$

$$n_a = 0.0225\ f^{1/4} \tag{21}$$

$$V = 1.3458\ R^{3/4}\ S^{1/2} \tag{22}$$

$$V = 16.116\ R^{2/3}\ S^{1/2} \tag{23}$$

The difference in the constant terms in Eqs 22 and 23 is compensated for by the exponent of R .

In 1936 Dr. N. K. Bose (28) and the staff of the Punjab Irrigation Research Institute presented the following formulas

$$P = 2.8\ Q^{1/2} \tag{24}$$

$$S \times 10^3 = 2.09\ d^{0.86}/Q^{0.21} \tag{25}$$

$$R = 0.47\ Q^{1/3} \tag{26}$$

These equations represent the results of several years of painstaking collection and statistical analysis of the data. Note the similarity of Eqs 16 and 24.

The Lacey equations were officially accepted as correct by the Central Board of Irrigation in India in 1934 and they have been in continuous use since. The coefficients currently associated with the equations have been modified to include new data as it has been collected. The equations as they now stand are:

$$V = 1.15473\ \sqrt{fR} \tag{27}$$

$$A\ f^2 = 4.000\ V^5 \tag{28}$$

$$S = 0.0003759\ f^{3/2}/R^{1/2} \tag{29}$$

$$P = \frac{8}{3}\ Q^{1/2} \tag{30}$$

$$A = 1.260\ Q^{5/6}/f^{1/3} \tag{31}$$

$$R = 0.47247\ Q^{1/3}/f^{1/3} \tag{32}$$

$$V = 0.7937\ Q^{1/6}/f^{1/3} \tag{33}$$

$$S = 0.0005469\ F^{5/3}/Q^{1/6}\ . \tag{34}$$

As before f is called the Lacey number or silt factor and is defined as

$$f = \frac{3}{4}\frac{V^2}{R}\ . \tag{35}$$

In addition, according to Lacey, f depends upon size of sediment particles but is not affected by concentration of silt load being transported by the stream. In applying the Lacey theory Q is known, f is estimated, and bed width, depth, and slope are calculated.

In 1951 Thomas Blench (6) presented his concept of the Regime Theory. His equations are expressed in terms of W and D where W is the mean width and D is the depth to an average line through the channel bottom such that:

Area of water cross-section = A = WD

This concept is illustrated in Fig. 1.

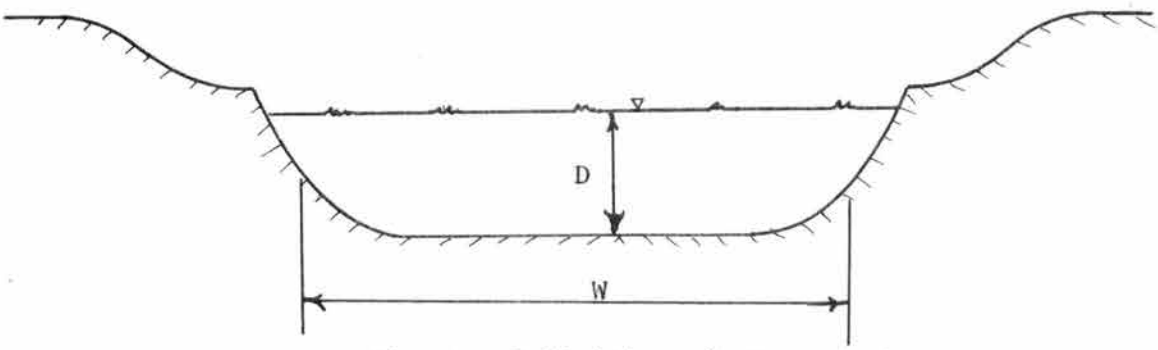


Fig. 1 Definition of W and D

The design equations presented by Blench (6) are:

$$W = \sqrt{\frac{b}{s}}\ Q^{1/2} \tag{36}$$

$$D = \sqrt[3]{\frac{s}{b^2}}\, Q^{1/3} \tag{37}$$

$$S = b^{5/6}\ s^{1/12}\ Q^{-1/6}/2080\, r \tag{38}$$

where

$$r = \left(\frac{10^{-5}}{\nu}\right)^{1/4}$$

$$b = \text{bed factor} = \frac{V^2}{D}$$

$$s = \text{side factor} = \frac{V^3}{W}\ .$$

During the same period of time that the regime theory developed, equations of a similar type were published in Egypt. For instance K. O. Ghabb (37) presented a non-silting, non-scouring equation similar to Kennedy's which stated that

$$Vo = 0.39\ D^{0.73} \tag{39}$$

Another equation developed for upper Egypt states that

$$D = \left[9060\ S + 0.725\right]\ B \tag{40}$$

this expression involves both slope and shape measurements.

Eq 40, as modified by A. B. Buckley states that

$$D = \frac{0.0025\ (100{,}000\ S + 8)^2}{1.62}\ B \tag{41}$$

where again slope, depth and bed width are all involved in one equation.

At least one American engineer, C. R. Pettis (37) has investigated the applicability of the regime theory to American rivers. The equations he presented were of the same form as the regime equations but did not have the same magnitude of constants and exponents. Hence one might conclude that regime equations depend on the conditions upon which they are based and are valid only within the range of the observed data.

The importance of sediment transport on the behavior of stable channels and the fact that it has never been quantitatively introduced into the regime theory has been a major factor retarding its use in the United States. One of the few equations involving concentration directly is the Beleida formula (37)

$$V = 147 + 3.92\ (C_1 - 10)^{0.383}\ R^{0.85}\ S^{0.72} \tag{42}$$

where C_1 = the sediment charge in grams per cubic meter of water.

This expression was developed originally for the Nile. If $147 + 3.72\ (C_1 - 10)^{0.383}$ is compared with the Chezy C it is obvious that they are vastly different since in this case C, being a function of charge, will vary continuously throughout the year.

Application of the Lacey and Blench Theories to Design

The design process, using the Lacey equations, is based on a knowledge of discharge capacity, an ability to estimate the Lacey silt factor, and the application of one form or another of his equations. Specifically if Q is known and f can be estimated then referring to Eqs 27 through 34, the wetted perimeter can be computed by means of Eq 30.

$$P = \frac{8}{3}\ Q^{1/2} \tag{30}$$

the hydraulic radius can be computed from Eq 32.

$$R = 0.47\ \frac{Q^{1/3}}{f^{1/3}} \tag{32}$$

and slope can be computed based on either Eq 29 or 34

$$S = 0.00038\ \frac{f^{3/2}}{R^{1/2}} \tag{29}$$

$$S = 0.00053\ \frac{f^{5/3}}{Q}\ . \tag{34}$$

Considering the complete group of equations presented, other combinations of them could also be used to evaluate the magnitude of P and R.

Knowing the values of S , P , and R and the geometry of stable shapes the design may be completed. If desired, R can be related to any measure of channel depth and P to any measure of channel width by means of correlations such as are shown in Figs. 36 and 37.

About the same results are obtained by using Eqs 24, 25 and 26 which Bose recommended. In this case it is necessary to know design Q and to be able to anticipate the mean size of bed material d , then P is computed from the expression

$$P = 2.8\ Q^{1/2} \tag{24}$$

R is computed from the equation

$$R = 0.47\ Q^{1/3} \tag{26}$$

and S is evaluated from the relationship

$$S \times 10^3 = 2.09\ \frac{d^{0.86}}{Q^{0.21}} \quad . \tag{25}$$

As before, width and depth can be obtained knowing P and R and the design is complete.

Using the Blench equations it is necessary to know b , s , and Q . The bed factor b seems to be a function of the course fraction of the sediment load that is in motion on and near the bed. The bed factor cannot be selected arbitrarily, its value is imposed by natural conditions. Determining a proper value of b by means of the Blench equations for additions to existing systems is not difficult. The engineer in charge of the project usually can provide information on changes that have occurred in the channels, as well as the necessary data required to compute b anywhere in the system. If one is then to design a new channel which is part of an old system a value of b can be estimated by referring to similar channels that are behaving satisfactorily. Values of b are usually computed by means of Eq 38 in this case. This is discussed in greater detail in Chapter III.

When a new canal system is being designed there is no reliable equation that enables the designer to evaluate b . The best method is to consult with experts, study records of similar successful canal systems, and study the effect of headworks and the possibility of using sediment exclusion and ejection devices. A value of b based on this approach is as good as can be obtained.

The correct evaluation of side factor is not nearly as critical as is the correct evaluation of bed factor. The magnitude of s can be estimated when designing canals that are part of an existing system by using a value based on similar canals operating successfully in the system or a value can be assumed based on the type of bank material. The latter method would be used in designing an entirely new system. Recommended values of s for design are:

Table 5. Recommended Side Factors

Type of Bank Material	Value of s, side factor
Shale and hardpan	0.30 - 0.40
Silty clay loam	0.20 - 0.25
Coarser material	0.15
Non-cohesive materials	0.10

The actual process of design once Q, b and s are known involves the simple application of Eqs 36, 37 and 38, that is, average width is determined by using

$$W = \sqrt{\frac{b}{s}}\ Q^{1/2} \tag{36}$$

the bed depth is given by

$$D = \sqrt[3]{\frac{s}{b^2}}\ Q^{1/3} \tag{37}$$

and S is evaluated from

$$S = \frac{b^{5/6}\ s^{1/12}}{2080r\ Q^{1/6}}\ . \tag{38}$$

The solution of these equations can be facilitated by using design charts as shown in Figs. 2, 3, and 4 taken from reference (6).

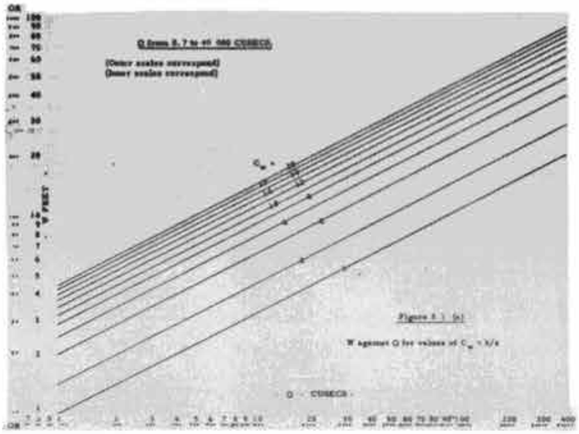


Fig. (2) - Variation of W with Q where $C_w = \frac{b}{s}$

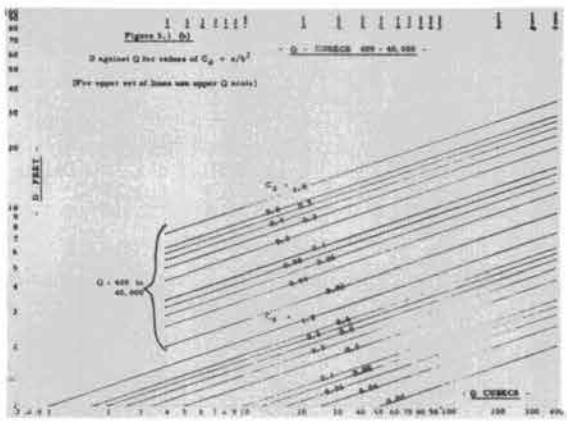


Fig. (3) - Variation of D vs. Q where $C_D = s/b^2$

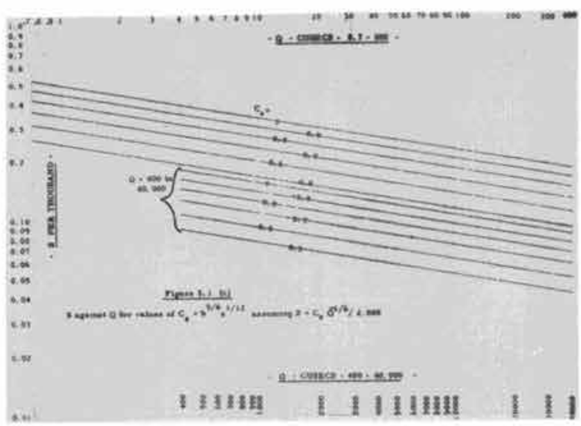


Fig. (4) - Variation of S vs. Q where $C_s = b^{5/6}s^{1/12}$ and $S = C_s Q^{-1/6}/2080$

Inadequacy of Regime Methods

The Lacey equations and modifications of them have been very popular in India but have never been used extensively elsewhere in the world. This group of equations undoubtedly provide as sound a basis for design as currently exists if they are used under circumstances similar to those from which they were obtained. The major disadvantages of the method are:

1. It has not been developed based on the wide variety of conditions encountered in practice.

2. It fails to recognize the important influence of sediment charge on design.

3. It involves factors that require a knowledge of the conditions upon which the formulas are based if they are to be applied successfully.

The regime equations presented by Blench modify the Lacey equations in such a way that the effect of the side and bed of the channel can be evaluated separately by means of the side factor and bed factor. This approach seems basically more sound than averaging the two effects as the Lacey equatións do since effect of bed and side conditions on flow are vastly different. To illustrate the point, canals have been designed by the Lacey method that have functioned properly during the normal period of operation but have failed to transport the sediment during the low flow period. These canals were later operated at full supply in an attempt to flush out the deposited sediment. The material would not flush out and the canal could not carry the design discharge thereafter. Blench points out that he believes this situation can be avoided by using his concept of the regime theory.

With the Blench equations, the major disadvantages facing the engineer are identical with those cited for the Lacey theory. That is, the theory involves factors that are difficult to evaluate, it fails to consider the influence of charge, and it is based on limited field conditinns.

To make either or both of the regime concepts, as presented by Lacey and Blench, generally acceptable, it will be necessary to modify these theories in such a way that effect of sediment transport is recognized. Better methods of estimating f in the Lacey theory and b, and s in the Blench theory would also materially increase the usefulness of these equations.

Inglis (28), Bose (9), Blench (6), and others have recognized the shortcomings of the regime theory as cited above and are currently attempting to introduce charge of sediment as a regime variable. Tentative equations qualitatively involving charge as a factor have been suggested by both Blench and Inglis. These new equations are presented and discussed in Chapter IV.

Tractive Force Method

The tractive force design theory is formulated on the basis that stability of bank and bed material is a function of the ability of the bank and bed to resist erosion resulting from the drag force exerted on them by the moving water.

This concept has been widely applied to the theory of sediment transport both in the United States and in other countries but only to a limited extent in connection with design of channels in alluvial material. Use of this method for design has been suggested by Williams (35) and Schoklitsch (57). The latter suggests that the following relations exist between type of soils and permissible tractive force and that these data are suitable for design purposes.

Table 6. Variation of Permissible Tractive Force with Type of Soil

Soil	Permissible tractive force (lbs/ft^2)
Loam	0.062
Sand	0.102
Stony and loamy soil	0.082
Course gravel	0.205
Very compact soil	0.256

More recently, owing to the efforts of E. W. Lane, the U. S. Bureau of Reclamation became convinced of the validity of the tractive force concept. Under Lane's supervision and leadership an entirely new line of approach has developed that has great promise. This new procedure as outlined in detail in reference (35) is based on the hypothesis that practical canal design is a tractive force problem, beyond that the approach is new and theoretical.

Three distinct classes of instability have been defined by Lane as follows:

1. Channels subjected to scour that do not silt.

2. Channels in which objectional deposition occurs but do not scour.

3. Channels in which objectional scour and silting both occur.

Class 1 instability is the simplest of the three proposed and fortunately it is also the one of primary importance since most of the present and future canal problems are and will be clear water problems.

The recommended design procedure was developed by considering:

1. Distribution of tractive force over the channel periphery for different side slopes with special emphasis on the magnitude of shear exerted on the sides as compared to the bed.

2. Relative stability of soil particles on the bed and on the sloping sides of the channel.

3. Magnitude of safe tractive force for different mean sizes and gradations of non-cohesive materials.

The shear distribution was worked out mathematically for rectangular channels and by membrane analogy and the method of finite differences for trapezoidal sections (24). It was found that maximum shear on the bed was approximately equal to γDS and on the sides it was about 0.76 of this value. The combined results of this study are presented graphically in Figs. 5 and 6.

Various theories have been developed making it possible to estimate magnitude of tractive force resulting from the movement of a fluid with respect to a fixed boundary with which it is in contact as follows. First

$$\tau = \gamma DS \tag{42}$$

where τ is the tractive force exerted on the bed at a point where the water depth is D. The derivation of this expression is based on equilibrium of forces tangent to the channel boundary and it is presented in Chapter IV. Second

$$\tau = \gamma RS \tag{43}$$

where τ is the average tractive force exerted on the channel periphery. This equation is derived by using the same procedure as for Eq 36. Third

$$\tau = \rho \left[\frac{V_1 - V_2}{5.75 \text{ Log } \frac{Y_2}{Y_1}} \right]^2 \tag{44}$$

where τ is defined as the tractive force on the channel bed directly beneath the normal to the bed in which V_1, V_2, Y_1, and Y_2 are measured. The derivation of this expression involves use of shear theory and the von Karman logarithmic velocity distribution law and is given in Chapter IV.

It should be noted that Eq 42 is only believed to be valid for relatively wide alluvial channels. For narrower channels τ should be computed as follows. Extend lines from the portion of the canal periphery in question in such a way that they are at right angles to the isovels (lines of equal velocity) of the cross-section. Next determine the volume of water confined between these lines per unit of channel length, and multiply it by the slope of the energy gradient s and the unit weight of water to obtain the magnitude of the tractive force. Using this procedure the net momentum transfer across the section is held to zero.

The effect of side slopes on limiting tractive shear was developed by considering the forces acting on the particles forming the sides of the canal, namely the tractive force exerted by the water and the force of gravity tending to move the particles down the inclined sides. A theoretical treatment, Chapter IV, considering these forces shows that

$$\tau = M\,(\cos^2 \phi \times \tan^2 \theta - \sin^2 \phi)^{1/2} \tag{45}$$

where ϕ is the angle the sloping side makes with the horizontal,

θ is the angle of repose of the material,

τ is the tractive shear corresponding to ϕ, and M is the weight of granular material whose stability is in question.

If ϕ is equal to zero the condition is equivalent to that on the bed and

$$\tau = M \tan \theta \ . \tag{46}$$

Taking the ratio of critical tractive force on the sides to that on the bed and defining this ratio as K

$$K = \left[\frac{\cos^2 \phi \tan^2\theta - \sin^2 \phi}{\tan^2 \theta}\right]^{1/2}$$

or

$$K = \cos \phi \left[1 - \frac{\tan^2 \phi}{\tan^2 \theta}\right]^{1/2} \tag{47}$$

A graphical solution of this equation as prepared by Lane is presented in Fig. 7.

In addition Lane presented another diagram relating the size, shape, and angle of repose of non-cohesive materials, see Fig. 8. A revision of this figure based on recent research carried out by the writer (60) under the direction of E. W. Lane, see Fig. 10, should be used instead of the foregoing.

The last step taken by Lane to complete the theory involved determining a relationship from which the critical value of the shear on a horizontal bed could be determined for various materials. Considering coarse materials first, a study of a group of San Luis Valley canals constructed in coarse non-cohesive materials was completed. Based on this investigation it was found that critical tractive force could be related to the size of bed material. In this case the size of the material which correlated best was the seventy-five per cent passing size. This correlation is presented graphically in Fig. 9. A similar relationship of not quite so high a quality results when τ is correlated with mean size.

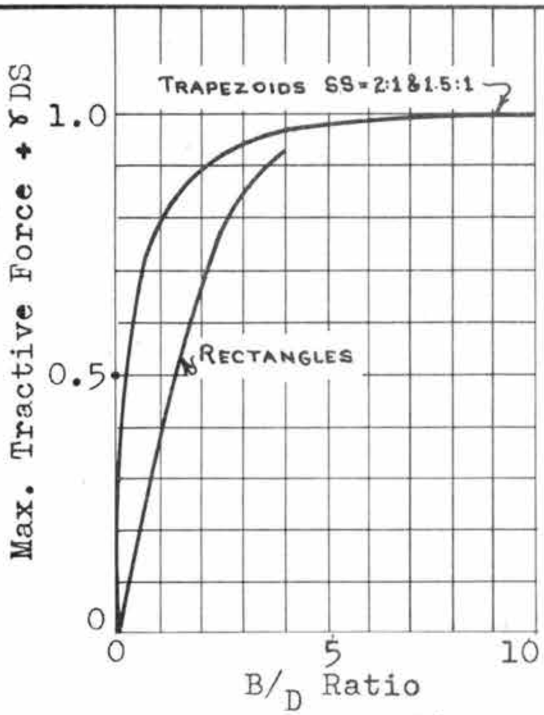
For the fine-grain non-cohesive size range, mean diameter less than 5 mm, no similar correlation has been developed. However, Lane has suggested tentative information for design as follows.

Table 7. Limiting Tractive Forces Recommended for Fine Non-cohesive Soils

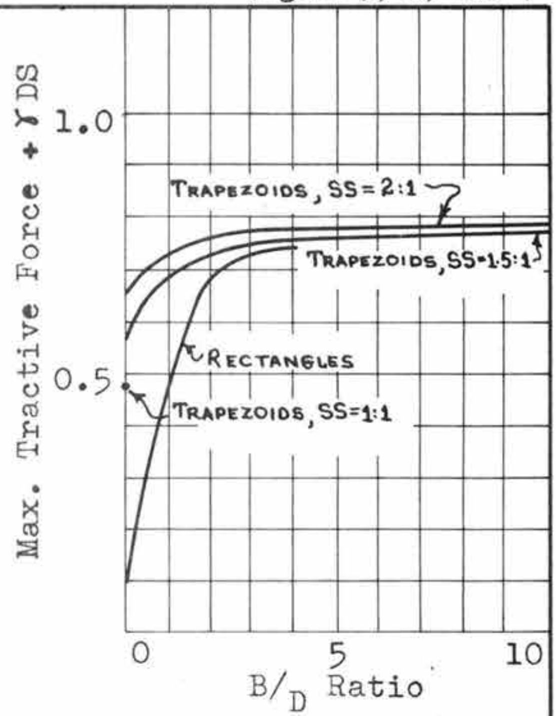
Median size of material (mm)	Limiting Tractive Force (lbs/sq ft) Clear Water	Light load of fine sediment	Heavy load of fine sediment
0.1	0.025	0.050	0.075
0.2	0.026	0.052	0.078
0.5	0.030	0.055	0.083
1.0	0.040	0.060	0.090
2.0	0.060	0.080	0.110
5.0	0.140	0.165	0.185

Values of limiting shear indicated in Table 7 are greater for canals than drag flume experiments indicate. Values given were determined by converting permissible canal velocities to the equivalent limiting shear.

The influence of bends on permissible tractive force has been similarly estimated by Lane (35).



$\tau_{max.}$ in Terms of γDS on Bottom of Channels
Fig. 5



$\tau_{max.}$ in Terms of γDS on Sides of Channels
Fig.6

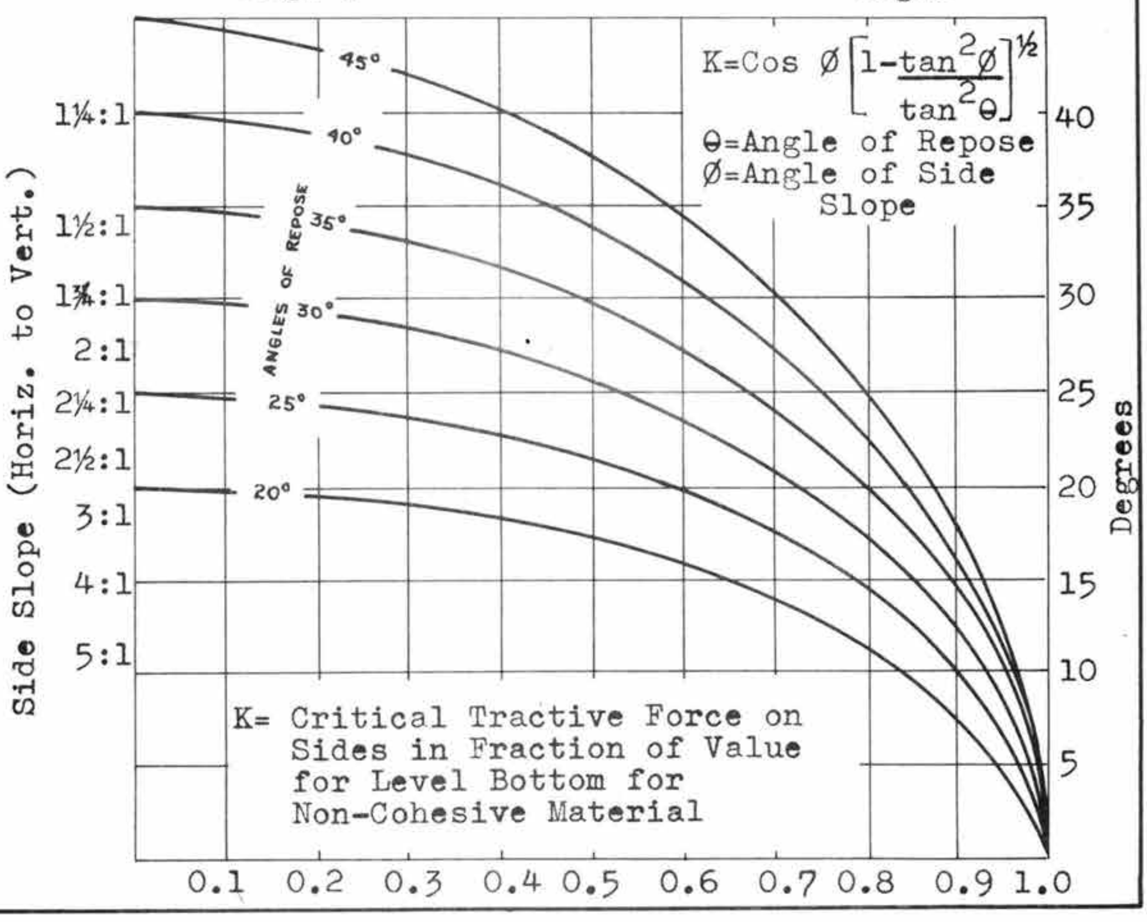


Fig. 7 Variation of K with side slope and angle of repose

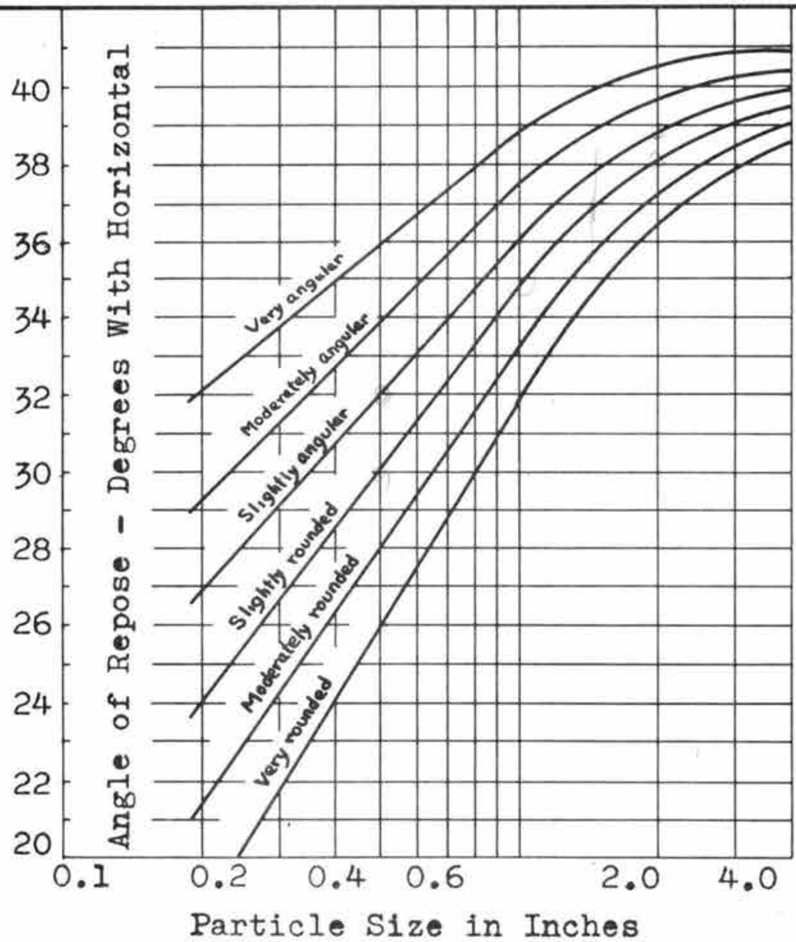


Fig. 8 Angle of repose for non-cohesive materials

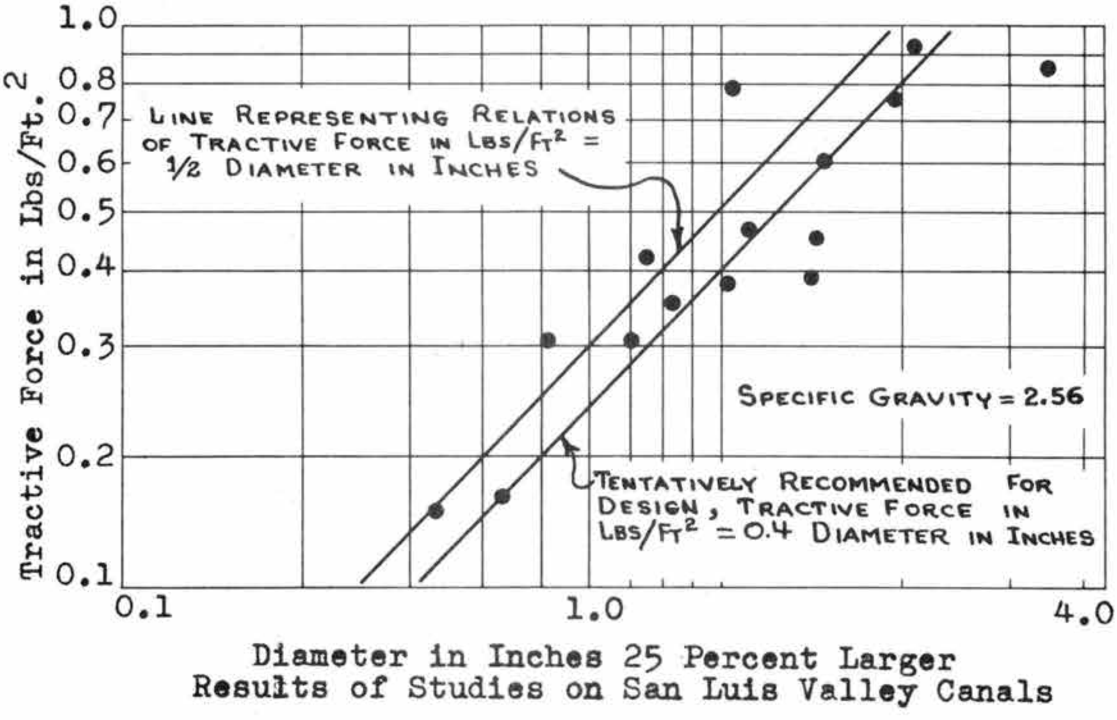


Fig. 9 Variation of tractive force τ with bed material d

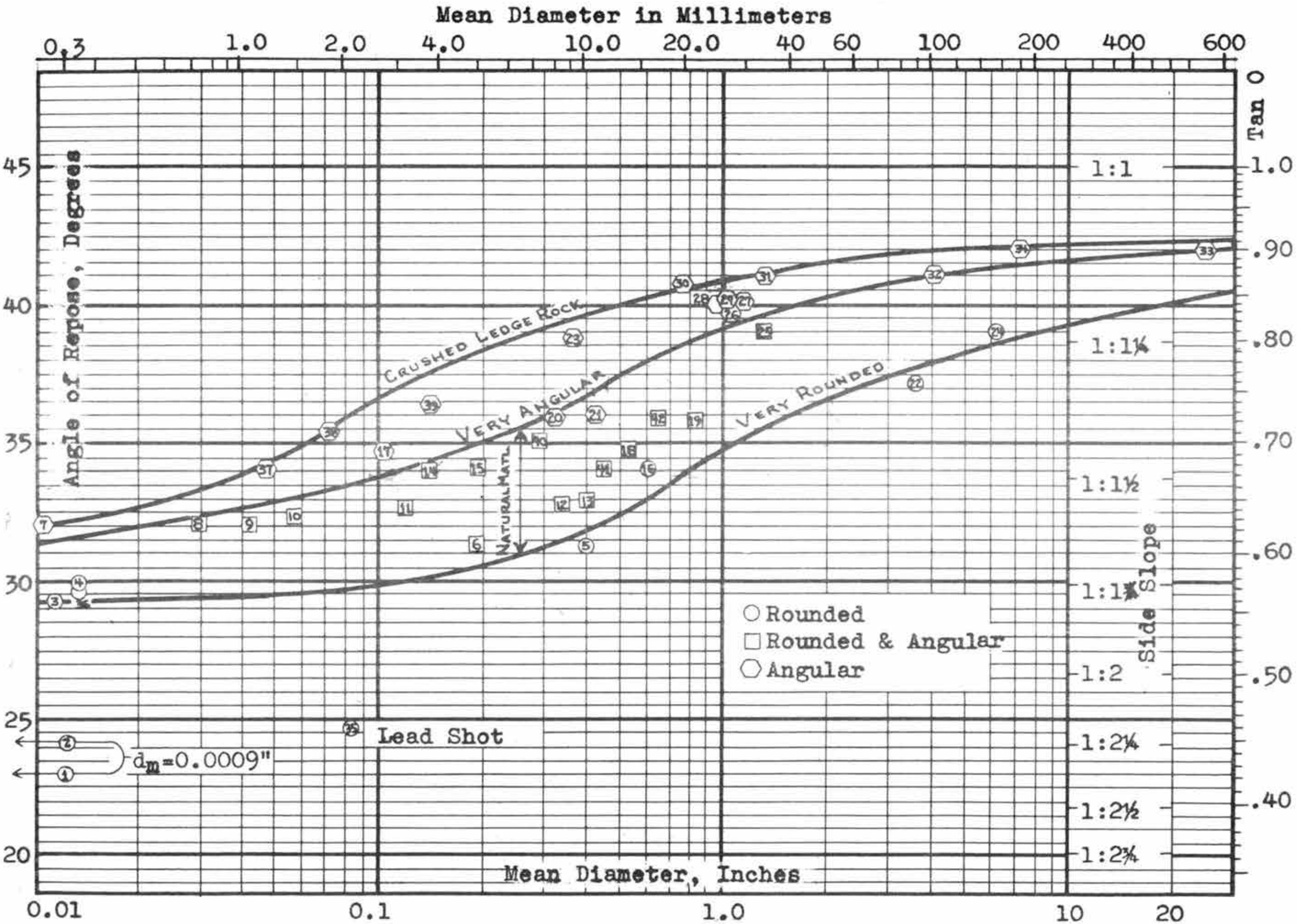


Fig. 10 Angle of Repose of Non-Cohesive Material

Table 8. Influence of Bends on Permissible Tractive Force

Degree of sinuosity	Relative limiting tractive force	Corresponding relative limiting velocity
Straight canals	1.00	1.00
Slightly sinuous canals	0.90	0.95
Moderately sinuous canals	0.75	0.87
Very sinuous canals	0.66	0.78

This information clearly indicates conformity with existing conditions, that is, reduced stability on the outsides of the canal bends.

For cohesive materials little or no research has been completed. Consequently, work must be done in this field.

In conclusion, it is of importance to note that because of the effect of sediment transport the basic laws of mechanics of transportation eventually may be a significant part of stable channel theory.

Tractive Force Design Procedure

Considering coarse non-cohesive materials, it is possible to design a canal for clear water conditions, class 1 instability, providing Q and the seventy-five per cent-passing size of bed material can be estimated by using the preceding theory as follows.

1. Knowing Q and d_{75} assume a shape.

2. Calculate B/D based on assumed shape. Enter Fig. 5 with this arbitrary value and determine the magnitude of C in the equation $\tau = C \gamma DS$, τ being defined as the critical tractive force.

3. Determine the value of τ from Fig. 9 corresponding to d_{75}.

4. Based on bed conditions estimate the maximum permissible longitudinal slope by equating the value of τ taken from Fig. 9 to $C \gamma DS$ and solve for S , that is

$$S = \frac{\tau}{C \gamma D} .$$

The influence of the stability of the canal sides on channel slope S must now be checked. Usually the side material cannot resist as great a tractive force as the bed because of the additional effect of gravity.

5. Knowing size and shape of material, enter Fig. 8 and estimate the angle of repose.

6. Evaluate K from Fig. 7. Knowing K and the critical tractive force acting on the bed the tractive force on the sides can be computed.

7. Enter Fig. 6 and determine the maximum tractive force in terms of γDS acting on the sides of the canal. That is, determine C in the expression $\tau = C \gamma DS$.

8. Equate τ from step 6 to $C \gamma DS$, and knowing C the slope S can be evaluated.

9. Compare the slope based on bed stability, step 4, with slope based on side stability, step 8, whichever is smaller governs.

10. Check the capacity of the canal using the established slope and assumed shape. If the capacity is incorrect assume a new shape and repeat the above procedure. This process continues until a satisfactory design results.

The application of the above procedure to a design problem is discussed and illustrated in reference (35).

<u>Channel Shape as Related to Tractive Force</u>

The distribution of tractive force in trapezoidal channels was thoroughly investigated as reported by Glover and Florey (24), see Bureau of Reclamation Hydraulic Laboratory Report No. Hyd - 325. In addition to investigating the intensity of tractive force distribution on the bed and banks of trapezoidal sections the possibility of determining a shape such that the material on the entire wetted perimeter is in a state of incipient motion was also investigated.

This shape which was developed and which is subjected to a limiting tractive force over the entire wetted perimeter proved to have many interesting properties. That is, a channel of this shape in coarse, noncohesive material according to Lane (35) proved to be:

1. The channel of minimum excavation where water surface is below ground level.

2. The channel of minimum top width.

3. The channel of maximum mean velocity.

4. The channel of minimum water area.

It is interesting to note that the most efficient trapezoidal shape as discussed by hydraulic and fluid mechanics texts for given side slopes and rate of flow give a channel having a minimum water cross-sectional area but this is not necessarily the channel of minimum excavation as described in the foregoing paragraph.

It is apparent that in design it may be desirable to design a channel such that it has a factor of safety against motion. This can be accomplished by reducing the angle of repose of the natural bank material below its actual value.

Limitations of the Tractive Force Method

The tractive force theory is basically sound insofar as it has been developed, that is, for clear water conditions in coarse non-cohesive materials. In this range the design procedure, in accordance with the foregoing outline, is valid and can be expected to yield good results.

Working with fine non-cohesive soils is more indefinite. Little or no field work has been done in this size range. The only basis for designing in this category is the tentative recommendations suggested by Lane (35) as shown in Table 7, Chapter II. It appears that additional research is needed to definitely relate limiting tractive force to size, gradation and possibly other characteristics such as particle shape for the soils in question.

In the cohesive range even less is known about design. Again research is needed to relate limiting tractive force to the properties of clay affecting its stability.

Thus far sediment transport has not been incorporated effectively into the tractive force theory. The basic effects created by introducing varying amounts of sediment are understood but only in a qualitative way. In this respect all methods thus far considered are in the same category. To obtain a complete theory applicable to the full range of design conditions encountered in nature, additional effort will be required. It seems that in the final analysis stable channel theory must incorporate sediment transport theory at least to a limited extent.

A detailed discussion of the field phase of the research including a description of canals investigated, the data collected and the equipment utilized is presented in Chapter V. As a prelude to this discussion, the factors influencing stability of canals, and a theoretical analysis of the problem follows.

Chapter III

FACTORS INFLUENCING STABILITY OF OPEN CHANNELS

A detailed study of existing design methods immediately verifies the complexities of stable channel theory. To cover adequately each existing design case, any suitable theory must include the effect of all of the pertinent variables. To date no theory has been conceived capable of adequately considering all of them and their influence on channel behavior. A brief discussion follows of the major variables involved.

Discharge

The primary purpose of any irrigation or power channel is to deliver, at a minimum annual cost to the project, the required amount of water to the point or points of need. The method of delivering water to the project units varies appreciably from area to area depending on such factors as soil conditions and climate. In connection with this, the method of delivery may have a rather profound affect on channel behavior. That is, channel stability may be influenced by the method of canal operation. A study of existing methods of canal operation and design shows that

1. Canals may be operated at full supply throughout the irrigation season.

2. Canals may operate in accordance with crop need which can vary widely over the irrigation season.

3. Canals may operate periodically during the irrigation season such that they are in operation a few days then out a few days.

4. Design may be such that some cross drainage from storms is picked up and this may cause the magnitude of discharge to vary drastically upward to discharge considerably in excess of design discharge for short periods of time. These various methods of operation will now be considered in more detail.

Steady Discharge

Canals which operate continuously throughout the irrigation season, or possibly throughout the year as in the case of some power canals, are rather common. This method of operation is the simplest case possible. The validity of this statement is more apparent after considering the influence of a slow, or rapid fluctuation in discharge with respect to time.

Variation of Discharge with Crop Needs

In many areas the initial demand for irrigation water may be very small. The discharge is then gradually or abruptly increased to meet peak demand, after which it tapers off again toward the end of the irrigation season. The influence of this method of operation on stability is somewhat different than in the case of the steady, full-supply method. In this instance initially only a small part of the stream cross-section is used and rate of increase in discharge is usually sufficiently slow that various forms of vegetation have a chance to develop at and above the water line -- depending on soil texture to a certain extent. The net result is that each increase in discharge submerges a new portion of the banks covered with weed growth. The roots of the weeds reinforce the banks. The weeds themselves superpose a roughness on the flow that causes reduced velocities at the bank and this condition thus presents a greater opportunity for berming to occur providing the necessary wash load is present in the flow.

Summarizing the foregoing situation, bank stability is increased, berm growth is encouraged, and over-all roughness is increased to the extent that the canal may not be capable of conveying the design discharge until the bank condition is improved by maintenance. Furthermore, it should be noted that these conditions also may encourage deposition of sediment on the bed -- thereby introducing instability.

Similarly, the demand for water may be of such a nature that a minor channel develops within the main channel that has shape characteristics consistent with an initial small discharge which remains fairly steady over the beginning and perhaps final periods of the irrigation season. This double channel condition has been observed on the Cozad Canal near Gothenburg, Nebraska. Fig. 11 illustrates this situation.

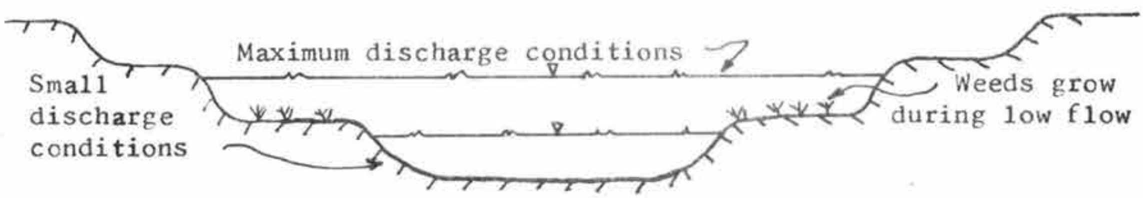


Fig. 11 Overbank Channel Caused by Method of Operation

Periodic Discharge

Type of distribution system, and availability of supply may necessitate operating in such a way that the canal is at full supply (maximum discharge) for a period varying from a few days to a week, after which the canal is dry for a similar time period. For a given type of bank material it appears that this type of operation yields the maximum W/D ratio possible for a given discharge. This is because of the extra forces brought into play on the banks by rapidly dropping the water surface in the canal. Sloughing of banks is encouraged by this type of operation.

The forces brought into play to cause the bank sloughing are similar to those experienced by an earth dam subjected to sudden drawdown except that they are even more severe since the banks of the channel are usually much steeper than those encountered in design of dams. The slope of the banks probably approaches closely the angle of repose of the material. However, in cohesive materials cohesion would exert some influence on bank slope also. Considering an element of canal bank and applying the fundamentals of soil mechanics it seems doubtful that stability would ever be achieved in a channel of this type. A common characteristic of channels resulting from this method of operation is ragged, irregular canal banks if they are of appreciable size, say of capacity greater than 100 cfs. One possibility of maintaining stability of banks for this range of conditions seems to be to build them at very flat slopes, 1:2, or 1:3 depending on characteristics of the bank material. It also may be worthwhile to consider using a gravel riprap, depending on the economics of the situation, to provide a further factor of safety against sloughing.

Design Discharge Exceeded

This situation is the exception other than the rule. However, on small irrigation canals and laterals it may not always be possible to afford adequate protection against influx of cross-drainage water. In this case small canals may fill and even overflow their banks for short periods of time during and immediately following storms. The damage to channels as a result of being subjected to excess flows may or may not be of importance depending on duration of the excess discharge, the degree of protection afforded the bank by existing vegetation, the amount of sediment carried in, and the expense of repairing the damage.

The most common damage noted in the canals subjected to this treatment has been either excessive scour or deposition. The banks are usually capable of resisting the extra shear due to increased strength derived from vegetal growth. Depending upon the effect of the design discharge being exceeded, either scour will occur and the bottom will gradually refill to the equilibrium level or deposition will occur and the canal must be cleaned out by maintenance crews.

Slope

Determination of correct slope is one of the most critical factors in stable channel design. If a channel is constructed on an excessive slope the upper end of the channel begins to degrade and over a period of years it will adjust to a new slope that suits existing conditions. The other danger is selecting a slope that is too small to maintain velocities capable of conveying the influx of sediment through the system. In addition, the channel under these circumstances may not even be capable of carrying design discharge. It is apparent that stability is a function of slope and in turn slope is a function of such variables as required capacity, magnitude and gradation of charge, channel shape, type of bed and bank material, bed condition, extent and nature of weeds, effect of wind, and bends. Most of these variables related to stability will be considered independently as they directly affect channel behavior.

Shape of Channel

The channel shape which is selected that will remain stable is a function of many variables some of which have already been discussed. As previously noted, width, depth, and slope of channel are all free to adjust if they are not properly selected initially. Two schools of thought exist regarding shape. In accordance with the tractive force theory any width and depth consistent with the magnitude of boundary shear and sediment transport may be selected. In fact a study of trapezoidal canals by the U. S. Bureau of Reclamation under the supervision of E. W. Lane (35) shows that limiting tractive forces occur over only part of the perimeter. Because of this they investigated the feasibility of designing channels so that limiting tractive shear acted over the entire perimeter. The shape yielding this condition was determined by application of the membrane analogy theory and also by the method of finite differences. The shape of channel arrived at is the channel of minimum excavation, minimum top width, maximum mean velocity and minimum water area. The significance of these findings needs additional study from the viewpoint of application.

According to the regime theory as developed and applied in India, there is only one correct shape of channel for a given set of design conditions, that is, shape cannot be arbitrarily selected. The basic equations (30 and 32) are the ones most commonly used to establish the channel dimensions P and R or if one prefers W and D can be estimated using Eqs 36 and 37, as recommended by Blench. The theory as presented by Lacey fails to consider the separate and different effects of bed and side conditions on regime. The modified regime theory as presented by Blench (6) supposedly takes this factor into account by means of a bed factor and a side factor as previously mentioned. A more specific discussion of the influence of soil type on stability follows.

Boundary Material

The effect of natural bed and bank materials on stability is in general taken care of when selecting shape since shape is a function of soil type. The major types of materials that form the initial peripheries of channels are:

1. Cohesive materials.
2. Non-cohesive materials, sand range.

3. Non-cohesive materials, gravel and cobble range.
4. Lensed materials, that is, alternate layers of sand and clay, etc.
5. Cemented materials.
6. Shales.
7. Some form or type of rock.

In this dissertation canals falling within the first three groups will be considered.

Cohesive Materials

Cohesive materials are more resistant to scour because of cohesive strength and they seem to present a smoother boundary to flow than the other material. They also seem to support vegetation more readily than the coarser materials and thus further increased bank stability. In conclusion, stable channels in material of this type do not require as large a W/D ratio as canals of equal capacity in the non-cohesive sand range.

Non-Cohesive Materials, Sand Range

These materials, due to lack of cohesive strength and reduced ability to support vegetal growth, must rely primarily on their weight, shape, and surface texture to resist displacement. Canals in sandy material tend to be wide and shallow. That is, W/D ratios are larger than those found in canals of similar size constructed in cohesive materials. Failure to recognize the need for a large W/D ratio in this group is a serious mistake since the channel will increase in width until stability is achieved and the eroded bank material may fill the smaller distributaries and laterals downstream of such a condition, causing tremendous maintenance problems.

Non-Cohesive Materials, Coarse Range

Due to the greater weight of individual particles, and larger angle of repose, materials in this range are much more stable than are the sands. As a result of Lane's study of canals in coarse non-cohesive materials it is known that tractive force in lbs/ft^2 is approximately equal to 0.45 times the particle size for which 75 per cent of the particles are finer. This fact means a greater latitude in selection of shape and greater permissible velocities are possible. As is pointed out on page 37 materials of this type are quite commonly used to stabilize banks which are composed of materials that are less resistant to scour. The bank slopes must, of course, be within the angle of repose of the protective layer.

Water Temperature

The precise and total effect of temperature variation is not completely understood. It is known however, that viscosity of the water-sediment complex changes with temperature and consequently the ability of the liquid to transport sediment also changes. Providing Blench's regime equations are valid, it can be noted by referring to Eq 38 that stable slope varies directly with kinematic viscosity to the one-fourth power. It can also be noted that shear exerted by the water on the boundary varies directly with its density which is a function of temperature.

The effect of temperature on sediment transport has been very clearly demonstrated by Lane (36) by considering concurrently observations of discharge, sediment concentration, and water temperature on the Colorado River for the period 1943-47. It was verified that a definite increase in the per cent by weight of the suspended sediment load transported per unit volume of water occurs as temperature decreases. The effect of temperature on stability as compared in magnitude with the effect of other variables is probably small. However, further investigations should be conducted before making this as a statement of fact.

Wash Load

Wash load is defined by the sub-committee on sediment terminology (3) as that part of the sediment load of a stream which is composed of particle size smaller than those found in appreciable quantities in the shifting portions of the stream bed. In general sizes are so small that very little turbulence is required to keep the material in suspension. The wash load may be quite uniformly distributed in the vertical. The effect of wash load on stability is not clearly understood but it is known that it is necessary if berming is to occur. The viscosity of the water-sediment complex is probably influenced by the presence of wash load and density is increased.

Recent laboratory research completed at Colorado State University, Fort Collins, Colorado by A. H. Makarechian indicates that sediment transport is related to the concentrations of wash load. That is, if wash load is increased, the amount of bed material load that can be transported, with no change in other conditions, is increased.

The primary effects of wash load on stability are:

1. It causes berms that are fairly tough and resistant to erosion to form.

2. The berm formation encourages weed growth above the water line, thereby increasing bank stability.

3. The sub-surface vegetal growth, such as moss is inhibited.

4. The mass density and viscosity of the water-sediment mixture is increased and its ability to transport bed material seems to increase.

Bed Load

This fraction of sediment load is defined as the coarse material moving on or near the bed of the channel. There is no distinct dividing line separating suspended load and bed load. The bed load is kept in motion by turbulence and boundary drag. Any given channel is capable of transporting a certain quantity of sediment depending on other related factors such as shape of channel, size of sediment, slope of energy gradient, and amount of wash load. The effect of reducing charge in an otherwise stable channel is to initiate scour and hence non-equilibrium. The water has excess energy when charge is reduced and this energy is dissipated by picking up sediment from the bed. The scouring agents are the velocity and the turbulence of the water. Turbulent action is apparent even at the water surface in the form of an undulating motion and dappled color effect. On the other hand, accretion begins if charge is increased above the stability level. This means that the effect of the scouring agents is more than counteracted by the rate of deposition. The situation has been illustrated in equation form by A. R. Thomas as follows:

Scouring agents = velocity and turbulence,

Depositing agents = bed load from upstream plus bombardment of bed by suspended particles,

Agents resisting scour = weight of particle plus friction and cohesion among the particles.

If equilibrium is to exist

Scouring agents = agents resisting scour plus depositing agents.

The delicate balance between stability of channel and charge has been even more clearly illustrated by E. W. Lane (33) and in a different manner. He presents the following relationship to assist with the qualitative analysis of stream morphology problems.

$$Q_S \, d \sim Q \, S$$

Where Q_S = quantity of sediment being transported,

d = mean particle diameter or size of sediment,

S = slope of energy gradient,

Q = water discharge

This expression shows that if a stream in equilibrium has its sediment load decreased, equilibrium can be restored by increasing d or by decreasing Q_W and/or S. The same line of reasoning can be applied in the event of instability originating as a result of increased charge. Other sub-factors that may be of importance to the stability problem are variability of charge, variation of concentration of sediment with depth and possibly chemical effects.

Berms

The interrelationship between wash load and berms and the effect of berms on stability have been discussed generally in the preceding paragraph. Some additional factors of interest will be considered at this time.

Deposition of Wash Load

The mechanics of berm deposition are not clearly defined. From theory, field and laboratory measurements, and observations it is known, however, that reduced velocity and turbulence adjacent to the banks, effect of gravity, precipitating effect, and bombardment of the bank with wash load resulting from the secondary circulation are all involved in the deposition of berm material. The rate at which the berm builds is also a function of concentration and possibly chemical composition of the wash load.

Shape of Channels Possessing Berms

The berms that form are of a cohesive nature and consequently are capable of standing on steep slopes. The most usual shape to which canals with natural berms adjust is a section having a fairly flat bottom with sides resembling parabolic, elliptic, or even semicircular curves that are tangent to the channel bed and in some cases nearly vertical at the water surface. The elliptic shape has been called the ideal theoretical shape. A typical canal shape is illustrated in Fig. 12.

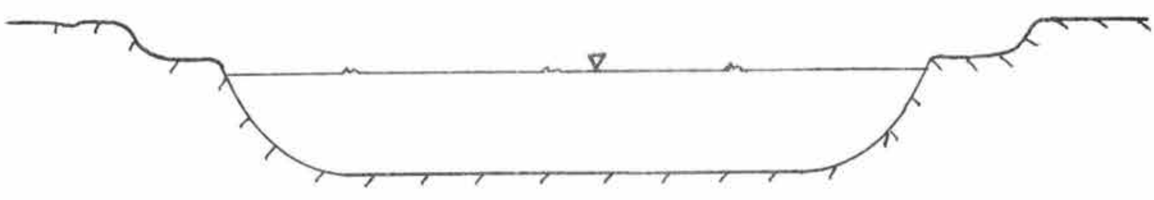


Fig. 12 Shape of Typical Stable Canal with Natural Berms

The Influence of Berm Formation on Bank Vegetation

This subject is interrelated with other variables influencing stability and it has already been briefly discussed. It is a well known fact that vegetal growth on the banks accelerates the formation of berms and that weeds and grass usually grow even more vigorously in berm material than in the natural material. The magnitude of the reinforcing effect of the root system is largely a function of type of vegetation growing in the berm. From observation two general types of plant growth predominate:

1. A high, dense bank weed growth that eventually bends from wind action and its own weight so that at least in part it hangs into the water cross-section.

2. A growth of grass usually so short that it does not bend over into the water cross-section to any appreciable extent.

In the first case the reduction in velocity, and the strength of the reinforced berm are capable of protecting the banks against erosion and the weeds encourage additional berm to form. The major disadvantages accompanying this condition are reduced capacity of channel because of berm formation and reduction in velocity due to the additional resistance caused by the weeds which may cause part of the sediment load to drop out — thereby further reducing the carrying capacity and increasing maintenance costs.

In the second case increase in resistance to flow is quite negligible and yet the banks are strengthened by the formation of the berm reinforced with grass roots. There may be some undercutting below the grass roots but in general no serious disadvantages develop such as in the preceding case.

Bank Stabilization

In many instances it may be desirable to stabilize scouring canal banks for one or more of the following reasons:

1. To confine the channel within the limits of the right of way.

2. To maintain a smaller W/D ratio to reduce seepage.

3. To act as a sediment load control measure.

4. To protect the access road adjacent to the canal.

5. To protect bridges and hydraulic structures.

6. To control erosion at bends where shears exerted are in excess of those occurring in the straight reaches.

Coarse non-cohesive materials are most commonly used to form the stable envelope. The size of material utilized must be capable of resisting the maximum boundary shear acting on the banks. The required mean size that must be equaled or exceeded can be estimated using the design procedure recommended by E. W. Lane (35).

The required depth of material is fixed rather arbitrarily according to experience. Along the Interstate Canal in Wyoming and Nebraska the depth of layer is about 3 in. - 6 in. The average size of material used is about $1\frac{1}{2}$ in. and average canal velocity is close to 3 fps. For greater velocities and coarser materials, a greater thickness of layer would be required since it seems that a lower limit would be on the order of thickness equal to the maximum size of material being used to protect the bank.

The side slope of channels being protected against erosion by this method must not exceed the angle of repose of the protective material revised downward to account for drag on the particle and to provide an adequate factor of safety.

The effect of the velocity of water on angle of repose was investigated in India (28) see Fig. 13.

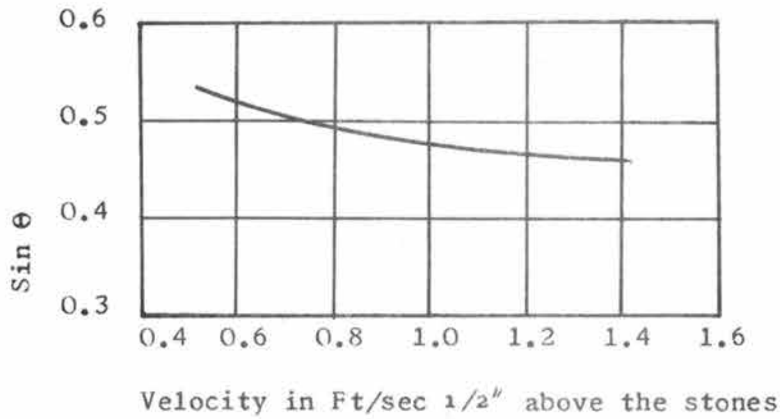


Fig. 13 Effect of Velocity on Angle of Repose

The results of this research provides a means of modifying angle of repose data downward to compensate for drag force. The velocity correlated with angle of repose was measured at a distance of one-half inch, in a normal direction, away from the bank.

A rather thorough study of angle of repose of non-cohesive materials, previously mentioned in Chapter II, ranging in size from 0.10 in. to 24 in. and ranging in shape from round to very angular was recently conducted and reported by the writer under the supervision of Lane (60). The results of this study are presented in Fig. 10 and should be used in preference to Fig. 8 to estimate angle of repose of non-cohesive materials.

As shown later in Chapter VII the effect of a protective blanket on channel roughness was found to be minor. Values of Manning's n for gravel channels are about 40 per cent higher than values found in the smooth cohesive ones and approximately the same as channels having sand beds with a well developed dune pattern.

Methods of placing protective blankets vary depending on cost of labor and methods of canal operation. If the canals are non-operative during any portion of the year, then during this time the bank can be shaped to proper slope, usually by hand labor, and the protective material can be dumped at the top of the canal bank and worked downward utilizing the effect of gravity to cover the entire bank. If the canal is in operation continuously, the Indian method, as described by Sir Claude Inglis (28) could be employed at the outset provided artificial berms exist. This procedure involves placing two rows of protective material parallel to the axis of the canal on the berms. The distance from the edge of the water to the protective material is fixed by desired width of channel as indicated in Fig. 14.

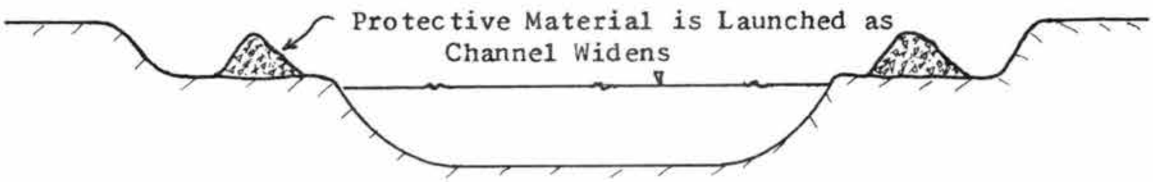


Fig. 14 Method Used to Launch Protective Blankets in India

As scour progressively widens the channel the windrows are undermined and the protective material is launched. A typical cross-section obtained by this type of treatment is shown in Fig. 15.

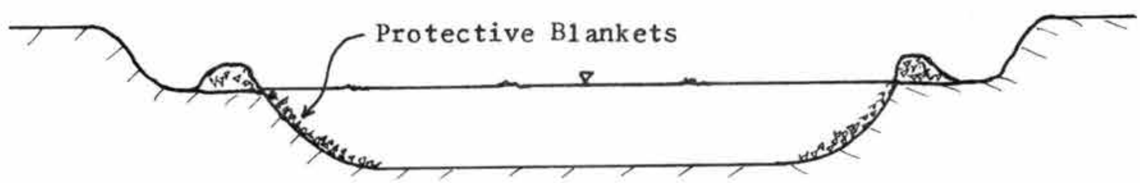


Fig. 15 Typical Shape of Channel Stabilized by India Method

A second method of placing protective material during the period of operation, used on the Interstate canal in Wyoming and Nebraska, is to shape the canal bank with hand shovels to a suitable slope and then dump the protective material over the bank from trucks as shown in Fig. 16.

Fig. 16 Placing of Protective Material on the Banks of the Interstate Canal in Wyoming

The protective material is worked on down the bank beneath the water surface by hand labor, by the action of the water and by gravity. This procedure is only used when a section of canal requires immediate attention.

The foregoing procedures can also be used to place protective materials on the outside banks of bends to avoid erosion resulting from the excessive shear exerted on them at these points.

Some concept of the influence of degree of sinuousity on permissible tractive force can be obtained by studying Table 8 in Chapter II, taken from reference (35). Additional research is needed to improve design methods and understanding of this phase of channel stability. Only a very limited knowledge of the magnitude of the tractive force at bends and the effect of the secondary circulation and turbulence developed and superposed on the channel below are currently available.

In areas where coarse non-cohesive material is not readily accessible similar results have been obtained by protecting banks of straight and curved sections of canals with Brule clay which is tough, highly cohesive and is found in the Brule formation. This material is placed in lump form. It gradually disintegrates over a period of two or three years to form a rather smooth protective surface. This procedure is used by the Farmers Irrigation District, Mitchell, Nebraska on their main canal. They estimate the life of such protection at about twenty years.

Secondary Circulation

Considerable speculation regarding the existance of secondary circulation in open channels and the extent of its effect on sediment transport, sediment distribution, velocity distribution, and channel roughness has been presented by various authors. A rather comprehensive summary of the beliefs and hypotheses of these writers has been presented on pages 116 to 125 of reference (68) by Paul F. Nemenyi as well as his own concepts of this phenomenon. According to Nemenyi, secondary circulation in open channels was first observed by the German geophysicist Max Moller and the American hydraulic engineer F. P. Sterns. They observed the existence of circulation simultaneously and independently in 1882. According to them secondary circulation consists of two perfectly symmetrical parts as illustrated in Fig. 17.

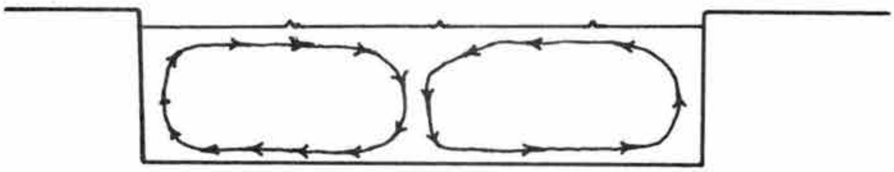


Fig. 17 Original Observation of Secondary Currents According to Moller and Sterns

The simple form indicated in this figure is challenged by the results of the more thorough research of L. Prandtl conducted in closed conduits. His research when applied to open channels suggests the presence of several cells as shown in Fig. 18.

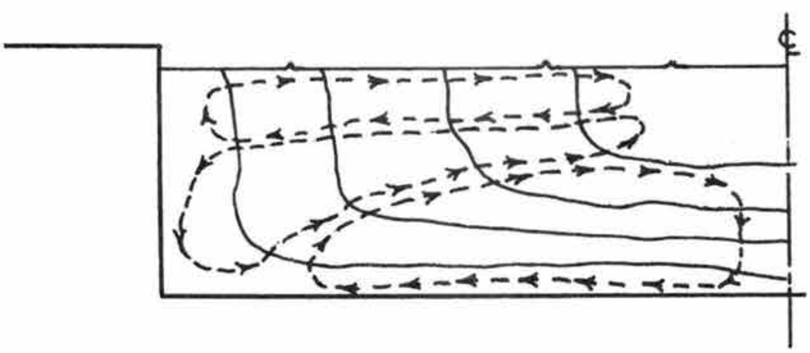


Fig. 18 Secondary Circulation According to Prandtl

Others contributing to the knowledge of secondary circulation in open channels mentioned by Nemenyi are Terada of Tokyo Imperial University and Hugh Casey. Based on laboratory observations in a wide and steep channel heated from below Terada found that secondary circulation resulting from temperature differences was of the form indicated in Fig. 19a. In a paper prepared by Casey a photograph was presented illustrating secondary circulation for a wide open channel with movable bed as shown in Fig. 19b.

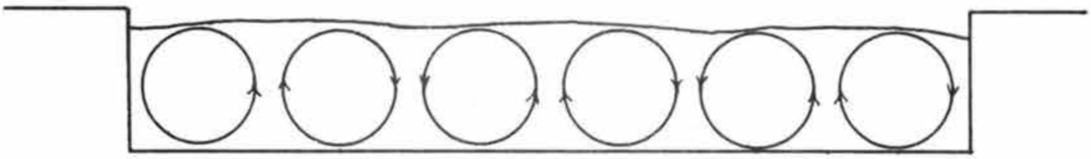


Fig. 19a Secondary Circulation in a Wide Open Channel Resulting from Temperature Differences

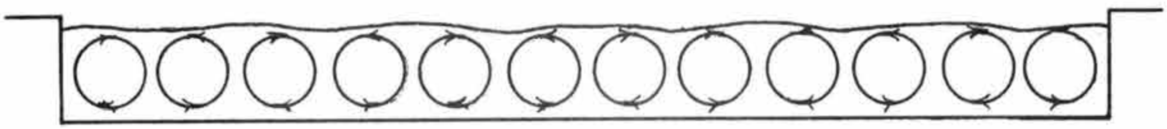


Fig. 19b Secondary Circulation as Observed by Casey

Fig. 19 Secondary Circulation

This pattern is very similar to that presented by Terada.

Vanoni (68) observed that the sediment was not uniformly distributed across the flume. When the flow was stopped, bands of sediment were deposited on the flume floor indicating the existence of a secondary circulation similar to that observed by Terada and Casey. It is also suggested that the number of cells is probably a function of width to depth ratio, W/D .

In his summary on circulation Nemenyi states that:

1. Secondary circulation is a normal occurence in open channel flow and it can occur without the influence of sediment or temperature.

2. The longitudinal velocity distribution, quantity and distribution of suspended sediment, and the magnitude of secondary circulation are all interrelated in such a way that if one is varied the others will be affected.

3. There is a possibility that artificial modification of secondary circulation might be used to modify or stabilize sediment distribution and bed formation.

4. Turbulent flow is of a three dimensional nature and this is probably a major reason for discrepancies between experimental results and results based on the von Karman theory of velocity distribution and sediment suspension.

The cause of circulation is debatable. In the above summary it was stated that circulation exists independently of temperature gradient and/or suspended sediment, and that non-uniform sediment distribution across the section is the result of secondary circulation. In contrast to this Vanoni (68) believes that secondary circulation is either caused or at least appreciably strengthened by the lateral non-uniform distribution of sediment.

The extent of the effect of secondary circulation on factors related to channel stability is unknown. Based on existing knowledge its influence may be negligible, of considerable importance, or somewhere in between these limits; however, many speculate that it is of minor importance. Only additional research can answer this question completely.

Lane suggested to the writer that one might gain additional insight to this phenomenon by studying the existence of secondary circulation, and the number of cells generated in channels having different W/D ratios by sprinkling material such as saw dust uniformly across the water surface in a straight reach then observing to see if the saw dust collects into bands as one suspects that it would. The number of cells being generated should be directly related to the number of bands observed. In accordance with the foregoing concept, see Fig. 20 which shows the channel immediately below Grand Coulee Dam. Here secondary circulation has gathered the surface foam into two distinct bands indicating the existence of four secondary cells.

Fig. 20 Secondary Circulation Below Grand Coulee Dam

A study of the data collected on stable canals, to be presented later, shows that very little variation in lateral sediment distribution occurs that could not be attributed to sampling error. On the other hand when tractive force is computed, based on vertical velocity distribution see Fig. 88, considerable variation of an almost cyclical nature occurs across the bed of the channels. There is a possibility that this may be related directly to secondary circulation. By combining these results with a visual study of the circulation pattern as suggested by Lane, more light might be thrown on this subject.

<u>Effect of Wind Action on Stability of Channels</u>

The stability of channels is influenced by wind action in several ways during both the operating and non-operating season. Very little has been reported on this subject to date and a definite need for investigation and research on problems related to wind action exists. The two major classifications of problems are:

1. Forces of wave motion.

2. Wind erosion and deposition.

The first classification of problems has been considered by the writer in a unpublished paper entitled "Forces of Wave Motion which Affect Canal Stability". The following material is summarized from that report.

Estimate of Tractive Shear Exerted on the Bed of a Channel Due to Waves

As an approximation the shear caused by wave action was computed by using the velocity distribution created by an oscillating flat plate (56). The velocity of oscillation assumed was $u = u_o \sin pt$ as shown in Fig. 21.

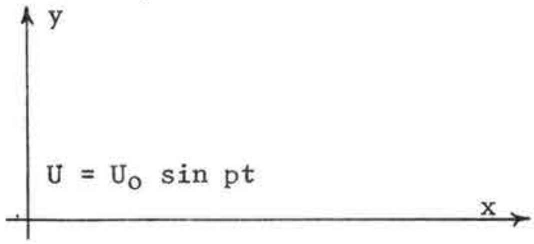


Fig. 21 Velocity of Oscillation of a Flat Plate

The concept of no slip at the plate gives the boundary condition $U = U_o$ at $y = y_o$ for all time and the Navier-Stokes equations reduce to

$$\frac{\partial u}{\partial t} = \nu \frac{\partial^2 u}{\partial y^2} \tag{48}$$

which is a simple linear equation of the second order. This expression has the same structure as the differential equation for thermal expansion in a rod (linear equation of heat conduction). Solving the differential equation yields the expression

$$U = U_o \, e^{-\sqrt{\frac{p}{2\nu}}\, y} \sin\left[pt - \sqrt{\frac{p}{2\nu}}\, y\right] \tag{49}$$

From wave theory the maximum velocity of water at the bed of a channel is

$$U_{max} = \frac{2\pi a}{T} \frac{1}{\sinh \frac{2\pi h}{L}} \tag{50}$$

where U_{max} = maximum velocity of the water at the bed of the channel,

a = the amplitude of the wave,

T = wave period,

h = water depth, and

L = wave length

The wave theory, in other words, implies a situation which violates the concept of no slip at the boundary. To proceed with the problem, Uo in Eq 49 is assumed to exist — not at the boundary, but slightly above it at the top of an assumed boundary layer and U_{max} from Eq 50 is assumed to be equal to Uo .

To compute the shear at the boundary the expression

$$\tau_{bed} = \mu \left(\frac{du}{dy}\right)_{bed} \tag{51}$$

was used. From Eq 43

$$\left(\frac{\partial u}{\partial y}\right)_{bed} = -\sqrt{\frac{p}{2\nu}}\, Uo\ (\sin pt + \cos pt) \tag{52}$$

and substituting

$$\tau_{bed} = -\mu \sqrt{\frac{p}{2\nu}}\, Uo\ (\sin pt + \cos pt) \tag{53}$$

If the term sin (pt + cos pt) is maximized it is found to be equal to 1.414, say 1.4 for this case, then

$$\tau_{bed} = -1.4\,\mu \sqrt{\frac{p}{2\nu}}\, Uo \quad . \tag{54}$$

The term p is the frequency and is related to the period as follows

$$p = \frac{1}{T} \quad . \tag{55}$$

Assuming a water temperature of 70°F and substituting $p = \frac{1}{T}$ in Eq 54 the relation

$$\tau_{bed} = 0.0062T^{1/2}\ Uo \tag{56}$$

is obtained. This expression was used to estimate magnitude of shear developed at the channel bed due to wave action (61). The results for various depths of water, wave heights, lengths of wave, celerity, and velocity of water at the bed due to wave action are presented in Table 9 which follows. Observing the magnitude of these shears and comparing them with the magnitude of tractive force caused by the normal flow of the water based on such Eqs as 42, 43, and 44 it is apparent that wave action might easily increase the resultant shear on the bed from as much as 50 to 60 per cent, for shallow canals where $d < 2.0$ ft down to a negligible quantity for deep canals where $d > 6.0$ ft.

Effect of Percolation on the Stability of a Permeable Bed

If water waves are produced in canals or channels having a relatively pervious sand bed a flow net may be drawn to represent the flow in the bed, see Fig. 22. This flow pattern may be determined mathematically by means of potential theory (61). The water flows into that part of the bed beneath the crest of the wave and emerges in those portions of the bed under the troughs adjacent to the wave crests. This flow, produced by the waves in the permeable bed, sets up seepage forces that reduce the stability of the bed under the wave troughs. The magnitudes of the seepage force resulting from this phenomenon, in terms of an equivalent shear expressed as a percentage of an average tractive shear equal to 0.035 lb per ft^2, is shown for various heights of waves and wave lengths in Table 10.

The additional two forces acting on channel beds as previously discussed fortunately do not exert their maximum effort at the same point on the bed at the same time. Nevertheless, as has been illustrated in Tables 9 and 10, the stability of bed material can be decreased as much as 20 to 30 per cent or more by wave action.

To cite an example of probable wind wave effect consider the Bijou canal, designated in this report as Canal No. 1 and 19. This canal was observed through two irrigation seasons during operation and while empty. It gave every indication that it was completely stable, then at the time of the last observed run a wind developed that was oriented with, but opposite in direction to, the flow in the reach. Waves at least 2.0 ft high resulted. The canal was subjected to this action for a period of an hour or more. Shortly after the storm subsided the water was cut completely out of the canal and the condition of the bed was observed. In this instance a section of canal bottom 300 ft long had been eroded to a depth of 2 to 3 ft. Fig. 23 records the observed condition. It seems likely that in this case the wave action may have contributed the additional forces necessary to cause the scour shown.

Table 9. Tractive Force on a Channel Bed Resulting from Wave Action

Depth of Water D = h	Height of Wave H = 2a	Length of Wave L = H/0.142	Celerity of Wave C	Period of Wave T = L/C	Velocity at Bed Due to Waves	Shear T_a
1	0.5	3.5	4.13	0.85	0.63	0.0043
1	1.0	7.0	5.07	1.38	2.22	0.0117
1	2.0	14.0	5.50	2.55	5.25	0.0204
2	0.5	3.5	4.24	0.83	0.10	0.0005
2	1.0	7.0	5.84	1.20	0.89	0.0051
2	2.0	14.0	7.17	1.95	3.14	0.0139
3	0.5	3.5	4.24	0.83	0.0017	0.00001
3	1.0	7.0	6.02	1.16	0.37	0.00212
3	2.0	14.0	7.91	1.77	2.00	0.0093
4	0.5	3.5	4.24	0.83	small	0
4	1.0	7.0	5.98	1.17	0.147	0.00084
4	2.0	14.0	8.27	1.69	1.26	0.0060
5	0.5	3.5	4.24	8.26	small	0
5	1.0	7.0	5.98	1.17	0.06	0.00033
5	2.0	14.0	8.57	1.63	0.83	0.0040
6	0.5	3.5	4.24	8.26	small	0
6	1.0	7.0	5.98	1.17	0.024	0.00014
6	2.0	14.0	8.50	1.65	0.52	0.0025
6	3.0	21.2	10.30	2.06	1.59	0.0069

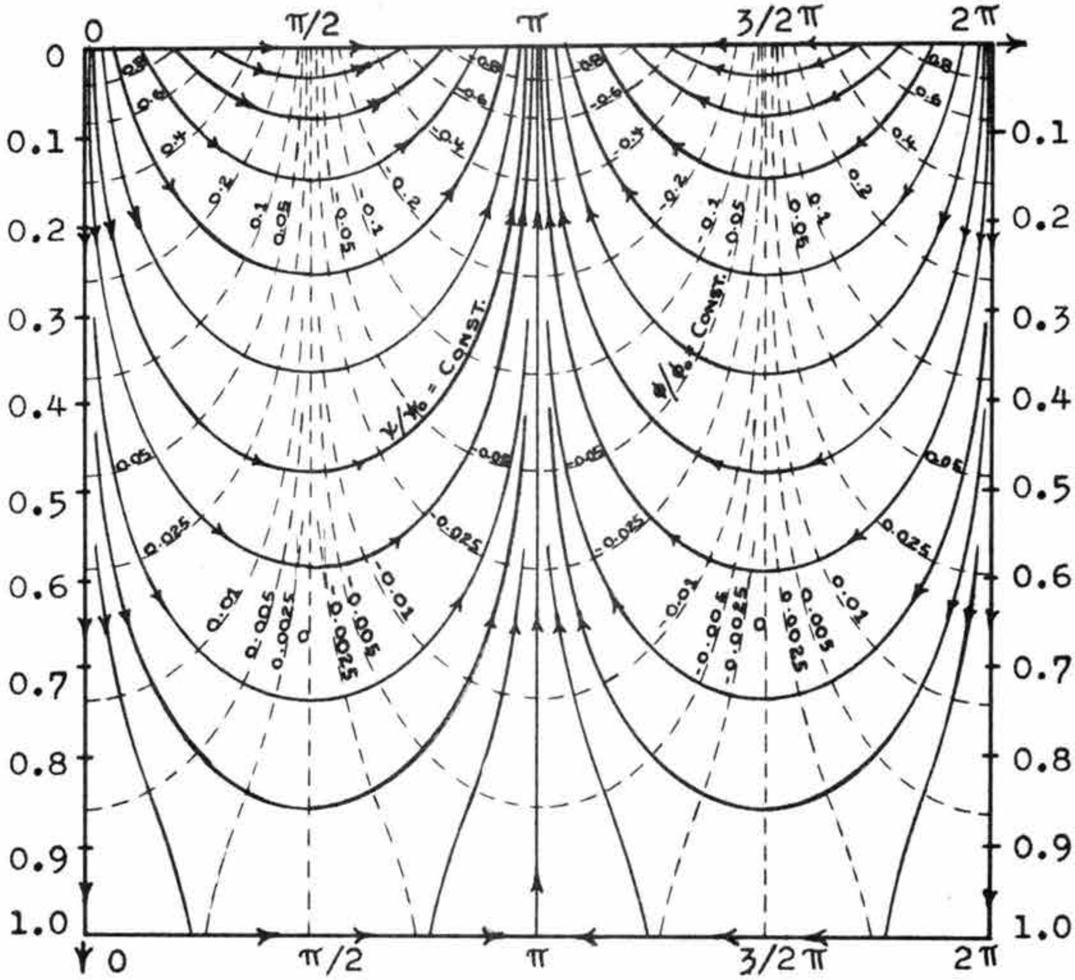


Fig. 22 Instantaneous Flow Net in Porous Bed Due to Wave Action

where

$$\frac{\phi}{\phi_0} = \left[e^{\frac{-2\pi y}{L}} + e^{\frac{-2\pi(2Y-y)}{L}} \right] \left[\frac{\cos 2\pi\left(\frac{x}{L} - \frac{t}{T}\right)}{1 + e^{\frac{-4\pi Y}{L}}} \right] \tag{57}$$

$$\frac{\psi}{\psi_0} = \left[e^{\frac{-2\pi y}{L}} - e^{\frac{-2\pi(2Y-y)}{L}} \right] \left[\frac{\sin 2\pi\left(\frac{x}{L} - \frac{t}{T}\right)}{1 + e^{\frac{-4\pi Y}{L}}} \right] \tag{58}$$

and

ϕ = Potential Function
ψ = Stream Function
Y = Thickness of Permeable Bed
T = Wave Period
L = Wave length in ft.
t = time

Table 10. The Effect of Seepage Forces on the Stability of a Channel Bed

Depth of Water (D=h)	Wave Height (H)	Length of Wave (L = H/0.142)	Head Loss (h_1) From - 0.8 To - 1.0 Taken from Fig. 22	Length (l) of Flow Path From - 0.8 To - 1.0 Taken from Fig. 22	Hydraulic Gradient ($i = \frac{h_1}{l}$)	Seepage force = $\frac{(i)\,(wt)}{unit\ vol.}$	Equivalent Tractive Force (τ) as a % of Average Tractive Force
1	0.5	3.5	0.035	0.1365	0.257	16.0	22.8
1	1.0	7.0	0.070	0.2731	0.257	16.0	22.8
1	2.0	14.0	0.180	0.546	0.330	20.6	29.4
2	0.5	3.5	0.0028	0.1365	0.021	1.28	1.83
2	1.0	7.0	0.032	0.2731	0.117	7.31	10.5
2	2.0	14.0	0.140	0.546	0.256	16.0	22.8
3	0.5	3.5	0.0005	0.1365	0.0036	0.23	0
3	1.0	7.0	0.0135	0.2731	0.0495	3.10	4.4
3	2.0	14.0	0.097	0.546	0.1780	11.0	15.7
4	0.5	3.5	0	0.1365	0	0	0
4	1.0	7.0	0.0055	0.2731	0.02	1.25	1.8
4	2.0	14.0	0.064	0.546	0.117	7.30	10.5
5	1.0	7.0	0	0.2731	0	0	0
5	2.0	14.0	0.042	0.546	0.077	4.80	6.9
5	3.0	21.2	0.130	0.825	0.158	9.80	14.0
6	1.0	7.0	0	0.2731	0	0	0
6	2.0	14.0	0.027	0.546	0.0495	3.10	4.5
6	3.0	21.2	0.099	0.825	0.120	7.48	10.7

Fig. 23 Erosion of the Bed of Canal No. 1 Caused by Wave Action

The study of wind effect on the bed indicates forces of sufficient magnitude that they might well play an important role in stability. It may be worthwhile to conduct further investigation of these actions in a more precise manner both mathematically and in the laboratory.

Effect of Waves on Bank Stability

Practically no work seems to have been done on the effect of waves on bank material. The fact that bank erosion may take place at an extremely rapid rate is well known from observation. The action of the waves causes a rapid rise and fall of water surface at the water line. As the water level rises water is forced into the bank, when the water level falls the water starts to drain back out of and down the face of the exposed bank so that erosion is encouraged both by seepage forces and by the scouring action of water draining down the steep side slopes. In addition the rise and fall of the water surface creates a tractive force that must be of significant magnitude.

Erosion of this type could be controlled providing it was economically feasible to do so by placing a protective blanket of coarse non-cohesive material on the banks as previously described. Size of material required and desirable bank side slope may need additional attention however. This erosion problem was discussed verbally by George H. Johnson, Chief Engineer of the Central Nebraska Public Power and Irrigation District of Nebraska. He pointed out that the wind damage to banks of the Central Nebraska Public Power and Irrigation District main canal, 2100 cfs capacity, was extremely great during the winter and spring of 1955 and 1956. In many cases the banks which are composed of loess have eroded back into the access road making it necessary to organize a maintenance program to control this problem. It should be noted also that in addition to bank instability millions of tons of soil are being dumped into the canal to be carried on downstream to fill reservoirs located along the canal, or simply to fill the main canal -- depending on its ability, or lack thereof, to transport this extra sediment load.

Another factor of interest is that wind blowing in the opposite direction to flow in canals causes a reduction in channel carrying capacity on the order of 10 per cent. The actual magnitude of the effect varies with the sinuosity of the canal, the percentage of length of the canal in cut and fill, the per cent of length oriented parallel to the direction of the wind, and the wind velocity.

Wind Effect During the Non-Operating Season

In many irrigated areas, particularly where sandy soils prevail, a large amount of top soil may be transported from time to time by wind during the dormant season because of lack of surface protection. As the air, laden with sediment, sweeps over canal sections some of the sediment is dropped out due to the reduction in wind velocity over the channel. It is not uncommon to find that some reaches of canal, depending on location relative to mean ground level and direction of the prevailing wind, are entirely filled by wind-borne sediment during the non-operating season. This is an expensive and disconcerting situation which can be controlled to a large extent by proper cultivation practices.

Another adverse feature of wind action on canals is that wind moving parallel to the channel picks up some of the fine bed material from the channel bottom and transports it along to the first bend, where it is deposited. This likewise means additional maintenance expense prior to the beginning of each new irrigation season.

Having in mind these major factors affecting channel stability, a more theoretical treatment of stable channel problems follows.

Chapter IV

THEORETICAL ANALYSIS

The theory of stable channel design is obviously neither completely clear cut nor definite. The fact that so many varied and different approaches to this problem are used by design engineers is in itself a verification of this situation. Considering the theories discussed in the introductory chapter, it is very apparent that no completely theoretical treatment of the subject exists. Current popular design methods including the regime theory of India, the tractive force concept, and other less complete theories must be expanded eventually to include quantitatively the effect of such factors as natural bank and bed material, and sediment transport.

Analysis of the Regime Theory

As already pointed out, the regime theory of India is largely empirical. It was initiated by Kennedy when he presented his non-silting non-scouring equation

$$V_o = 0.84\ D^{0.64} \tag{4}$$

as previously cited. At the time of its presentation this equation was based upon data from twenty reaches of the Bari Doab Canal in the Punjab.

It was derived by simply noting that a relationship could be written relating measured values of V and D for silt stable reaches in this canal system. As already mentioned further investigators verified that both the constant and the exponent in Kennedy's equation changed from one canal system to another. Actually, the constant term varied between the limits 0.67 to 0.95 and the exponent varied between 0.52 and 0.64. It is interesting to note that Kennedy's original exponent is at the upper limit.

Lindley Equations

The Lindley equations as presented in Chapter II were published in 1919 in a paper entitled "Regime Channels", in the Proceedings of the Punjab Irrigation Congress, vol. 7.

These equations were developed empirically based on 786 observations made in the Lower Chenab Canal system. The only additional point of interest not previously mentioned in Chapter II is that Lindley was the first to organize stable channel theory into a group of three equations that recognized width, depth, and slope as regime variables.

Lacey Equations

The potential of Lindley's equations was quickly recognized in India even though some confusion naturally existed regarding their validity. To eliminate this confusion and to capitalize on Lindley's contribution, the governments of India and England commissioned Gerald Lacey to investigate and systematize all available stable channel data.

Lacey accepted the form of Lindley's equations as correct but adopted P and R as variables in preference to W and D. Arguments both pro and con developed as a result of this change. Eqs 27 through 34 in Chapter II are the ones most generally used for design and analysis. The slight differences between these and the originals has resulted from continual study and adjustment based on new data. They were derived empirically, as were Lindley's by correlating measured data taken from one of the most extensive irrigation systems in the world.

Blench Equations

The Blench equations, Eqs 36, 37, and 38 are modifications of Lacey's equations. Blench stated that Lacey's adoption of P and R in preference to W and D as variables was retrograde. He maintains that the bed and the sides function differently and, since P and R averaged these effects, use of W and D make it possible to achieve superior results.

In order to clarify the development and use of regime theories, an analysis of them follows.

The Development of the Lacey Equations

The reasoning leading to the Lacey equations is in some cases obscure. Obviously, his approach was in many ways identical to that employed by Kennedy and Lindley. That is, it is based on concepts indicated by observing and studying stable canals and the data collected from them. Lacey's first equation

$$\frac{V^2}{R} = C \tag{59}$$

was verified by plotting V versus R on log-log paper. Having satisfied himself of the validity of this expression he modified it to the form

$$f = 3/4 \frac{V^2}{R} \tag{60}$$

and defined f as a silt factor. The significance of f was previously discussed.

His next step was to correlate P and Q. These data plotted in straight line form on log-log paper to yield the equation

$$P = 2.67\ Q^{1/2} \tag{61}$$

Neither the constant nor the exponent of this relation are universal. They vary within certain prescribed limits depending upon the data used to establish the relation.

As examples, considering Sind canals the constant term varies from 1.955 to 3.122. Considering the 42 Punjab canals used in this report, the relation between P and Q is

$$P = 2.658\ Q^{0.5052} \tag{62}$$

It is also of interest to note that a similar equation is obtained by correlating W and Q. Working with the Punjab canals again

$$W = 2.148\ Q^{0.5285} \tag{63}$$

From a statistical viewpoint either of the preceeding two relationships yield good results, the coefficient of correlation being 0.995 in both cases.

A third relationship was derived by first correlating R and S. This showed that

$$R^{1/2}\ S = \text{constant} \tag{64}$$

Then using equation (59)

$$V = C\ R^{1/2}$$

and noting that since $R^{1/2}$ S is a constant it is possible to say that

$$V = C\, R^{1/2}\ (R^{1/2} S)^n \tag{65}$$

If, based on Manning's equation, it is assumed that V is a function of $S^{1/2}$ then the exponent $n = 1/2$ and

$$V = C\, R^{3/4}\ S^{1/2} \tag{66}$$

The constant C was then found to be a function of a roughness coefficient similar to Manning's, that is,

$$C = \frac{1.346}{n_a} \tag{67}$$

where n_a is defined as the Lacey roughness coefficient. Substituting this value of C in Eq 66 yields

$$V = \frac{1.346}{n_a} R^{3/4}\ S^{1/2} \tag{68}$$

This equation has the same form as Manning's except for the exponent of R which has increased. Lacey also verified that

$$n_a = 0.0225\ f^{1/4} \tag{69}$$

Substituting n_a into Eq 68 yields the expression

$$V = 16\ R^{2/3}\ S^{1/3} \tag{70}$$

This equation can be verified more directly by correlating V and $R^2\, S$ as shown in Fig. 73, taken from reference (28). Capacities of canals yielding these data ranged from approximately 5.0 to 9000.0 cfs. Lacey calls Eq 70 his regime test formula. Accordingly, canals which agree with it are classified as regime channels and those that do not agree as unstable. In connection with stability Blench (6) points out that all Lacey channels are regime channels but not all regime channels are Lacey channels. This simply means that the Lacey criterion of stability does not cover all situations.

Since the Lacey coefficient, n_a, has been used but very little in this country it is interesting to compare it with the Kutter and the Manning coefficients for both stable and unstable canals. This is done in Table 11.

Table 11

Comparison of the Kutter, Lacey, & Manning Coefficients

Number of observations	Condition of canal	$Q = 200$	n_k	n_a	n
65	stable	more	0.0213	.0220	.0203
30	unstable	more	.0218	.0220	.0213
35	stable	less	.0199	.0194	.0209
55	unstable	less	.0206	.0202	.0220

Note that

$$n_a < n_k < n \text{ for } Q < 200 \text{ cfs.}$$

$$n < n_k < n_a \text{ for } Q > 200 \text{ cfs.}$$

Refering again to Eq 70 the fact that it is not completely valid for all canal systems was clearly demonstrated by Inglis and Heranandani in reference (28). Working with Sind canals Inglis found that

$$V = 12\ (R^2\ S)^{0.29} \tag{71}$$

working with essentially the same data Heranandani found that

$$V = 11.96\ (R^2\ S)^{0.2902} \tag{72}$$

These equations are essentially the same. There usefulness is considered debatable by most, however, since comparing computed values of V with observed values reveals errors as large as 32.6 percent. Other Lacey equations can be derived directly from Eqs 60, 62, and 70 or by correlation procedures similar to those already described.

The Development of the Blench Equations

The Blench regime equations for width and depth are inherent in the Lacey theory and can be developed therefrom. Begin with the Lacey equation

$$P = k\,Q^{1/2} \qquad (30)$$

which may be squared to give

$$P^2 = C\,Q \qquad (73)$$

Next replace Q by its equivalent AV. This yields

$$P^2 = C\,A\,V \qquad (74)$$

The A can be replaced by P R and

$$P^2 = C\,P\,R\,V$$

which reduces to

$$\frac{P}{R\,V} = C \qquad (68)$$

Since P is closely related to W and R is closely related to D, see Figs. 45 and 46, Eq 68 can be written as

$$\frac{W}{D\,V} = C \qquad (69)$$

Multiplying the top and bottom of this expression by V^2 and rearranging terms

$$\frac{W}{D\,V}\,\frac{V^2}{V^2} = \frac{V^2}{D} \Big/ \frac{V^3}{W} = C \qquad (70)$$

The parameters in the above relation were defined by Blench as follows

$$\frac{W}{D\,V} = \quad \text{shape factor}$$

$$b = \frac{V^2}{D} = \text{bed factor}$$

$$s = \frac{V^3}{W} = \text{side factor}$$

The bed factor is closely related to the Lacey silt factor

$$f = \frac{3}{4}\ \frac{V^2}{R} \tag{35}$$

and is designated as such for several reasons. That is, it is a function of bed depth; it seems to be a measure of force per unit mass of fluid acting to overcome gravity of the bed sediment as preliminary to permitting it to be transported by the flow and the side factor, s, seems to fully consider the side effect.

To illustrate the concept that side factor is a measure of side effect, Blench assumes that a laminar film exists on the sides. For this situation

$$\tau = u \left(\frac{dv}{dy}\right)_{y=0} = \mu\left(C\ \frac{Vo}{\delta}\right) \tag{77}$$

where Vo is the velocity at the top of the laminar sublayer and δ is its thickness (69). It is also known that

$$\frac{\delta}{X} = \frac{5}{\sqrt{\frac{Vo\ X}{\nu}}} \tag{78}$$

where X is a distance measured in the direction parallel to flow along a flat plate. Next, multiply numerator and denominator of Eq 77 by X to obtain

$$\tau \sim \mu \frac{Vo}{X}\ \frac{X}{\delta} \tag{79}$$

Using Eq 78, $\frac{X}{\delta}$ can be eliminated from Eq 79 yielding

$$\tau \sim \mu \frac{Vo}{X} \left(\frac{Vo\ X}{\nu}\right)^{1/2} \tag{80}$$

or

$$\tau \sim \mu \left(\frac{Vo^3\ X}{X^2\ \nu}\right)^{1/2} \sim \frac{\mu}{(\nu)^{1/2}} \left(\frac{Vo^3}{X}\right)^{1/2} \tag{81}$$

In this equation if $V \sim Vo$ (which is probable) and $X \sim W$ (which seems improbable) then

$$\tau \sim \frac{\mu}{(\nu)^{1/2}} \left(\frac{V^3}{W}\right)^{1/2} \tag{82}$$

and shear on the sides of the channel is proportional to the side factor, $\frac{V^3}{W}$.

The generalized Blench and King design equation for estimating slope

$$\frac{V^2}{gDS} = C \left(\frac{VW}{\nu}\right)^{1/4} \tag{83}$$

is somewhat different from the Lacey slope equation. It was derived by plotting W/D against various non-dimensional groups established by a dimensional analysis of the problem. It could have been obtained at once by plotting $\frac{V^2}{gDS}$ against $\frac{VW}{\nu}$ on log-log paper. This equation was modified by Blench into the design form

$$S = \frac{b^{5/6}\ s^{1/12}}{2080\ r\ Q^{1/6}} \tag{38}$$

Evaluation of Bed and Side Factors

The process of development of both the Lacey and the Blench equations has been presented. Consider again the Blench equation

$$W = \sqrt{\frac{b}{s}}\ Q^{1/2} \qquad (36)$$

Substituting the assigned values of bed and side factor gives

$$W = \left(\frac{V^2}{D} \times \frac{W}{V^3}\right)^{1/2} Q^{1/2}$$

Squaring both sides of this expression and substituting $W \times D \times V$ for Q yields

$$W^2 = \frac{V^2}{D}\,\frac{W}{V^3}\ W\ D\ V = W^2$$

or

$$W = W$$

The same situation arises if the values of b and s are substituted in the Blench equation

$$D = \left(\frac{s}{b^2}\right)^{1/3} Q^{1/2} \qquad (37)$$

That is, one verifies that

$$D^2 = D^2$$

or

$$D = D$$

It is then obvious that if $W/Q^{1/2}$ is plotted against $(b/s)^{1/2}$ a straight line having a slope of 45 degrees results.

The same is true if $D/Q^{1/2}$ is plotted versus $(s/b^2)^{1/2}$. It is then also obvious that the usefulness of Blench's regime equations hinges on how accurately b and s can be evaluated by independent relationships. The determination of these factors for use in design was discussed earlier in Chapter II.

It should be emphasized that the influence of selected side factor on design slope is relatively small since it appears in the slope equation, Eq 38, to the 1/12th power. Blench (6) points out that a 24 percent error in s will make but 2 percent error in slope. In general s can be selected for design by referring to the side factor of a few existing channels that are apt to be similar and using the average value.

The influence of bed factor on canal behavior, on the other hand, is much more pronounced. This is made obvious by referring again to Eq 38. In this case it is noted that slope varies directly with bed factor to the 5/6 power and any large error in b causes a correspondingly large error in slope, hence the best possible methods of evaluating b should be used.

Lacey has provided a rough qualitative rule which relates bed factor to the square root of the mean diameter of the sediment exposed on the bed. His rule is based on rough data and covers the sand to boulder range inclusively and it states that

$$b \sim \sqrt{d} \tag{84}$$

where

b = bed factor

d = mean diameter in millimeters of sediment exposed on a regime channel bed.

This rule should be used only in a realistic manner. That is, it should only be used to estimate order of magnitude of an effect or where a small error in estimated b will not have much effect on the final results.

Blench (4) states that at present there is no satisfactory rule or equation linking bed factor with sediment diameter. It does seem reasonable, however, that an improved method of describing b having a form similar to that indicated in Eq 85 might be developed

$$b = f\ (d, \sigma, q_s/q_w) \tag{85}$$

q_s = mass discharge of bed sediment per unit of bed width

q_w = water discharge per unit of bed width

σ = standard deviation of d

Blench (4) presented a speculative non-dimensional formula having a more complex form as indicated

$$\frac{(\nu g)^{1/3}\ b}{g} = k\ \sqrt{dg} \left(\frac{V_s}{(\nu g)^{1/3}}\right)^x \left(\frac{q_s}{q_w}\right)^y B\left(\rho_s\right) + F\left(\rho_s\right) \tag{86}$$

where

k = non-dimensional constant

d = the mean diameter of sediment exposed on the bed

V_s is the fall velocity of bed sediment in still water

B and F are functions of the relative density of the sediment

ν = the kinematic viscosity

g = the acceleration due to gravity

The importance of suspended sediment on the bed factor is unknown and deserves study. It is fairly definite, however, that increasing the wash load increases the ability of the sediment-water complex to carry sediment load and reduces viscosity which in turn reduces channel resistance to flow.

Blench (6) states that the upper limit of b is fixed by the coarsest grade of suspended sediment as modified by quantity and that the upper limit can be estimated by

$$b = 2.0\ \sqrt{d} \tag{87}$$

where d is defined as before. This expression is subject to severe limitations and should only be used by those who fully appreciate this fact.

Effect of Sediment Concentration

In a recent paper presented by Blench in 1955 titled "Regime Formulas for Bed Load Transport" (7) an equation for bed factor of the following form was proposed

$$b = \frac{V^2}{D} = f\ (d)\ \ (1 + f\ (C')) \tag{88}$$

where C' = charge as a ratio of weight of sediment per second divided by weight of water per second reduced to thousands of a percent. Other terms retain their original meanings. Note that the equation reduces to $b = f\ (d)$ for vanishingly small charge.

Based on current research at the University of Alberta, Blench recommends that the following equation for bed factor be used for natural materials

$$b = \frac{V^2}{D}\ \ (1 + 0.12C') \tag{89}$$

and points out that additional work must be done before an exact formulation of bed factor can be developed.

The basic slope equation has likewise been modified to include influence of charge. The new recommended slope equation is

$$\frac{V^2}{gDS} = 3.63\ (1 + \frac{C'}{233})(\frac{VW}{\nu})^{1/4} \tag{90}$$

Considering this expression it is doubtful that concentrations such as are usually experienced in irrigation canals will cause an appreciable difference in results.

The Lacey equations have been modified by Ingles (28), see pages 136 and 137, to show the qualitative effect of charge on channel regime. In the following table a partial list of these newly derived equations, considering charge, and their Lacey equivalents are given.

Table 12

Regime Equations Which Qualitatively Recognize The Influence of Sediment Load

New Formulas	Lacey Equivalent
$b = f\left[\frac{Q^{2/5}}{g^{1/5}} \left(\frac{Q}{d^{5/2} g^{1/2}}\right)^{1/10} \left(\frac{C' V_s}{(\nu g)^{1/3}}\right)^{1/4} \right]$	$P = 2.67\, Q^{1/2}$
$A = f\left[\frac{Q^{4/5}}{g^{2/5}} \left(\frac{Q}{d^{5/2}\ g^{1/2}}\right)^{1/30} \left(\frac{C' V_s}{(\nu g)^{1/3}}\right)^{-1/12} \right]$	$A = 1.26\, Q^{5/6}\ f^{1/3}$
$V = f\left[\frac{g^{7/18}}{\nu^{1/36}}\ Q^{1/6}\ (d\ C' V_s)^{1/12} \right]$	$V = 0.7937\, Q^{1/6}\ f^{1/3}$
$D = f\left[\frac{Q^{2/5}}{g^{1/5}} \left(\frac{Q}{d^{5/2} g^{1/2}}\right)^{-1/15} \left(\frac{C' V_s}{(\nu g)^{1/3}}\right)^{-1/3} \right]$	$R = 0.4725\, \frac{Q}{f}^{\ 1/3}$
$S = f\left[\left(\frac{Q}{d^{5/2} g^{1/2}}\right)^{-1/5} \left(\frac{C' V_s}{(\nu g)^{1/3}}\right)^{5/12} \right]$	$S = 0.000547\, f^{5/3}\ Q^{1/6}$
where $C' = q_s/q_w$	

These modifications to the various Lacey equations conform with the generally-accepted significance of sediment load on regime. That is, variation of charge has:

1. Little effect on required area of channel and its mean velocity.

2. A rather large effect on slope.

3. An influence on channel shape.

4. Considerable effect on channel width.

5. An influence on the viscosity of the water sediment complex.

Additional research must be completed before engineers will be able to predict the quantitative effect of charge on channel regime.

Physical Significance of the Lacey Equations

The Lacey equations presented are empirical in nature. They have been and currently are being used rather widely and with good success in many cases. The physical meanings of the formulas have never been explained completely. However, certain relationships exist which should be pointed out.

The parameter, $3/4\ V^2/R$ is called the silt factor. This factor can be expressed as a function of the Froude number by dividing both sides of the foregoing expression by g as follows:

$$\frac{f}{g} = 3/4\ \frac{V^2}{gR} = 3/4\ (F_r)^2 \tag{91}$$

Perhaps, however, it is more significant to relate f to the Euler number and in turn to a discharge coefficient, that is,

$$f = \emptyset\ (F_r) = \emptyset_1\ (E) = C_D \tag{92}$$

Certainly other parameters would be necessary to define a completely satisfactory discharge coefficient but E may well be the one of major concern for the conditions existing in the canals observed to establish the Lacey theory.

Using the basic relationships it can be shown that

$$f^2 \sim gVS \tag{93}$$

The product VS is the vertical distance moved by the water per second. The term gVS is then a measure of the rate at which gravity is doing work.

The silt factor can be related in a similar manner to the boundary shear or tractive force. Thus, Eq 43 states that $\tau = \gamma RS$, combining this expression with Eq 93 it can be shown that

$$f \sim \left(\frac{\tau V}{\rho R}\right)^{1/2} \tag{94}$$

By such means as this it may be possible to relate regime and tractive force methods of design.

Physical Significance of the Blench Equations

The bed factor, as in the case of silt factor, is closely related to a discharge coefficient, that is

$$\frac{b}{g} = \frac{V^2}{gD} = (N_f)^2 = \phi\,(E) = C_D \qquad (95)$$

The complete physical significance of b is obscure but some speculation regarding its meaning has been done. Lacey considers the term to be a "turbulence criterion". Blench states that he and others think of it as a measure of force per unit mass of fluid acting to overcome the gravity of the bed sediment as a preliminary to permitting it to be transported by the flow, and in a more complete theory, would be associated with at least a function of relative density of bed material.

The parameter V^2/D has been designated as a bed factor since geometrically it is a function of depth of flow over the bed only, and in addition V^3/W, the side factor, according to Blench (6) clearly evaluates side effect.

Tractive Force Concept

The validity of tractive force concept is generally recognized but has never been generally accepted as a basis for canal design particularly in this country except possibly by the U. S. Bureau of Reclamation. In applying this concept to design of stable channels two different situations must be evaluated properly, these are,

(1) the forces acting on the bed material and,

(2) the forces acting on the side material.

Tractive Force on the Bed

As water flows in a channel it exerts a drag or tractive force on its periphery. To estimate the magnitude of this effect consider the free body of unit width and length shown in Fig. 24. For this free body to be in equilibrium the summation of the forces acting must be zero. Based on this fact

$$\tau = \gamma D \sin\beta$$

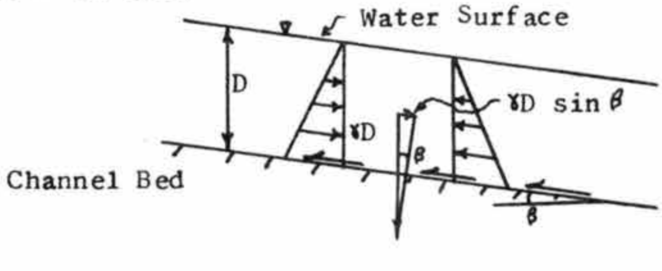


Fig. 24 Tractive Force Analysis

For small values of β , $\sin\beta = \tan\beta$ and since $\tan\beta$ equals the slope the above expression becomes

$$\tau = \gamma DS \tag{42}$$

where τ equals shear per unit area corresponding to a particular depth. This equation is Eq 42 of Chapter II. A similar expression based on hydraulic radius is obtained by extending the foregoing unit width of free body all the way across the channel, in this case as before

$$(\tau)(P)(1) = \gamma A(1)\sin\beta$$

or

$$\tau = \gamma \frac{A}{P} S = \gamma RS \tag{43}$$

and τ is the average shear per unit of area acting on the periphery of the canal. This equation is Eq 43 of Chapter II.

Referring to the principles of fluid mechanics, it is known that shear stress per unit area is a function of velocity gradient adjacent to the boundary. This principle can be employed to evaluate tractive force. First refer to the general logarithmic velocity distribution equation as presented by Einstein (16).

$$V_1 = 5.75 \sqrt{\frac{\tau}{\rho}} \log 30.2 \frac{Y}{\Delta} \tag{96}$$

where V_1 = the average point velocity at a distance y from the bed

τ = the unit tractive force or shear

ρ = the density of the water

Δ = the apparent roughness of the surface and contains a corrective parameter

5.75 = a constant which includes the Karman coefficient, 0.40.

Next consider two points on a velocity vertical at distances y_1 and y_2 above the channel bed. The difference in the velocities at these points according to Eq 96 is

$$V_2 - V_1 = 5.75 \sqrt{\frac{\tau}{\rho}} \quad \text{Log}\, \frac{30.2Y_2}{\Delta} - \text{Log}\, \frac{30.2Y_1}{\Delta}$$

or

$$V_2 - V_1 = 5.75 \sqrt{\frac{\tau}{\rho}} \quad \text{Log}\, \frac{Y_2}{Y_1}$$

and solving for τ

$$\tau = \rho \left[\frac{V_2 - V_1}{5.75 \text{ Log } \frac{Y_2}{Y_1}} \right]^2 \tag{44}$$

This equation is Eq 44 of Chapter II. If Y_1 and Y_2 are constant distances and ρ is also constant this equation reduces to

$$\tau = C\,(V_2 - V_1)^2 \tag{97}$$

For best results Y_1 and Y_2 should be small relative to the dimensions of the section.

The computation of shear by means of Eq 42 has quite often been criticized, except in the case of very wide rivers and canals, because of transverse momentum exchange. The reason for this criticism is made more apparent by referring to Fig. 25 taken from reference (37).

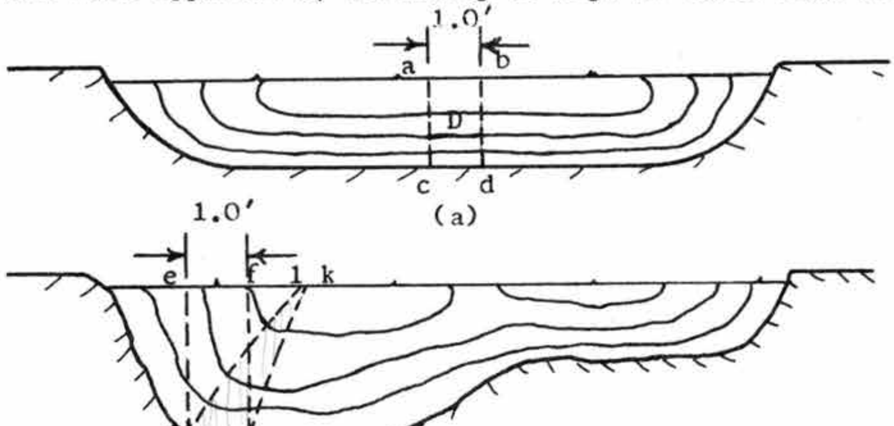


Fig. (25)- Tractive Force Considering the Effect of Momentum Exchange

Beginning with Fig. 25a the isovels are very nearly parallel to the bed of the channel particularly toward the center. This means that velocity distribution to the left of ac and to the right of bd are essentially the same as at ac and bd. This also means that there can be little or no momentum exchange across the surfaces. In this case Eq 42 should apply. Next consider Fig. 25b. Here the velocity profiles change drastically from point to point across the section and a definite momentum exchange takes place across the verticals eh and fg. In this case depth is no longer a measure of tractive force on the periphery. In order to eliminate momentum exchange draw two lines, one extending from h the other from g so that they are normal to the isovels, see lines hl and gk. The shear on the area of bed (gh x 1) conforming with the concept of zero momentum exchange can now be evaluated as follows

$$\tau = (\text{Area})_{hlkg} \times 1 \times \gamma \times S / _{hgx1}$$

This procedure is preferable to direct application of Eq 42 for determining shear intensity and distribution in narrow and/ or irregular canals.

The ability of a particle to resist the tractive force generated by the flowing water depends upon its weight, shape, specific gravity, its location relative to other particles, the lift force created by the water and the way it is related to adjacent particles cohesively.

Tractive Force on the Sides

The magnitude of tractive force on the sides can be estimated by means of Eq 44 provided the velocity distribution normal to the point in question is known, or by isolating the weight of water associated with a certain portion of the side of the channel consistent with zero momentum exchange along the defining boundaries, that is, in the manner indicated in Fig. 25.

Considering the complete stability picture it is necessary to consider rolling down or gravitational effect on the particles forming the sides since it tends to displace them and to relate magnitude of shear on the bed to shear on the sides. Fig. 26 is a three-dimensional stress diagram showing the combined effect of tractive force and gravity.

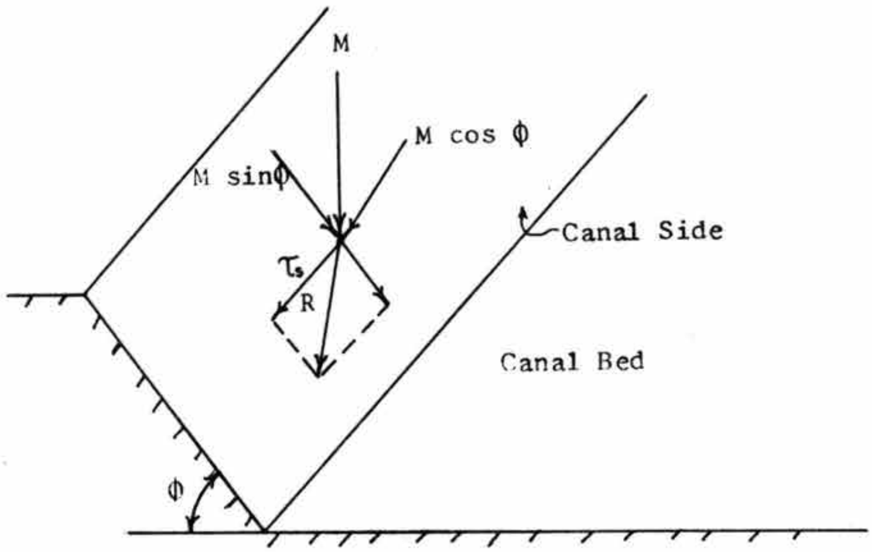


Fig. (26) Stress Diagram of the Major Forces Acting on the Sides of An Open Channel

The resultant force R tending to cause particle movement is equal to

$$R = \sqrt{\tau_s^2 + \overline{M \sin \phi}^2} \tag{98}$$

The criterion for stability is that the friction force equal to the normal component of M multiplied by the angle of repose must equal or exceed R, that is

$$(\tau^2_s + M^2 \sin^2 \phi)^{1/2} = (M \cos \phi)(\tan \theta) \tag{99}$$

solving for τ_s

$$\tau_s = (M^2 \cos^2 \phi \tan^2 \theta - \sin^2 \phi)^{1/2} \tag{100}$$

It is now a simple matter to compare the magnitude of the tractive force on the side to that on the bed. Letting K equal the ratio of these two drags

$$K = \frac{\tau_s}{\tau} = \left[\frac{M^2 \cos^2 \phi \tan^2 \theta - M^2 \sin^2 \phi}{M^2 \tan^2 \phi} \right]^{1/2}$$

or

$$K = \cos \phi \left[1 - \frac{\tan^2 \phi}{\tan^2 \theta} \right]^{1/2} \tag{101}$$

Considering the total resultant force the value of R in equation 98, may indicate a value slightly smaller than it should because of the lifting action (which has been ignored) that the water probably exerts on the particles as it flows over them.

The total force tending to hold a particle in position is made up of

1. The friction force, see Fig. 24 as used above
$$F = M \cos \phi \tan \theta \tag{102}$$

   where

   θ = angle of repose of the material

2. The cohesive force which is absent in the case of non-cohesive materials.

3. The shear caused by secondary circulation which may or may not increase stability.

4. The effect of turbulence and eddies superposed on the normal flow.

A qualitative illustration of theoretical shear distribution on the boundary of a trapezoidal irrigation canal based on the procedure indicated by the United States Bureau of Reclamation(24) is shown in Fig. 27.

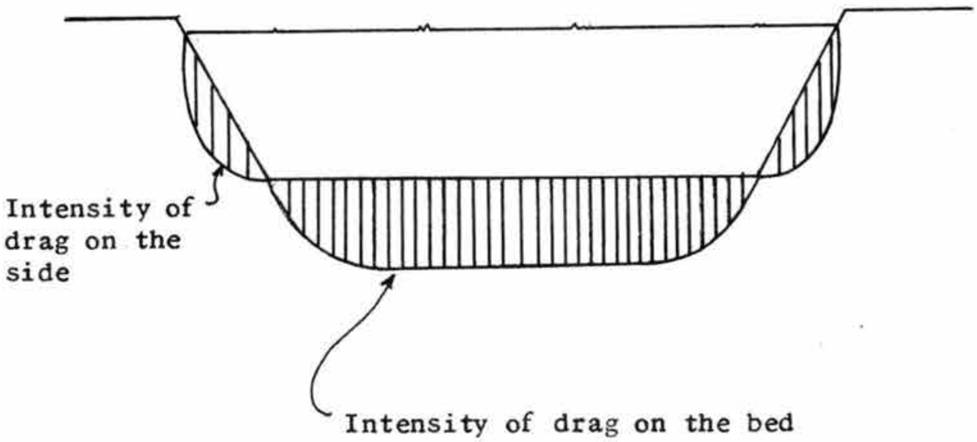


Fig. 27 Theoretical Distribution of Tractive Force

Significance of the Tractive Force Theory

The tractive force theory is based on the hypothesis that stable channel design is a tractive force problem. Beyond this point the method of design as outlined by Lane is theoretical except that it has been modified by empirical coefficients developed from a field study. Three classes of instability were cited. The latter two are a function of sediment transport and consequently are difficult to use since effect of sediment on stability is understood only in a qualitative sense.

The two types of problems for which the tractive force theory provides a quantitative solution at present are:

1. Design of clear-water canals in course non-cohesive materials.

2. Design of sediment-laden canals provided the natural material forming the periphery of the channel is sufficiently resistant to scour that an average velocity can be selected which is capable of transporting the sediment load without scouring the banks and bed.

Effect of Charge

Proper design of canals required to transport sediment involves a knowledge of factors influencing transport capacity. The designer must be able to establish in his design such factors as shape and slope, which will guarantee that material being introduced at the upper end of a canal will be carried on through the system and at the same time objectional scour will not occur.

So far information has not been developed that enables the inexperienced engineer to achieve these results. A great many factors and their interrelationship first must be determined on a quantitative basis before this will be possible. Current research activity on basic sediment transport laws, effect of wash load, factors influencing channel roughness, and secondary circulation and turbulence will undoubtedly improve existing knowledge in the field of stable channel design.

Analysis of the Geometry of Stable Channels

Referring to the regime equations, very simple expressions have been developed to evaluate such channel dimensions as D, R, P, and W. They are of the form:

$$D = \phi \left(Q, f \right) \tag{103}$$

$$R = \phi_1 \left(Q, f \right) \tag{104}$$

$$P = \phi \left(Q \right) \tag{105}$$

$$W = \phi_1 \left(Q \right) \tag{106}$$

where f = Lacey silt factor

These equations are based on field data collected from canals that have sand beds, and sides that are related to the sediment being transported. Considering all of the possible design conditions encountered in nature, it is apparent that if equations for channel dimensions are to apply other variables should be considered. In terms of channel width and depth it seems logical that

$$W = f \left(\begin{array}{l} Q,\ qs,\ \text{wash load, natural boundary material,} \\ \text{method of operation} \end{array} \right) \tag{107}$$

and

$$D = f \left(\begin{array}{l} Q,\ qs,\ \text{wash load, natural boundary material,} \\ \text{method of operation} \end{array} \right) \tag{108}$$

The possibility of generalizing the basic regime equations in terms of additional variables will be considered in Chapter VII.

Dimensional Analysis of the Variables Influencing $C/\sqrt{g}$, Bed Factor, and Side Factor

For the purpose of initiating a preliminary analysis of the stable channel problem refer again to Fig. 24, in this Chapter and the results obtained there, namely

$$\tau = \gamma RS \tag{43}$$

To develop an equation of a more inclusive nature than Eq 43, dimensional analysis will be employed. The general relation that exists may be stated as:

$$\tau = \phi_1 (V, D, W, \rho, \gamma, \mu, d, \rho_s, \sigma) \tag{109}$$

Choosing V, D, and ρ as repeating variables, dimensional analysis yields

$$\frac{\tau}{\rho V^2} = \phi_2 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{\rho_s}{\rho}, \frac{d}{D}, \frac{V}{\frac{\gamma}{\rho} D}, \frac{VD}{\mu} \right] \tag{110}$$

and

$$\tau = \rho V^2 \phi_2 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{\rho_s}{\rho}, \frac{d}{D}, R_e, F_r \right] \tag{111}$$

Equating Eq 43 to Eq 111 yields,

$$\gamma RS = \rho V^2 \phi_2 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{d}{D}, \frac{\rho_s}{\rho}, R_e, F_r \right] \tag{112}$$

Solving for V

$$V = \sqrt{\frac{\gamma}{\rho}}\, \phi_3 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{d}{D}, \frac{\rho_s}{\rho}, R_e, F_r \right] \sqrt{RS} \tag{113}$$

and

$$V = \sqrt{g}\, \phi_3 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{d}{D}, \frac{\rho_s}{\rho}, R_e, F_r \right] \sqrt{RS} \tag{114}$$

Comparison with the Chezy equation, $V = C\sqrt{RS}$, shows that

$$C = \sqrt{g}\, \phi_3 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{d}{D}, \frac{\rho_s}{\rho}, R_e, F_r \right] \tag{115}$$

and

$$\frac{C}{\sqrt{g}} = \phi_3 \left[\frac{W}{D}, \frac{\sigma}{D}, \frac{d}{D}, \frac{\rho_s}{\rho}, R_e, F_r \right] \tag{116}$$

For steady flow in alluvial channels $\frac{\rho_s}{\rho}$ and $\frac{\sigma}{D}$ will be considered constant and Eq 116 simplifies to

$$\frac{C}{\sqrt{g}} = \phi_4 \left[\frac{W}{D}, \frac{d}{D}, R_e, F_r \right] \tag{117}$$

The foregoing theory is based on the premise that the canal presents a homogeneous boundary. Actually, differences between bed and side material are great and their respective effects on flow should be considered. To account for these differences, the mean diameter of bed material d will be designated as d_b in the remaining dimensional analysis equations, and an additional term d_s, a measure of the effect of side material, are introduced in the dimensional analysis so that

$$C/\sqrt{g} = \phi_5 \left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r \right] \tag{118}$$

Now consider Blench's regime slope equation in the form

$$V = C^{1/2} \left(\frac{Db}{(s\,\nu)^{1/2}} \right)^{1/4} \sqrt{gDS} \tag{119}$$

where b and s are respectively Blench's bed factor and side factor. From this eliminate C because of its absolute value then

$$V = \sqrt{g}\left[\frac{Db}{(s\nu)^{1/2}}\right]^{1/4}\sqrt{DS} \tag{120}$$

Now comparison with the Chezy equation

$$V = C\sqrt{RS}$$

shows that provided R~D

$$\frac{C}{\sqrt{g}} = \left[\frac{Db}{(s\nu)^{1/2}}\right]^{1/4} \tag{121}$$

and Eq 118 and Eq 121 may be equated to obtain

$$\left[\frac{Db}{(s\nu)^{1/2}}\right]^{1/4} = \phi_5\left[\frac{W}{D}, \frac{db}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{122}$$

or

$$\frac{Db}{(s\nu)^{1/2}} = \phi_6\left[\frac{W}{D}\ \frac{d_b}{D}\ \frac{d_s}{D}, R_e, F_r\right] \tag{123}$$

Solving for b and s

$$b = \frac{(s\nu)^{1/2}}{D}\phi_6\left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{124}$$

and

$$s = \frac{D^2b^2}{\nu}\phi_7\left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{125}$$

According to Blench's regime equations

$$b = V^2/D = \text{bed factor}$$

and

$$s = V^3/W = \text{side factor}$$

Substituting these expressions in Eq 124 and 125 respectively shows that

$$b = \frac{V^{3/2} \ \nu^{1/2}}{W^{1/2} \ D} \ \phi_6 \left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{126}$$

or

$$b = \sqrt{\frac{V^4 \nu}{A \ D}} \ \phi_7 \left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{127}$$

and

$$s = \frac{V^4}{\nu} \ \phi_8 \left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{128}$$

or

$$s = \frac{\rho V^4}{\mu} \ \phi_9 \left[\frac{W}{D}, \frac{d_b}{D}, \frac{d_s}{D}, R_e, F_r\right] \tag{129}$$

These expressions for b and s are very complex and even then may be incomplete in that certain assumptions have been made and again the effect of sediment charge has been neglected.

Eliminating what appears to be the least important terms, Eqs 127 and 129 can be rewritten as indicated

$$b = \frac{V^{3/2}\ \nu^{1/2}}{W^{1/2}\ D}\ \phi_8 \left[\frac{W}{D}, \frac{d_b}{D}, F_r \right] \tag{130}$$

$$s = \frac{V^4}{\nu}\ \phi_{10} \left[\frac{W}{D}, \frac{d_s}{D}, R_e \right] \tag{131}$$

With complete field data on reaches of stable channels, the validity of these and similar expressions for b and s can be investigated.

Relationship Between Regime Theory and Tractive Force

The regime theory has evolved principally as a result of making field observations and developing empirical relationships by a correlation procedure. Consequently, the results should be applied only to those cases falling within the realm of the originally observed data. To try to extrapolate information beyond the actual scope covered is to invite large errors.

The tractive force theory, on the other hand is fundamental and is the result of deductive rational thinking. Once the concept of stability of particles being related to tractive force is established the procedure is purely theoretical provided equations such as 42, 43, and 44 are an adequate measure of this force. It does seem, however, that certain points from both theories could be incorporated to facilitate the solution of practical design problems.

Slope Relationship

It is conceivable that a study of canals in general might provide information relating shear stress, mean diameter of bed material, and/or other variables in the manner indicated by Lane (35) for the canals studied by the United States Bureau of Reclamation, see Fig. 9, Chapter II. Perhaps this type of expression then would yield information on design slope for the complete range of conditions. It has been verified that good correlations result when τ is plotted versus d for at least some of the various existing canal systems. It is also obvious by comparison that two systems of canals carrying the same size of sediment and having the same diameter of bed material are not in agreement at all regarding magnitude of tractive force being exerted on the bed. The fact that the tractive force in one canal system can be so very different from those in another similar system, both of which are stable, may be due to the fact that important variables are being neglected particularly for bed and side material in the sand range and finer. The fact that important variables are perhaps being neglected and that regime and tractive force theories can be related is easily verified by first referring to the correlation of τ versus d in Fig. 9 used to estimate channel slope when canals are constructed in course non-cohesive material, namely

$$\tau \sim d \tag{132}$$

Next consider the regime equation recommended by Bose (25) to determine slope in the sand bed range of conditions

$$S \times 10^3 = 2.09 \frac{d^{0.86}}{Q^{0.21}} \tag{25}$$

Rewriting this expression

$$S\, A^{0.21}\, V^{0.21} = C\, d^{0.86}$$

since $\quad A = W\, D$

$$S\, W^{0.21}\, D^{0.21} V^{0.21} = C\, d^{0.86}$$

Multiplying both sides by γ and $D^{0.79}$

$$DS\, W^{0.21}\, V^{0.21} = C \quad D^{0.79}\, d^{0.86}$$

or

$$DS = \frac{C \quad D^{0.79}\, d^{0.86}}{W^{0.21}\, V^{0.21}}$$

and hence

$$\tau = \phi\,(\,\gamma\,,\, d,\, D,\, W,\, V) \tag{133}$$

Comparing Eq 132 and 133 from the view point of variables involved the second of the two is similar to the first but much more comprehensive and should apply with better accuracy to slope determination than an expression of the original type in the sand bed range.

Modifying Eq 133 to include viscosity

$$\tau = \phi_1 (\gamma, d, D, W, V, \nu) \tag{134}$$

and applying the principles of dimensional analysis selecting V, D, and ν as the repeating variables

$$\tau = \phi_2 \left(\frac{D}{d}, \frac{W}{D}, \frac{VD}{\nu} \right) \tag{135}$$

In effect this suggestion implies again that sediment transport theory must be incorporated in present design methods if the current empirical elements ultimately are to be reduced to a minimum.

Width to Depth Ratios

According to regime theory, only one stable canal cross-section exists for a given set of conditions, that is, a channel has but one regime slope, depth, and width. The theoretical shape indicated, unfortunately, is not always in agreement with actual shape. This was verified as a result of Lane's comprehensive and systematic analysis of existing design methods which he conducted prior to the design of the All-American canal.

On the other hand, it must be recognized that regime relationships such as those presented by Lacey and Blench are suitable for estimating stable widths to depths under certain circumstances. In view of this it may be feasible to expand the scope of these expressions so that they apply to all design conditions. Provided the foregoing can be accomplished, the resultant equations then could be employed to estimate stable width and depth and relations of the tractive force type could be utilized to estimate slope, provided the tractive force relationships could be similarly expanded to apply to all design conditions. The expansion or generalization of the tractive force theory would involve bringing additional pertinent variables into the relationship as implied by Eq 135. Such a relation would undoubtedly consider median size, gradation plasticity, cohesion of the natural bed and bank material. Also effect of magnitude and gradation of sediment load should be included.

From the viewpoint of effect of soil type on shape, ignoring sediment load, it seems that three distinct classes of natural boundary conditions exist.

1. Completely non-cohesive sand channels.

2. Channels having sand beds and cohesive sides.

3. Channels with completely cohesive beds and sides.

It is quite obvious considering the magnitudes of gravitational and cohesive forces that channels in sandy material will tend to have large W/D ratios, channels in completely cohesive materials will exhibit minimum W/D ratios, and intermediate cases will be primarily a function of the cohesiveness of side material and their W/D ratios will range between the above limiting cases. These foregoing suppositions are also at least partially dependent on the type and magnitude of sediment load.

Relationship Between Bed and Side Factors and Tractive Force

The analysis of the side factor according to the procedure suggested by Blench (6), shows that s is a measure of shear on the sides. He also points out that the bed factor might be a measure of the force per unit mass of fluid acting to overcome the gravity of the bed sediment as preliminary to permitting it to be transported by the flow. Both of these terms then should be directly, or at least indirectly, related to tractive force and size of sediment. Considering these factors, it seems that this provides still another possibility of relating these parameters, and consequently relating tractive force procedure, with regime theory.

As a means of expanding and possibly combining the various theories as described in this Chapter in accordance with the objectives as cited in Chapter I, a field study of stable channel was organized. A discussion of the study, the equipment used, and the data collected are presented in the following chapter.

Chapter V

EQUIPMENT AND PROCEDURE

The objectives of this thesis as previously outlined are as follows:

1. To investigate and extend the scope of the regime theory as developed in India.

2. To investigate and extend the scope of the tractive force method of stable channel design.

3. To relate the regime theory to the tractive force theory insofar as possible.

To obtain data that would assist in achieving the foregoing objectives, a field study of straight reaches of stable irrigation canals was proposed. This study was jointly sponsored by the Corps of Engineers, the U. S. Geological Survey, the U. S. Bureau of Reclamation, Colorado State University, and the University of Wyoming. Field data on selected sites were taken during the summers of 1953 and 54 in the Wyoming, Colorado, and Nebraska area. Figs. 28 and 29 show the typical characteristics of the canals investigated.

The nature of the problem, design of stable channels in alluvial materials, dictated that the studies should be conducted on stable irrigation canals. In all cases only straight reaches considered to be of sufficient length to eliminate effect of sinuosity were investigated. Other factors of major consideration that also governed site selection were:

1. Location relative to downstream hydraulic structures that might cause back water in the test reach.

2. Accessibility of site.

3. Insofar as possible, the selected canals were investigated while operating more or less continuously at nearly full-supply conditions.

4. Canals were selected for observation that covered a wide range of situations with respect to both capacity and the type of natural material in which they were constructed.

a - full supply

b - empty

Fig. 28 Photographs of Canal No. 1
Located - 9 Miles West of Fort Morgan, Colorado

a - Canal No. 9 at full supply

b - Canal No. 9, empty

Fig. 29 Photographs of Canal No. 9
Located - 1 Mile West of Fort Morgan, Colorado

The discharge capacity of canals investigated ranged from 43 cfs to 1400 cfs. It was not always possible to obtain data from the canals studied while they were discharging at 100 percent of capacity. The reason for this was that during the 1953 and 1954 irrigation seasons water was in short supply because of drouth conditions in the western United States. In all cases, however, observations were taken at discharges equal to or greater than 80 percent of design discharge.

The stability of the reaches selected for study was determined by a careful visual examination. In addition the history of each reach was investigated by checking with irrigation company engineers and ditch riders in charge of operation and maintenance of these canals.

The data taken in the field from the selected straight stable reaches included magnitude of discharge, velocity distribution, slope of water surface, shape of canal cross-section, suspended sediment distribution, total sediment load whenever possible, samples of bed material and side material, armor coat samples, general condition of the bed, temperature of the water, and photographs. The sequence in which these data were taken varied somewhat from canal to canal, but generally the procedure was as follows.

Slope Measurements

The length of the stable reaches investigated varied from 500 to 2000 ft depending on the size and slope of the canal. The upper end of each reach was always located a sufficient distance downstream from bends to insure that the effects of the bend on flow conditions would be negligible.

Beginning at the upper end of the reach, the zero station, standard 4-ft laths were driven into the canal bank approximately 1-1/2-ft from the edge of the canal at each 100-ft station over the entire length of the reach. Each lath was driven so that its top extended about 0.1-ft above the water surface. Stakes of this type were used because they were always available, were fairly cheap, and were of sufficient length and strength to satisfy the stability requirements of the situation, that is, capable of supporting the weight of a Philadelphia surveying rod without buckling and without being driven further into the canal banks.

With the stakes properly located, the next step involved determining as accurately as possible the elevation of the water surface relative to the top of each stake. This was accomplished by using a portable hook gage developed for this purpose by the United States Bureau of Reclamation. The gage used is pictured in

Fig. 30 and consists simply of a pitot tube without a stagnation point orifice through which water enters a plastic stilling well equipped with a hook gage. The entry and exit of water into the stilling well is controlled by a valve. Briefly, the procedure followed to determine water level relative to top of stake involved setting the adjustable foot of the gage on top of the stake. With the pitot tube below water level the valve to the stilling basin was opened. Sufficient time was allowed to elapse for the water in the stilling basin to rise to the same level as the water in the canal. The valve was closed and the gage was removed from the stake. The water level in the stilling basin was determined to the nearest one thousandth of a foot by means of the small hook gage within it. Knowing depth of water in the stilling basin and position of stilling basin relative to top of stake the distance from top of stake to water surface was accurately established. To insure maximum accuracy, measurements were always taken in the downstream direction and were repeated at least twice and in some instances as many as five times. The need for several determinations at each stake arose when small surges or waves generated by wind or an upstream hydraulic structure had to be averaged.

Having established elevation of the water surface relative to the top of each stake, the elevation of the stakes with respect to an arbitrary bench mark was next determined using precise differential leveling procedure. The method followed, which gave best results, involved setting up the level at every other station. This way backsight and foresight distances were equal and the two peg method of adjusting levels was used to determine accurately the difference in elevation between these alternate stations. The elevation of stakes adjacent to the level were sufficiently close to the instrument, which was continuously checked for proper adjustment, to enable precise determination of their elevations. As an additional precaution care was taken to eliminate temperature effects on the instrument by surveying early in the morning, in the evening, or while cloudy conditions prevailed. The elevations of water surface thus obtained were plotted and water surface slopes were determined from best fit lines drawn through these data using the method of averages. In most instances, except where very flat slopes were involved, slope determination was a clear cut process and success or failure was entirely a function of proper technique and use of instruments.

Velocity Measurements

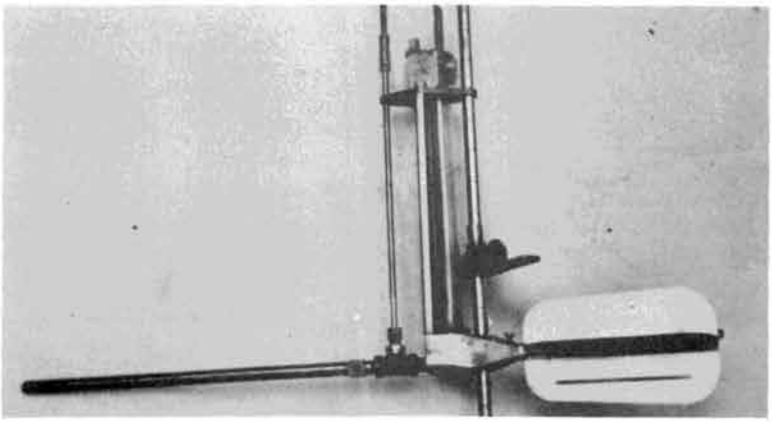
The following items were used in connection with making velocity determinations: a standard Price current meter, a pygmy meter, a current meter rod, a 16-pound sounding weight, a U. S. Geological Survey Model A sounding reel and cable, a 14-foot aluminum boat, a cable tag line, and a wooden boom to support the sounding reel, the current meter, and the sounding weight.

The current meters provided by the U. S. Bureau of Reclamation were carefully protected at all times and were calibrated in the calibration flume with and without a sounding weight at Fort Collins, Colorado both in the spring and again in the fall of each year to insure the accuracy of the velocity data. The standard Price meter was used to determine velocities to within 0.4-ft of the bed. The Pygmy meter was used to try to establish the magnitude of the velocities at points closer to the bed than 0.4-ft. The successful determination of velocities close to the bottom depended on bed conditions. That is, the use of a Pygmy meter was successful only in those canals having a smooth bottom free from loose sand and dunes.

In the smaller canals the current meter was used on a rod and the section was traversed by wading or from a plank. To determine velocities in the larger canals it was necessary, because of depth, to work from a boat. A cable tag line marked in feet was stretched across the section to be investigated and normal to direction of flow. This tag line was used to hold the boat in position and to fix the location relative to the banks. The current meter was attached to the cable of the class A reel 0.4-ft above the bottom of the 16-lb sounding weight at the end of the cable. The meter and weight supported by the cable could then be lowered by means of the reel and boom to any desired depth to determine the velocity at that point. To overcome a slight tendency of the meter to twist out of orientation with direction of flow, extra fins were attached to the sounding weight. Some non-alignment still existed after modifying the equipment. This was attributed to secondary circulation effect. With the reel depth scale properly zeroed, lowering the 16-lb weight to the bed gave depth of section at the point.

Data to establish vertical velocity profiles were taken every 2 to 5 feet, depending on size of channel, at one cross-section in each reach investigated. This gave from 5 to 15 vertical distributions of velocity in each canal cross-section. The velocities in each vertical were measured at 0.1, 0.2, 0.4, 0.6, 0.9 the depth and at a point 0.4-ft above the bed. When 0.1 the depth was less than 0.4-ft, and when nine-tenths of the depth was close to the 0.4-ft point, these readings were usually omitted.

All velocities were based on time intervals of observation equal to or greater than 70 seconds. The minimum 70-second interval used to record the revolutions of the current meter was established by experimentation to be the minimum that should be used to insure accurate results. Current metering equipment is shown in Fig. 31.



(a) Portable hook gage

(b) Using the Portable hook gage

Fig. 30 - Construction and Use of the Portable hook gage.

Fig. 31 - Current Metering Equipment

Sediment Samples

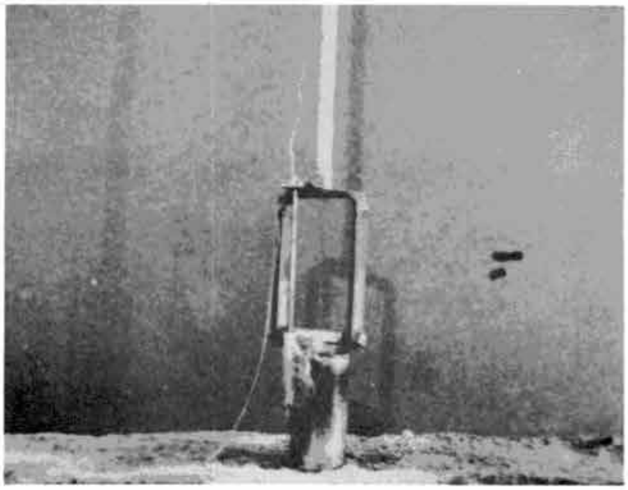
Both suspended and total load sediment samples were taken with a U. S. DH48 hand sampler. The sampler was fitted with a nose cap which sealed off the nozzle of the sampler. The cap could be opened at any time by means of a string attached to it. The use of this device prevented partial filling of the sample bottle before it reached the sampling point. The sampler was fitted to a specially-constructed two-piece rectangular aluminum bar. The two pieces could be attached together when extra length of bar was required. The bar was graduated in feet and tenths of feet. The suspended sediment verticals were always at one of the velocity verticals, usually every other one. Samples were taken with the same vertical spacing as the velocity spacing.

During the summer of 1953 the size of samples collected consisted of two pint bottles at each point. From each bottle sufficient clear water was decanted so that the remaining contents could be combined into one. Analysis of these samples was difficult because of the small concentrations. To improve this situation, four pint bottle samples were taken at each point during the summer of 1954. As before, sufficient clear water was decanted from each of the four bottles to allow them to be combined into a single pint container.

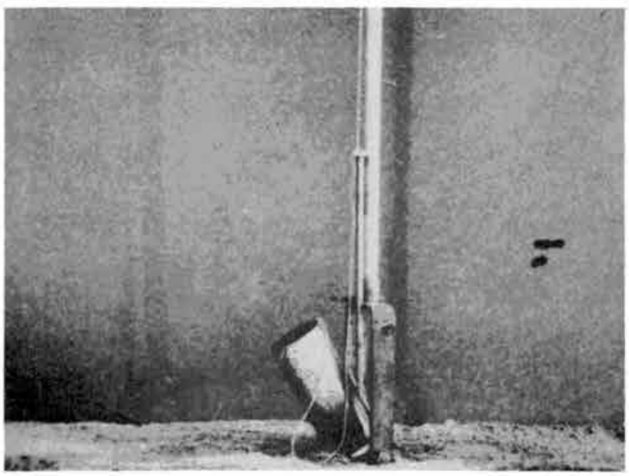
The total load samples could only be taken when hydraulic structures causing extreme turbulence existed upstream or downstream of the reach in question. When suitable structures existed, depth integrated samples were taken in verticals immediately downstream of the structure and combined into a single sample. Turbulence at the structure had to be sufficient to force the total sediment load upward into suspension.

Sampling of Bed and Side Material

Samples of bed and side material were taken from each reach. Usually, one or two samples were taken from each of the sides and three to five across the bed. The material was collected from the top 1 to 2 in. of the canal boundary. The samples of side material were usually cohesive and it was found that good samples could be obtained by pushing a piece of 2 in. plastic tubing into the material to be sampled, twisting it loose, and lifting it out. The problem of sampling non-cohesive bed material was not always as simple. In the case of fairly shallow canals, the foregoing method worked but in deeper canals the sample was usually lost before the tube could be brought to the surface. To overcome this situation the sampler shown in Fig. 32 was developed by Donald L. Bender and the writer. This sampler consists of a



(a) Sampler in Cutting Position



(b) Sampler in Retrieving Position

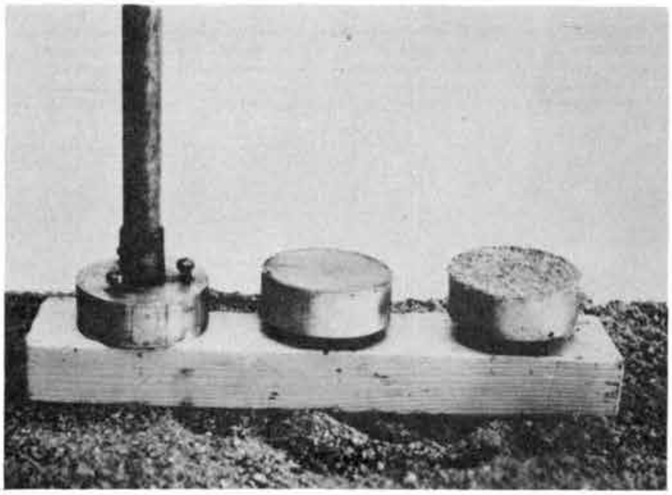
Fig. 32 Bed Material Sampler

handle made up of pipe sections terminating in a 4-in. diameter by 6-in. high cylinder attached to the handle by means of a hinge. A pin connected to the handle and extending through a smaller pipe welded to the cylinder gives the handle and cylinder stability. The cylinder with pin in position is driven into the bed, the pin is then pulled by a string allowing the cylinder to rotate with respect to the vertical handle. The string used to pull the pin is also attached to the lower lip of the pivoting cylinder. By pulling the string and pushing down on the handle the cylinder is rotated into an upright position trapping the sample and it can then be brought to the surface. No good method was found for sampling beds of gravel or cobble stone during operation. Canals having beds of this type are best sampled during the non-operating season.

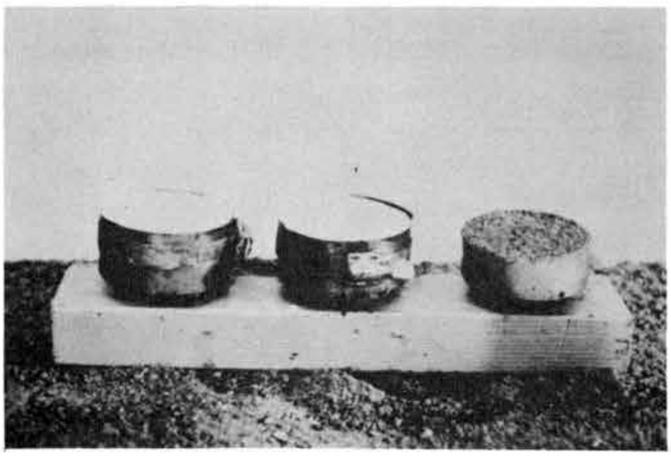
Armor Coat

Samples of the material directly in contact with the flowing water, defined here as armor coat, were also collected. To the best of the writer's knowledge no method for doing this had been established previously so some experimentation was required. This was carried out during the spring of 1953. The method developed consisted of using a handle made up of 2-1/2-ft sections of 3/4-in. pipe. The first section was threaded to receive a 3-in cup as indicated in Fig. 33a. The cup was filled with a thin layer of pump grease, Conoco pump grease gave best results. The cup filled with grease was lowered slowly vertically downward by means of the handle and pressed lightly against the bed material. The top layer of bed material adhered to the grease and was brought to the surface. The cap was then unscrewed from the handle, a metal form was clamped around the cup, and the form was filled with a moderately liquid mixture of plaster of Paris, see Fig. 33b.

After the plaster of Paris had set the form could be removed and the plaster of Paris cap pulled away from the grease bringing the armor coat with it. This leaves the material picked up from the bed imbedded in the plaster of Paris with the side of the particles that had originally extended into the water exposed. Typical armor coat samples obtained by this method are shown in Fig. 34. A method similar to this is currently being used by the U. S. Geological Survey to sample armor coat. The principle difference is that the sand collected in the grease is scraped off the surface of the container and separated from the grease by titration. The sand is then analyzed by conventional methods.

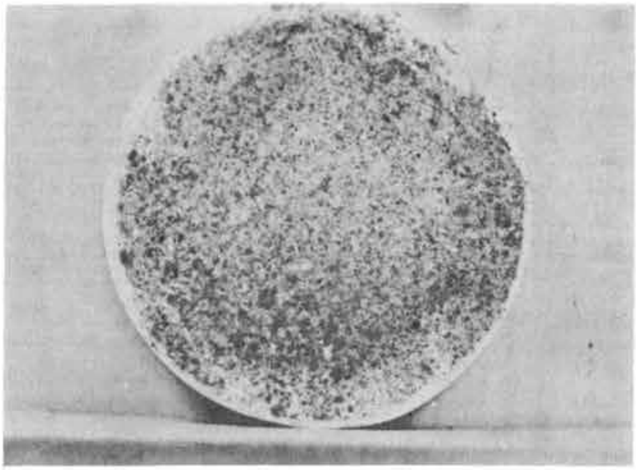


(a) Armor Coat Sampler

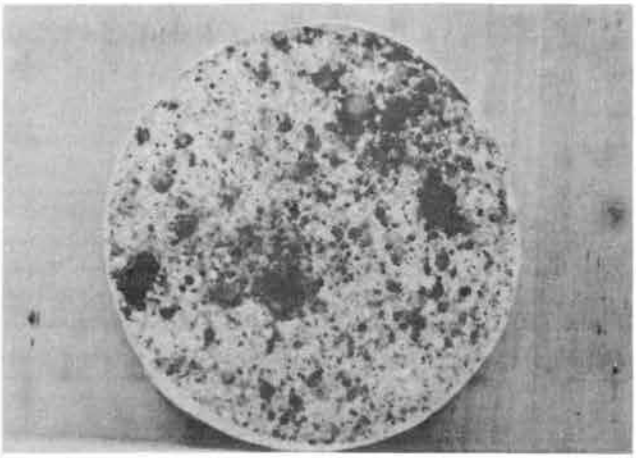


(b) Capping Sample with Plaster of Paris

Fig. 33 Armor Coat Sampling Equipment



(a) Canal No. 9



(b) Canal No. 23

Fig. 34 Armor Coat Samples

Shape of Canal

The shape of the canal cross-section at the sampling station was determined while taking velocity measurements. To establish uniformity of shape or lack thereof the shape of cross-section at from two to four additional stations was taken in each reach. These additional shapes were determined by direct depth measurement using a current meter rod either from the boat or by wading depending on depth of canal.

Water Temperatures

Temperatures of the water were taken every one-half to one hour during the two-to-four-day period spent at the site. Additional supplementary readings were occasionally obtained by revisiting the site. In many cases the canals investigated were sufficiently similar both with regard to size and location that temperatures recorded at one site probably also applied to others. The temperature variation of the canal water during a twenty-four hour period was in some cases as much as 25 degrees F.

Vegetation

The extent of vegetal growth on the banks and its probable influence on canal stability, operation, and maintenance was recorded, see table 13, based on visual observation.

Discharge

The flow rate at the time of the investigation was established from the velocity measurements. The record of flow for each canal was checked by referring to irrigation company records and ditch riders reports to establish how near full supply the canal was operating.

Bed Condition

The condition of the bed of each reach was examined for the presence of dunes. In the canals having depths in excess of 2 to 2-1/2-ft the bed condition was determined by probing. A rod with a shoe fitted to its base was used for this purpose. In the shallower canals, probing was used and in addition a more intimate examination was made by wading on the bed. Insofar as possible, whenever any form of dunes existed, an attempt was made to measure their relative location, height, and spacing. It proved impractical to determine the rate of movement of the dunes with the equipment available.

Photographs

The reaches examined were photographed in both the upstream and downstream direction at full supply and when empty with both a standard 35 mm camera and a 35 mm stereo camera. Kodachrome film was used exclusively on the canals examined during 1953. In 1954 a second 35 mm camera was used to photograph the canals in black and white. It would have been advantageous to photograph all canals in this manner from the report point of view.

In the following chapter the data collected will be presented and discussed.

Chapter VI

PRESENTATION OF DATA

All data collected as indicated in Chapter V have been tabulated and are presented in Appendix B. Figures developed from these data are given in Appendix A. A discussion of these tabulations follows.

General Information on the Canal Reaches Investigated

A total of 24 reaches were investigated. General information on each reach is presented in Table 13.

In the first column each canal is assigned a reference number. In the second column the name of the canal is stated, in the third column the general location of each reach is given, in the fourth column the extent of bank vegetation is indicated, in the fifth column type of bank material is given, and in the sixth column general remarks regarding method of operation, degree of stability, and extent of maintenance required are given.

Velocity Data

All velocity observations taken for each of the reaches are presented in Table 14. Based on these tabulated data the velocity distribution curves for each vertical of each reach can be plotted. To illustrate, vertical velocity distribution curves for canal No. 9 are presented in Fig. 35 on semi-logarithmic paper. These curves are more or less typical of the canals investigated. In some cases maximum velocities in the sections occurred at or near the water surface. In other instances maximum velocities were found at about 0.2D below the surface. A study of the various canals reveals that those having large W/D values follow the semi-logarithmic law of velocity distribution more closely than do the narrow deep canals. The curving back of the velocity distribution curves near the surface may be caused to a certain extent by secondary circulation.

The cross-sections at the sampling stations can be drawn based on depths taken while making the velocity determinations. Table 14, and isovels are obtained by plotting point velocities in the cross-sections and connecting points of equal velocity with smooth continuous lines. Fig. 36 shows the shape of the cross-sections and the isovels at the sampling stations for the canals numbered 4 and 20.

Cross-sectional Shape and Properties of the Sections

The shape of each canal investigated was automatically determined at the sampling station by making the current meter measurements as previously discussed. Additional cross-sectional shapes were taken to establish the degree of uniformity of section within the reach and also to provide a means of computing slope of energy gradient if the variation in shape was sufficiently great to warrant it. On some canals two additional shape measurements were taken while on the others still more measurements were taken. The data on shape including shape at the sampling station, are presented for all 24 canals in Table 15.

These data were used to plot actual scale shapes of all cross-sections measured in each reach. Fairly large scales were used, that is 1-in. = 1-ft and 1-in. = 2 ft. Using a carefully calibrated map measurer, the wetted perimeter of each section was measured. From the same scale drawings, areas of the cross-sections were determined by planimetering. Knowing the magnitudes of areas and wetted perimeters, the hydraulic radii were computed. Values of A , P , and R are given in Table 28, in which a summary of all the important data and parameters are presented.

To observe shape and shape variation within particular reaches, refer to Figs. 37, 38 and 39. These figures illustrate graphically the variation in shape from section to section for sandy, moderately cohesive, and very cohesive materials. Values of A , P , and R for each of the sections are also given to indicate numerically the change occurring from point to point within a particular reach.

Slope of Energy Grade Line

The water surface elevations of each reach were obtained as indicated in Chapter V. These elevations for each station of each canal are given in Table 16. By plotting elevation of water surface against distance along the channel, and drawing a best-fit line to these data, the water surface slope of each reach was established. This procedure is illustrated in Fig. 40. The best-fit line was determined by the method of averages because it gives good accuracy and does not require as much time as finding the best fit line by the method of least squares. For a perfectly uniform reach, flow is steady and uniform. In this case slope of water surface (hydraulic gradient) and slope of energy gradient S are parallel to each other and the energy gradient lies a distance above the water surface equal to the velocity head. If appreciable variation of water cross-section occurs within a given reach, flow is not uniform and the hydraulic gradient and energy gradient are not parallel because of this fact. That is, the velocity head and water surface slope are not constant along the reach. In this case it is necessary to establish the energy gradient line for the channel by plotting new points a distance, equal to the velocity head, above the water surface and drawing a best fit-line through them. The slope of this best-fit line through these points gives the slope of the energy gradient. Careful analysis verifies, however, that for all practical purposes slope of energy gradient and hydraulic gradient are the same within the limits of accuracy of the data. Values of slope for each canal reach are given in Table 28.

Suspended Sediment

Samples of suspended sediment were taken as described in Chapter V. All of these samples were analyzed for concentration and size distribution by the U. S. Geological Survey at their Lincoln, Nebraska laboratory. The location of sampling points and the results of their analysis are summarized in Table 17.

Typical variations of concentration with depth are shown in Fig. 41. In some cases the actual amount of sediment in a given sample was so small, because of low concentration in the canal and the small size of samples taken, that the range and accuracy of the data yielded by the size analysis of the sediment was very limited. In the extreme cases some percent finer curves are based on as few as one to two points. When such is the case it has been necessary to determine the 50-percent passing size of the suspended sediment by extrapolation.

The extrapolation procedure used to determine the 50 percent size was based on the fact that percent finer curves plotted on log probability paper followed a definite pattern, that is, typical percent finer curves consisted of two families of straight lines as shown in Fig. 42. The slopes of the two sets of lines are fairly constant for each canal.

Using the assumption that slopes of lines are nearly equal for similar canals in similar regions it was possible when desired to estimate the 50 percent size of suspended sediment for all canals as well as other sizes greater or smaller than the 50 per cent size.

It should be noted that the sand fractions of all suspended sediment samples were retained and are on file. These could be composited to obtain a more accurate estimate of the coarse fraction of the suspended sediment load. An additional study involving a more detailed analysis of these sediment samples is planned.

It should be noted also that the data being discussed have been used to prepare a masters thesis entitled "Suspended Sediment Transport in Alluvial Irrigation Channels" by Donald L. Bender (5) at Colorado A and M College, Fort Collins, Colorado. A limited number of copies of this thesis are available upon request. Only data collected during the summer of 1953 were utilized in the preparation of this thesis.

Total Sediment Load

The procedure used to obtain total load samples was described in Chapter V. These samples were analyzed in the same manner as the suspended sediment samples. Only fourteen of the twenty-four canals investigated were sampled for total load.

The results of the analysis including concentration and size distribution are presented in summarized form in Table 18. The 50 percent sizes based on total load samples for these fourteen canals are also included in the table.

Bed and Side Material

The bed and side materials comprising the top 1 to 2 in. of canal periphery were sampled as described in Chapter V. The number of samples taken per canal varied with canal size and shape.

Standard sieving and hydrometer analysis procedures were used to establish the size distribution of each sample. The results of this analysis for each sample of each canal are presented in Table 19. Columns of data pertaining to samples that required both sieve and hydrometer analysis are broken by two horizontal parallel lines. The data above the lines has been determined by sieving, the data below the lines by hydrometer.

Based on the data in Table 19, it is possible to draw percent-finer curves from which sizes corresponding to any desired percent passing value can be obtained. Typical percent-finer curves for canal No. 23 are shown in Fig. 43. These curves have been presented on log-probability paper in preference to semi-log paper since normally distributed materials tend to plot as straight lines. The resulting plots are not straight lines but there is a strong tendency toward straightness, and straight lines were forced through the data to facilitate the determination of the standard deviation of the material.

Standard Deviation

From plots of the foregoing type, the sizes of material corresponding to various percent-passing values can be obtained and used to evaluate standard deviation.

Standard deviation is a measure of dispersion that is widely used in the technical fields. It is symbolized as σ and is described mathematically by the equation

$$\sigma = \sqrt{\frac{\Sigma (X^2)}{N} - \bar{X}^2} \tag{136}$$

where X = values involved,

N = the number of values occurring, and

$\bar{X}$ = the mean of these values.

One method of determining σ involves selecting points or values of X from the percent-finer curves and applying Eq 136. A second method described by Rouse (55) provides a means of computing a measure of standard deviation in dimensionless form. It is based on the relationship between slope of the percent-finer curve when the data are plotted on log-probability paper and standard deviation. Using this later method of approach the value of σ_1 for data that plot as a straight line can be computed as follows

$$\sigma_1 = \frac{\frac{d85}{d50} + \frac{d50}{d15}}{2} \tag{137}$$

Although the size distribution curves deviated considerably from a straight line in some cases, this procedure was used. Values of the 15 percent, and the 85 percent passing sizes as well as values of σ_1 computed by means of Eq 121 are presented in Table 20. The values in the columns occurring outside the horizontal lines are classified as side material, the ones inside as bed material.

The size distribution curves exhibit a discontinuity at the point where the curves are based on hydrometer sizes instead of sieve sizes. There is also a marked tendency for a steeper slope in the section of the curve based on hydrometer analysis. At the point of discontinuity the sizes indicated by hydrometer are larger than the sizes indicated by sieving. This is difficult to explain since usually the reverse situation is encountered. It is perhaps possible that in high concentrations of fine material a certain amount of flocculation occurs in spite of the use of dispersants. It is conceivable too that some small particles are carried down by the larger ones during the fall out. Finally, and probably of greatest importance, is the fact that at the point of discontinuity both methods of analysis tend to give questionable values.

Visual Tube Analysis

During the process of evaluating sizes of materials it was decided that it would be beneficial to determine also at least some size distributions by means of the visual accumulation tube, more commonly known as the V.A. tube. This matter was discussed with Paul C. Benedict of the U. S. Geological Survey and he arranged to have the bed and side material samples from three canals, Nos. 4, 11, and 13 analyzed by the V.A. tube method in the Lincoln, Nebraska laboratory. The results of this investigation are presented in Table 28.

Percent fine curves were prepared from these data and used to evaluate the 15 percent, the 50 percent, and the 85 percent passing sizes from which values of σ_1 were computed. These values are given in Table 22.

To facilitate a comparison of the sizes and σ_1-values resulting from the V.A.-tube analysis with results from the sieve and hydrometer method Table 23 was prepared. In this table the values of d obtained by the two independent methods have been tabulated and compared. Values of σ_1 and percentage differences in σ_1 values for the two methods of investigations are also given. It is to be noted that the diameters of the fifty percent passing agree quite well in most cases. That is, the V.A.-tube sand and the sieve hydrometer methods give essentially indentical results in this size range. This is verified further by observing Fig. 44. Here percent-finer curves resulting from both methods are plotted to the same scale on the same sheet.

Magnitude of Suspended Sediment Load

Using the suspended sediment data given in Table 17, the suspended load was estimated in the manner indicated in Table 24. At the bottom of the last column of Table 24 the value of

$$\Sigma\left[(PPM)(V)(A)\right]$$

has been determined. This value was utilized in the following equation to estimate the quantity of suspended sediment in tons per day, that is,

$$\text{Tons per day of suspended sediment} = \Sigma\ (PPM \times V)_{ave} \times A\ \frac{(62.4)}{10^6}\ \frac{86400}{2000}\ .$$

The suspended load thus obtained for each of the canals is given in Table 25. It is important to note that the total discharge cross-section was used to compute sediment load and that concentrations used were taken within the limits of the water surface and 0.4 ft above the bed of the channel.

Magnitude of Total Sediment Load

Based on data for the total sediment load presented in Table 18, the total number of tons of sediment transported was computed as follows.

$$\text{Total sediment} = Q \times \frac{PPM}{10^6}(62.4)\ \frac{86400}{2000} = \text{load, tons per day}\ .$$

The results of these computations are presented for the 13 canals yielding total load samples in Table 25, together with estimated suspended sediment load.

Computation of Tractive Force

In accordance with the tractive force theories presented, values of tractive force were computed as follows.

Tractive Force Based on $\tau = \gamma DS$

Corresponding to measured values of depth, the shears along the periphery of each channel were computed, see Table 26. The depths used were measured normal to the periphery of the channels.

Average Tractive Forced Based on $\tau_{ave} = \gamma RS$

With the magnitude of R and S known, the average shear was computed for each of the 24 canals by means of the foregoing equation. These values of τ_{ave} are given in Table 28.

Tractive Force Based on Velocity Gradient

The tractive force based on slope of velocity gradient was computed by means of the equation

$$\tau = \rho \left[\frac{V_2 - V_1}{5.75 \log \frac{Y_2}{Y_1}} \right] \quad . \tag{44}$$

The value of ρ used in this analysis was assumed to be constant having a magnitude of $\rho = 1.936$. This value corresponds to a water temperature of 70°F. In each case Y_1 and Y_2 were respectively equal to 0.4 and 0.8 ft, and were measured normal to the boundary. The velocities V_1 and V_2 were measured at the distances Y_1 and Y_2 above the bed. With the values of Y_1 , Y_2 , and ρ known, Eq 38 reduces to

$$\tau = 0.65 \, (V_2 - V_1)^2 \quad . \tag{138}$$

Values of V_1 and V_2 corresponding to Y_1 and Y_2 respectively are given in Table 26. They were used as indicated to compute the magnitudes of the tractive forces which are also given in this table.

Tractive Force Based on the Concept of Zero Momentum Exchange

The method of estimating the tractive force on the sides and/or the beds of narrow and/or irregular channels as outlined in Chapter IV was utilized to evaluate tractive force on the canal beds. This involved determining the volume of water immediately over the area of bed or side in question such that transverse momentum transfer into or out of the volume of water was zero.

Accordingly, the volumes of water related to small areas of the beds near the center line of each of the twenty-four canals was established by planimetering. These and the corresponding tractive forces are given in Table 27. The tractive force in each case was determined by multiplying the foregoing volumes by the unit weight of water and the approximate water surface slope.

Summary of Data for the Twenty-four Canals Investigated

All data collected on these canals as well as parameters computed for correlation work are summarized in Table 28. This procedure was used to facilitate the correlation and analysis phase of the study that follows in Chapter VII.

United States Bureau of Reclamation Data

Because of the limited amount of data on tractive force for coarse non-cohesive material, the Bureau of Reclamation in accordance with the advice of Lane, investigated canals constructed in this type of material in the San Luis Valley of Colorado (35). The canals were located on an alluvial fan. The size of the natural material varied considerably, decreasing in size from the apex outward. The canals constructed in the cone were stable, straight, and of uniform cross-section. Fifteen reaches of canals were investigated. Values of Q varied from 17 to 1500 cfs and slopes from 0.79×10^{-3} to 0.97×10^{-2}. The basic data and parameters derived therefrom are given in Table 29.

The primary purpose of using these data is to increase the range of conditions considered and to establish more points for the correlation phases of this study.

India Data

A rather thorough study of the available literature on regime theory, its conception, and evolution was undertaken. During the course of this investigation considerable information was found on the canal systems of India which was used to help establish and develop the regime theory were found. Two groups of these data were sufficiently complete and pertinent to warrant inclusion for use in the theoretical analysis.

The first group of data is for forty-two stable Punjab canals, see pages 60 through 64 of reference (49). Their capacity varies from 5 to 9000 cfs. Slopes are on the order of 0.12×10^{-3} to 0.34×10^{-3} and the average diameter of the bed material is approximately 0.43 mm. These data and the derived parameters to be used in the subsequent analysis are summarized in Table 30.

The Punjab canals have been subjected to a long period of investigation and are classified as stable. They may be considered, according to page 77 of reference (40), as a sample from an infinite population of possible observations.

An insight to the magnitude of sediment load carried by the Punjab canals is given in Table 31. These data were obtained from reference (39), page 87. The mean silt intensity for the channels listed is 0.238 grams per liter or 238 ppm. This value is within the order of magnitude of sediment concentration in the canals measured by Simons and Bender. Considering the small difference in magnitude of sediment load for these two groups of canals, it is anticipated that they will behave as a single group except possibly where major differences in bed and bank conditions exist.

The second group of canal data was found in statement I, pages 70 and 71 of reference (26), and statement II, pages 74 and 75 of reference (27). These data were collected from twenty-eight different reaches of thirteen Sind canals and according to the foregoing reference are stable. Their capacity ranges from 311 to 9057 cfs, slopes vary between 0.0592×10^{-3} and 0.0995×10^{-3} and mean size of bed material is within the limits 0.0346 mm to 0.1642 mm. A summary of data taken from statements I and II plus the additional computed parameters are given in Table 32.

The Sind canals seem to carry a larger amount of sediment than those of the Punjab, at least during part of each year. This is verified by studying the data presented in Table 33 taken from reference (28). In accordance with observations 3 and 4 taken in 1934, the magnitude of the suspended sediment load ranges from 3.59 grams per liter down to 0.156 grams per liter or from 3590 ppm down to 156 ppm. The silt in the Sind canals has a smaller mean diameter than that found in the Punjab canals. With the somewhat larger sediment load, it is anticipated that these canals will behave differently from the Punjab canals and the canals studied by Simons and Bender unless sufficient wash load occurs in the Sind group to automatically compensate for the difference in conditions.

Data from four irrigation canals in the Imperial Valley canal systems were obtained from a technical bulletin by Fortier and Blaney (21) and a masters degree report by Raju (50). These data are unique in that their sediment concentrations are relatively high ranging from 2500 to 8000 ppm and their bed and bank conditions are similar to those found in the Punjab canals, the Sind canals, and the canals investigated by the writer. A summary of these data including the computed parameters are given in Table 34.

Richardsons Number

Values of Richardsons number and $C/\sqrt{g}$ taken from reference (4) plus additional values of the same parameters based on Niobrara River data are presented in Table 35. These last data were made available by the U. S. Geological Survey.

The primary purpose for introducing river data at this point is to increase the range of sediment load data with the ultimate goal in mind that it might assist in determining the effect of sediment load on stability.

Temperature Data

An average effective temperature for the twenty-four canal reaches investigated by the writer has been worked out for each canal. These data are given in Table 28.

The temperature of the San Luis Valley canals is not known but based on climatological conditions an effective temperature of 65°F has been assumed for each of the fifteen reaches reported.

No specific information on temperature of individual canals in the Punjab or the Sind was found. It has been pointed out, by N. K. Bose, on page 55 of reference (9), however, that temperature variation in the Punjab canals ranges from 9°C to 28°C and that 20°C is a good average for the entire year. In addition Blench (6) reports that the climate of the Punjab is similar to that of desert Arizona and that water temperatures vary from 50°F to 85°F. Based on the foregoing information a base temperature of 70°F was utilized whenever temperatures of water were involved for the Punjab and Sind canals. This base temperature probably introduces some scatter in those relationships in which it is involved.

Chapter VII

ANALYSIS OF DATA

The summary of basic data and the parameters computed therefrom can now be utilized to investigate the theory of stable channels. These data are tabulated in Tables 28, 29, 30, 32, and 34. The shape characteristics of these canals will be investigated first.

Relationship Between R and D, and P and W

The Lacey theory is expressed in terms of wetted perimeter and hydraulic radius. The Blench theory is in terms of average depth on the channel bed and average width such that

$$\text{Area} = W \times D \ .$$

Considering the 42 Punjab canals, see Table 30, the average depth on the bed and average width were not given. The only measurements pertaining to shape were wetted perimeter, hydraulic radius, and top width. To overcome this deficiency of data, hydraulic radii were correlated with average bed depths and wetted perimeters were correlated with average width of channel as shown in Figs. 45 and 46. Only the 24 canals investigated by the writer, Table 28, and the 28 Sind canals, Table 32, were utilized to establish these curves.

The Imperial Valley canal data have been plotted on Figs. 45 and 46 to show that increased charge has little effect on the relationships between R and D, and W and P.

Based on Figs. 45 and 46 it is now obvious that average width and bed depth can be estimated rather accurately if P and R are known.

The actual method used to compute W and D for the 42 Punjab canals involved estimating W, knowing P, and then computing average bed depth by means of equation $A = WD$. That is,

$$D = \frac{A}{W} \ .$$

Estimating the W/D Ratio

The proper selection of the W/D ratio is undoubtedly a function of discharge, type of natural bed and bank material, (primarily the latter) and concentration and gradation of sediment load.

The curve of Fig. 47 illustrates that at least a qualitative relationship exists between W/D and median size of side material. This curve is based on the information collected on the 24 canals investigated by the writer.

It may be worthy of note at this time that in some instances the canals had natural berms. In these cases the median diameter is that of the berm material. In other instances very little or no berm had formed and hence the d of the sides in these cases is at least partially a function of the natural material. The fact that these two different conditions exist probably accounts for some of the scatter in this particular figure. Canals having side material more or less independent of the berm are Nos. 1, 12 through 19, 22, and 23, see Table 12.

The implication of Fig. 47 is quite clear. It shows that the W/D ratio increases with increasing median diameter of side material, that is sandy materials exhibit a large width-to-depth ratio.

The same type of relationship as shown by Fig. 47 was also obtained by correlating type of bank material and the W/D ratio, see Fig. 48. It should be understood clearly in every case that soil types used are rather arbitrary. No specific soil classification tests were run on natural bank material and hence classifications used are based on field observations. Types of natural bank materials were previously indicated in Table 12.

A slightly more comprehensive insight to variation of W/D ratios was obtained by correlating Q , W/D , and type of bank material as shown in Fig. 49. This illustrates that W/D increases with discharge and size of side material.

In Fig. 50, W/D , $C/\sqrt{g}$, and type of bed and bank material have been correlated. Three curves resulted, the A-curve is for canals having cohesive beds and banks, the B-curve applies when the canals have cohesive banks and sand beds, and the C-curve characterizes the relationship for those canals possessing both sand beds and sand banks.

As a final possibility the relationship between P/R and Q was considered, Fig. 51. This is similar to Fig. 49 since P/R W/D . Values of P/R and Q for all the canals have been utilized in this case. Values of P/R are related to W_T/D as shown in Fig. 52.

The trends indicated in the preceding four figures illustrates that stable width-to-depth ratios of canals are quite definitely related to soil type and capacity. More precise relations could probably be obtained by conducting a more accurate analysis of soil types and introducing the effect of sediment concentration.

The fact that sediment load and its characteristics are involved is illustrated in Fig. 53. Here W , d_{85} of the suspended sediment, and

Q are correlated. The 85 percent passing size was obtained directly from Table 28, and indirectly from the basic suspended sediment data presented in Table 17. The reason why width should correlate with d_{85} is not clear unless the presence of a larger size of sediment in suspension indicates a smaller amount of wash load which should influence berming, bank stability, and width of channel.

In Fig. 54, an attempt was made to correlate the d_{85} size of suspended sediment with mean size of bank material. The results are rather insignificant except it is interesting to note that canals with sand banks are at the top of the figure and those with very cohesive banks at the bottom.

It is difficult to accomplish a highly significant correlation involving sediment because of the narrow range of concentrations occurring in the 24 canals sampled.

Estimating W and D and/or P and R

According to the Lacey and Blench theories it is to be expected that either wetted perimeter or some channel width dimension such as top width or average width should correlate with rate of discharge. Based on this type of correlation Lacey arrived at the equation

$$P = 2.668\ Q^{1/2} \tag{16}$$

Estimating W and P

Using Lacey's procedure, values of P and corresponding values of Q were plotted in Fig. 55, for the canals investigated by Simons and Bender (referred to as Simons and Bender data), along with a few of the values from the Punjab canals. The range of materials forming the periphery of these canals extends from fine cohesive material to coarse non-cohesive material. The effect of soil type on P is clearly exhibited in this figure. The sand channels all require a relatively large P for a given Q while cohesive materials reach stability at a relatively small P for a given Q. The few points based on India data were added to define the relationship better.

To illustrate more fully how the 24 Simons and Bender canals plot relative to the India canals, consider Fig. 56. Here values of P vs Q have been plotted for the 24 canals, Table 28, and the forty-two Punjab canals, Table 30. Three curves have been fitted to these data based on type of bed and bank material. The equation of the arbitrary straight line representing canals with sand beds and cohesive banks is

$$P = 2.5\ Q^{0.51}\ . \tag{139}$$

Note the similarity of Eqs 16 and 139.

The effect of bank and bed materials on such a relationship is illustrated further by also considering the U. S. Bureau of Reclamation data as shown in Fig. 57. Here it is seen that values of P for a given Q are even smaller than in the case of cohesive materials. This simply illustrates the ability of the coarse material to resist a greater tractive force.

The Imperial Valley canal data have also been plotted in Fig. 57 to illustrate the quantitative effect of increased charge. From the view point of type of bank and bed materials these canals are similar to the other canals excluding those formed in coarse non-cohesive material. The trend line, however, falls approximately on the trend line representing the relationship between P and Q for canals formed in coarse non-cohesive material. This indicates that as charge of the type found in the Imperial canals decreases, the stable wetted perimeter P and consequently stable width W decreases.

Next consider the relationship existing between average width W and Q for the canals investigated by Simons and Bender, Fig. 58. As before the fact is clearly illustrated that a stable channel in sandy material develops a greater width for a given Q . In this case two separate curves have been drawn, one for canals in sandy materials having sand banks, the other includes all other types. It should be noted that canals 12 and 13 have boundaries of coarse non-cohesive material and the fact that they fall on the second line may be purely coincidental since velocities are low compared to stability of sides and bed. That is, it is doubtful if forces ever existed of sufficient magnitude to cause channel shape to adjust appreciably.

A more comprehensive W vs Q diagram is given in Fig. 59. All of the canals excluding the Imperial Valley canals are represented in this plot, including the canals investigated by the U. S. Bureau of Reclamation (referred to as USBR canals). The sand channels still group in a separate category. The India canals conform to the same type of relationship as the non-sand channels, and the USBR canals fall in a group slightly lower than for the other two cases. The validity of the relationship for the latter group of canals may be questionable since their boundaries are of extremely stable material and the present stable shapes may not differ appreciably from the original design shapes. This is particularly true in the case of the USBR canals numbered 8 and 10 which have very small velocities relative to those experienced in the other channels.

It is apparent that W and P are functions of the natural soil type in which the canals are constructed and the discharge. The preceding indicates that three curves, one for sandy material, one for slightly cohesive and cohesive material, and one for coarse non-cohesive materials farily well cover the range of conditions normally experienced in canal design.

In most of the relationships involving width W , the average value has been employed. Under certain circumstances it may be advantageous to convert average width to top width W_T. To facilitate this conversion, see Fig. 60. This correlates W with W_T based on the data from the canals investigated by Simons and Bender and the Punjab canal data. A good straight line correlation exists between these variables up to a top width of approximately 300.0 ft. However, for the larger values of W the relationship is based on limited data. The equation relating these variables is

$$W = 0.92\ W_T - 2.0\ . \tag{140}$$

Estimating D and R

A relationship between D and R for stable irrigation canals was given in Fig. 45. It is now desirable to relate D and/or R to other quantities or parameters. Lindley showed that both D and R were very closely related to Q. The truth of this for D is illustrated in Fig. 61. In this case values of D and Q for all canals have been utilized, as in the foregoing relations, between Q and P or Q and W.

The effect of natural bed and bank material is apparent and consistent with the preceding relations. The canals constructed in cohesive materials fall in one group, those having a sand bed and natural berm in a second group, those in sandy material in a third group, and those in coarse non-cohesive material fall in a fourth group. The value of D used in the correlation is average depth on the bed and it should be remembered that values of D for the 42 Punjab canals were estimated as stated earlier.

The basic relationship relating D and Q for canals having a sand bed and natural berm for $Q > 50$ cfs is

$$D = 0.685\ Q^{0.314}\ . \tag{141}$$

The same type relationship for the canals in coarse non-choesive material is

$$D = 0.408\ Q^{0.314}\ . \tag{142}$$

An equation for sand range and the cohesive range has not been developed because of the limited number of canals involved.

This same procedure can also be followed to obtain relationships between R, Q, and soil type, see Fig. 62. The basic relation for canals having sand beds and natural berms is

$$R = 0.43\ Q^{0.361}\ . \tag{143}$$

For coarse non-cohesive material the expression is

$$R = 0.247\ Q^{0.361} \tag{144}$$

The influence of sand banks on R has not been expressed in equation form but their effects are clearly illustrated.

The Imperial Valley canal data have been plotted to illustrate the importance of charge on stability of channels, see Fig. 62. Comparing the trend line for these limited data with similar lines representing the Simons and Bender, Punjab, and Sind data it is apparent that the hydraulic radius R decreases with increased charge for a given discharge Q indicating that as the magnitude of charge is increased it is necessary to increase the average velocity V so that deposition will not occur.

<u>Determination of W and D by the Blench Regime Equations</u>

The Blench regime equations recommended for determining average width and bed depth, such that $W \times D = A$, are restated here for convenience

$$\checkmark\ W = \left[\frac{s}{b}\right]^{1/2} Q^{1/2} \tag{36}$$

$$\checkmark\ D = \sqrt[3]{\frac{b}{s^2}}\ Q^{1/3} \tag{37}$$

where as before

$$s = \frac{V^3}{W}$$

and

$$b = \frac{V^2}{D}\ .$$

It was established earlier that, when these expressions for bed factor and side factor are substituted into Eqs 36 and 37, these equations reduce to

$$W = W$$

and

$$D = D \;.$$

This implied that the following relations based on these equations

$$\frac{W}{Q^{1/2}} \text{ vs } \left(\frac{s}{b}\right)^{1/2}$$

and

$$\frac{D}{Q^{1/3}} \text{ vs } \left(\frac{b}{s^2}\right)^{1/3}$$

should give straight lines having slopes of 45 degrees.

It is apparent based on these considerations that the usefulness of the regime equations for width and depth hinges on establishing independent expressions for bed and side factors probably in terms of parameters of the form suggested by Blench, Inglis and others.

In spite of the foregoing it is of interest to make use of the Blench equations. This has been done by correlating $P/Q^{1/2}$ with $W/VD = b/s$, see Fig. 63. In this plot all canal data with the exception of the Imperial Valley canals have been utilized. It is interesting to note that effect of soil type is no longer apparent and that the range covered by the 24 canals studied by Simons and Bender is very great, exceeding that of any other group or combination of groups considered. The relationship indicated in Fig. 63 is

$$\frac{P}{Q^{1/2}} = 0.193 \, \frac{W}{VD} + 1.79 \quad . \tag{145}$$

This expression can be useful in design as will be illustrated later. The expression $W/VD = b/s$ is defined as a shape factor by Blench.

Estimating Bed and Side Factors

Using the Simons and Bender data, attempts to establish other definite relationships for b and s were made with limited success. The results that are of interest follow.

Lacey gave a relationship between bed factor and mean diameter of exposed bed material in millimeters as already indicated and discussed. Following this concept, Fig. 64, shows the relationship between b and d. Note that two arbitrary lines have been drawn, one for canals with dunes on the bed the other for channels having a more or less smooth cohesive bed.

Actually canals 16, 17, and 18 do not fit this scheme completely since they have plane sand beds not plane cohesive beds. These three canals are all small, their sides are nearly vertical, and considerable vegetation grows on their banks — some of it trailing in the water.

In Fig. 65 d vs b data for all canals excluding the USBR group and the Imperial Valley canals have been plotted. It is obvious that the correlation for India canals as a group is better than that for the canals investigated by Simons and Bender. This is probably due to the fact that a wider range of conditions exist in the latter group. A correlation line for the 70 India canals would fall in between the two lines representing the Simons and Bender data. It is also quite definite that the bed material of the India canals is a function of sediment being transported whereas in the other group the bed material, particularly in the cohesive and very coarse size ranges, is probably largely independent of sediment being transported. In any event b can be estimated only roughly from such a relationship.

As a result of visually observing the data presented in the summary tables, the shear velocity was plotted against bed factor for the Simons and Bender data to obtain Fig. 66. The correlation in this case is more eratic than before. Some of the canals with plane beds fall on the line marked dunes — specifically, numbers 1, 17, 18, and 20 and numbers 12 and 14 are very eratic.

A duplicate of Fig. 66 including the India data is shown in Fig. 67. In this case the India data spread out rather haphazardly detracting appreciably from the preceding correlation and unless a third variable can be introduced to help explain the arrangement the results are not particularly helpful.

The most recent expression recommended for bed factor by Blench (7), includes effect of charge. It is difficult to say whether or not it possesses advantages over other expressions based on the Simons and Bender data because of the uniformity of concentration in these channels.

The side factor should be closely related to type of side material. Values of s for different soil types were previously recommended in Chapter II. In accordance with this concept, type of bank material and s have been plotted to obtain Fig. 68. It is again important to note that type of bank material is rather arbitrary — being based on field observations only. The general trend indicates an increase of side factor with decrease in cohesiveness of material.

In accordance with the foregoing observation, the mean size of side material has been correlated with the side factor in Fig. 69. The plotted points have been broken down into two groups by drawing two lines. The upper line seems to hold for sand bed canals with dunes and for those which are smooth for Q greater than 100 cfs. The lower line holds for channels having plane cohesive beds and also for some plane sand beds where

Q is less than 100 cfs. The exceptions to this observation are No. 18 which should fall on the lower curve and No. 15 which should fall on the upper curve.

Relationship Between Q and A

It is of interest to note the close relationship existing between Q and A for regime channels. Once again, however, it is expedient to introduce type of bank material as a third variable, see Fig. 70. Values of Q and A from all canals have been plotted. Four curves have been drawn as indicated by bank material and bed condition. The short uppermost curve is for canals having sand banks. The intermediate curve is for all other bank materials finer than sand. The lower curve is for coarse non-cohesive materials as represented by the U. S. Bureau of Reclamation canal data.

Equations relating A and Q for two of the foregoing three conditions follows. For banks of material finer than sand extending into the very cohesive range

$$A = 1.076^{0.873} \tag{146}$$

and for coarse non-cohesive materials

$$A = 0.45\, Q^{0.873} \quad . \tag{147}$$

The relationship between Q and A for the Imperial Valley canal data shows that as magnitude of charge increases the required area A corresponding to a given discharge Q decreases and the permissible average velocity V is increased. This is consistent with the trends indicated in Figs. 57 and 62. It is also important to note in this case, the variation of vertical displacement of each point relative to the line representing sand beds and cohesive banks. The effect of variation of charge shows up very clearly. These expressions cover a wide range of discharge and boundary conditions and should be very useful in practical design work.

Expressions Involving Velocity, Discharge, and Slope

The velocity correlates reasonably well with discharge as shown by Figs. 71 and 72. In Fig. 72 bank material is introduced as a third variable and four curves result. The upper curve is for the coarse non-cohesive materials of the U. S. Bureau of Reclamation canal data, the second curve is for channels with plane beds, the third curve represents canals possessing slightly cohesive to cohesive banks with rough sand beds, and the fourth curve represents sand bed and bank conditions. Expressions for the three most significant of these four cases follow. Coarse non-cohesive banks and beds.

$$V = 1.68\ Q^{0.182} \quad . \tag{148}$$

Slightly cohesive to cohesive banks with dunes on the bed.

$$V = 0.843\ A^{0.156} \tag{149}$$

and sand banks and beds

$$V = 0.72\ Q^{0.156} \quad . \tag{150}$$

The three subdivisions indicated for the lower group of data are based on a rather intimate knowledge of the canals investigated by Simons and Bender and to a limited extent on Indian Literature and consultation with Singe Bhala, a graduate Civil Engineering student from India currently working on an M.S. degree at the University of Wyoming.

A variety of regime type equations have been recommended to determine design slope by one individual or another. One of the most significant is the Lacey formula relating V and $R^2 S$ as follows

$$V = 16.0\ R^{2/3}\ S^{1/3} \quad . \tag{151}$$

The general validity of this expression is shown in Fig. 73 taken from reference (25). An extremely wide range of discharge is covered. Data used include the Punjab data summarized in Table 30, and other miscellaneous India canal data which are not presented or utilized elsewhere in this report. The difficulty with this expression is that, although the trend is very definite, some slopes computed by this relationship vary considerably from the measured slopes used to establish the correlation.

To serve as a further check on Fig. 73, V vs R^2S has been plotted in Fig. 74 for all the canals included in this report. These data fall in three separate groups in the plot and a line has been drawn through each group. The upper line correlates V with R^2S for the coarse non-cohesive materials represented by the U. S. Bureau of Reclamation canal data. The intermediate line does the same for canals with sand beds and slightly cohesive to cohesive banks. The third line represents sand bed conditions, at least insofar as the Simons and Bender data are concerned. The equations of these lines are:

$$V = 17.9\ (R^2S)^{0.286} \tag{152}$$

$$V = 16.0\ R^{2/3}\ S^{1/3} \tag{153}$$

and

$$V = 13.86\ (R^2S)^{1/3} \tag{154}$$

respectively. The second equation is identical with the preceding Eq 151 corresponding to the plot of Fig. 73.

The Imperial Valley canal data show that for a given value of R^2S the permissible average velocity V increases as charge increases and knowing R and V from Figs. 62 and 70 the slope consistent with stability can be estimated.

From another point of view, careful observation of the data in the sand range and finer of Fig. 74 reveals that the log-log plot does not yield a perfectly straight line. To improve this condition $V + 1$ vs R^2D has been plotted in Fig. 75. The equation of the new line for sand bed and cohesive banks is

$$V = 9.3\ (R^2S)^{0.18} - 1 \tag{155}$$

and for sand beds and banks is

$$V = 8.53\ (R^2S)^{0.18} - 1\ . \tag{156}$$

In the event that it is more desirable to work in terms of D instead of R, it should be noted that V vs D^2S also correlates fairly well, see Fig. 76. Again, two lines have been drawn, one for the coarse materials the other for the sand range and finer. The equations of these two lines have not been established because of the excess curvature and the superiority of the preceding relations.

<u>Other Regime Slope Equations</u>

Other slope equations recommended by Lacey were

$$S = 0.000383\ f^{3/2}/R^{1/2} \tag{15}$$

and later

$$S = 0.000547\ f^{5/3}/Q^{1/6} \tag{20}$$

where f is the Lacey silt factor.

In 1936 Bose and the Punjab Irrigation Research Institute staff presented the equation

$$S \times 10^3 = 2.09\ \frac{d^{0.86}}{Q^{0.21}} \tag{25}$$

where d is the mean diameter of material exposed on the bed. This expression was developed as a result of collecting data over several years and subjecting it to statistical analysis. It is very closely related to Eq 34 presented by Lacey.

It is of interest to demonstrate graphically the degree of correlation of Eqs 20 and 25. In Fig. 77, S vs $f^{5/3}/Q^{1/6}$ has been plotted for the Simons and Bender data. Note that these data again tend to divide into two groups. The steeper line is fairly well defined being based upon the canals having sand beds and dunes. The flatter line is not well defined but more or less signifies the condition when plane cohesive or plane sand beds exist. Canals 12 and 13 probably should be excluded from the plot since they are formed in coarse non-cohesive material.

The scope covered by the Fig. 77 is now expanded in Fig. 78 to include the India and the U. S. Bureau of Reclamation canal data. A study of the results verifies that for the India canals a good correlation exists, on the other hand agreement of data on an over-all basis is not particularly significant. The best fit line to the India data falls in between the two lines drawn based on the Simons and Bender canal data.

In Fig. 79 slopes and corresponding values of $d^{0.86}/Q^{0.21}$ have been plotted. In this case the 24 points based on Simons and Bender canal data scatter rather badly. A trend, however, is indicated. Canals No. 12 and No. 13 should probably be excluded or grouped with the U. S. Bureau of Reclamation canal data. The effect of the 70 India canals on Fig. 79 is illustrated in Fig. 80. The values of $d^{0.86}/Q^{0.21}$ for the 42 Punjab canals were taken from pages 60 through 64 of reference (49). They can also be computed from the basic data given in Table 30. Values of $d^{0.86}/Q^{0.21}$ for the 28 Sind canals were computed from basic data, see Table 32. These data correlate quite well passing more or less centrally through the Simons and Bender data. Values of S computed by Eq 25 agree quite well with values used to establish the relation. This is verified in Table 36 except where values of d are less than one tenth of a millimeter. In this case computed slopes are only about one half as large as they should be. This deviation may be due to effect of plasticity in the bed material, in fact these samples may be of the original material and independent of sediment load.

The foregoing may also help explain why the points given by the Simons and Bender data scattered so badly in Fig. 79. That is, several of these canals did not have the typical sand bed with dunes, in addition some had natural cohesive beds and the corresponding size of bed material was smaller than one would normally anticipate in a canal carrying a sediment load with a sand fraction.

Based on the preceding information it seems logical that a family of equations of the form

$$S = f(d\ ,\ W\ ,\ D\ ,\ V\ ,\ q_s) \tag{157}$$

could be verified for various general types of natural bank and bed material, particularly if canals possessing cohesive bed material were excluded and handled on some other basis.

<u>The Blench-King Regime Slope Formula</u>

The regime slope equation recommended by Blench for design is

$$S = \frac{b^{5/6}\ s^{1/12}}{2080r\ Q^{1/6}} \quad . \tag{38}$$

This was derived by plotting W/D against a variety of non-dimensional groups and would have been found at once, according to Blench, by plotting V^2/gDS against VW/ν . The basic regime slope formula is

$$\frac{C^2}{g} = \frac{V^2}{gDS} = C\left[\frac{VW}{\nu}\right]^{1/4} \tag{158}$$

where W is the average channel width.

In Fig. 81, values of V^2/gDS have been plotted against VW/ν . A value of ν corresponding to 70°F has been assumed for all India canals. The 42 Punjab canals yield points that plot quite close to a straight line on log-log paper between the limits of $10^5 < VW/\nu < 10^7$. Beyond this upper limit the V^2/gDS terms are nearly constant and the slope of the line flattens until it lies approximately parallel to the horizontal axis.

The 28 points corresponding to the Sind data lie more or less on an extension of the straight line portion of the Punjab data.

The Simons and Bender data give points that generally intermingle with the India canal data except that seven of the points corresponding to canals with non-cohesive banks fall lower as one would anticipate.

The significance of the basic regime slope equation presented by King and Blench is quite apparent from study of Fig. 81. The India data as a group plot close to a straight line between the limits of $10^5 < VW/\nu < (5)^8$. Beyond $WV/\nu = (5)^8$ more points fall below the straight line than above it, however, this may be a function of the canals sampled.

Other Correlations Involving Slope

Several combinations of data involving slope were tested for correlation in dimensionless and dimensional forms in accordance with and independent of dimensional analysis.

In Fig. 82, slope is correlated with the product of the Froude number and d/D using Simons and Bender data. It is observed that appreciable scatter exists but nevertheless there is a definite trend.

In Fig. 83, the scope of the above figure has been expanded to include the effect of the Punjab canals. The results of Fig. 82 are not altered appreciably. The Punjab data plot with about the same scatter and in the same region as the Simons and Bender data.

A plot of d/D vs $U_* D/\nu$ for the Simons and Bender data correlate very poorly. On the other hand, using Punjab data a much better correlation is obtained, see Fig. 84. The fact that the latter plot shows considerable improvement over the first is undoubtedly due to the fact that all of the Punjab canals have beds that are related to the sediment being transported while this is not true of the canals investigated by Simons and Bender. Using essentially the same procedure as that illustrated in Figs. 82 and 83,

$$S\left(\frac{D}{W}\right)^{1/2}$$

is plotted against

$$\frac{V}{\sqrt{gD}}\frac{d}{D}$$

in Fig. 85. The Simons and Bender data again split into two groups, one representing plane beds and great weed effect, the other representing dune beds and negligible weed effect except for canals 1, 19, 12, and 13. Considering these, Nos. 1 and 19 have nearly plane beds and are only slightly influenced by weeds. Nos. 12 and 13 have gravel beds and sides and there is no appreciable weed effect.

Other relations of a dimensional form that show significant trends, but which will not be presented because of their limited value, are

$$\frac{S}{(W)^{1/2}} \quad vs \quad \frac{V}{\sqrt{gD}} \frac{d}{D}$$

and

$$\frac{S}{W^{1/2}} \quad vs \quad \frac{V^{11/12} \; d^{0.86}}{D^{11/6} \; W^{13/12}} \quad .$$

Tractive Force Relationships

In Chapter IV various procedures used to estimate magnitude of tractive force on the bed and sides of channels were discussed. Values of shear on the channel periphery were computed for the 24 canals investigated by Simons and Bender using all of the methods described. A summary of these data is given in Table 28.

Magnitude of Tractive Force

The magnitude of boundary shear varies with method of computation. In Figs. 86, 87, and 88 some typical canal cross-sections are given including the shear distribution on their boundaries as indicated by the various methods of computation, size of side and bed material, and standard deviation of side and bed material. The data required to establish the foregoing figures were taken from Table 28. As illustrated in Figs. 86, 87 and 88, shears computed by the various methods for a given channel are by no means in close agreement. In general, shears computed by the equation

$$\tau = \gamma DS \tag{42}$$

and shears computed by use of isovels and the concept of zero momentum transfer are both larger than shears indicated by the velocity gradients measured normal to the boundary across the channel. The lack of agreement in results, and the fact that shears based on velocity gradients are smaller, leads one to believe that something is being neglected when shears are computed based on the latter method. It may be that this results because the energy required to transport the sediment load and/or the energy involved in secondary circulation are being neglected.

Another interesting observation based on shears computed from knowledge of velocity distributions is the way shears vary across the bed section of each canal. Generally, one might expect a more uniform shear distribution such as is indicated by computations based on $\tau = \gamma DS$. This variation in distribution may be intimately related to secondary circulation in the canals. It has been proposed that secondary circulation be studied in the canals investigated by Simons and Bender at some future date to provide a better knowledge of its effect on shear and shear distribution, sediment transport, and channel stability in general.

<u>Correlation of Tractive Force with Mean Diameter of Bed Material</u>

In the U. S. Bureau of Reclamation, "Progress Report on Design of Stable Channels", (35), a good relationship was developed which relates size of bed material and tractive force, see Fig. 9. This correlation provides a very useful means of establishing the design slope of channels and canals in coarse non-cohesive materials provided size of bed and bank material can be estimated with reasonable accuracy. Design procedure, taking advantage of this information, was previously outlined in detail in Chapter II.

Making use of the foregoing approach to design, values of average shear on the bed based on $\tau = \gamma DS$ and corresponding values of d have been plotted to obtain Fig. 89 using the Simons and Bender and U. S. Bureau of Reclamation data given in Tables 28 and 29. The resulting points indicate a curve that is quite steep for small mean diameters. That is, allowable tractive force does not increase at an appreciable rate with size in the range of material, $d < 0.6$ mm.

In Fig. 90 values of $\tau = \gamma RS$ have been plotted against d for the U. S. Bureau of Reclamation and the Simons and Bender data. The same type of curve results as did in Fig. 89. The spread of points relative to arbitrarily-drawn curves is similar in each case.

The values of average shear on the bed based on slope of velocity gradient, see Eq 97, are plotted against mean size of bed material in Fig. 91 for the Simons and Bender data. The U. S. Bureau of Reclamation data are also presented, but since data on velocity gradient are not available shears for this group are again based on $\tau = \gamma RS$. The spread of the Simons and Bender data relative to the arbitrarily-drawn curve is a little greater than in the preceding two figures -- indicating that they might be more reliable for design than this last figure. They also have the advantage that shears are expressed in terms of D and R respectively.

The same type of analysis can be presented modifying the tractive force based on isovels and zero momentum transfer. The results are very similar to the foregoing and hence are not presented here in figure form. Data upon which Figs. 89, 90, and 91 were based were taken from Tables 28 and 29 respectively.

By working in terms of tractive force based on D and/or R, the effect of the Punjab and Sind canal data on the foregoing relations can be shown. In Fig. 92 values of $\tau = \gamma RS$ and corresponding values of mean diameter of bed material have been plotted for all of the canals involved in this study, that is the Simons and Bender data, the U. S. Bureau of Reclamation data and the India data.

The information used to establish the plot is given in Tables 28, 29, 30, and 32. Several facts of interest are immediately apparent in Fig. 92. First a general line extending through all of the data can be drawn. There is, however, considerable scatter about this line. Next, secondary lines crossing the major trend line have been drawn based upon an intimate knowledge of the Simons and Bender data and a limited knowledge of the India data from a study of the literature and existing data. Moving in the upward direction the first of these lines is associated with canals having cohesive beds and banks, the second with canals having fine sand beds and probably berm banks or natural banks of a cohesive nature, the third with canals having coarser sand beds and berm banks or banks of slightly cohesive natural material, the fourth with canals having sand beds and banks, and the fifth with coarse non-cohesive beds and banks. Roughness of bed seems to increase traveling from the bottom secondary line to the fourth secondary line associated with sand beds and banks.

Next consider each of the five secondary lines. Moving along these lines in the direction of increasing shear, it is found that canal capacity increases. The points on the extreme right end of the secondary lines correspond to large Q values, and the points at the extreme left on these same lines correspond to small Q values. The whole system of lines shown in this figure are placed rather arbitrarily and would undoubtedly shift slightly if additional new data were incorporated into the plot.

The Imperial Valley canal data have not been plotted in Fig. 92 because of uncertainty regarding the mean size of bed material. An effort is currently being made to secure these data since it will be of importance to reflect the effect of increasing the magnitude of charge on permissible tractive force.

Considering the lowest element of the major curve, it is noted that if it were curved to the right it would fit the plotted points somewhat better. This indicates that allowable tractive force probably increases with a decrease in mean size of sediment smaller than that size where the material starts to become plastic. This aspect of the problem was investigated by a flume study at the University of Wyoming (62). The flume study verified that limiting tractive force increases with increase in plastic index. This is shown in Fig. 93. The investigation was carried out under the supervision of the writer using natural materials from canal beds investigated by Simons and Bender.

The data in Fig. 93 have been added to the data of Fig. 92 in Fig. 94. It should be noted that shears used from the flume study were computed based on slope of velocity gradient and this in part accounts for lack of agreement in values of shear obtained by the two methods. It was pointed out earlier that shears based on slope of energy gradient were in general smaller than shears computed by other methods. Another factor causing some error was that since the flume was small it is questionable whether or not two-dimensional flow existed.

Channel Shape

Considering the canals investigated by Simons and Bender it was observed that channel shapes varied widely. It was also apparent that shape was appreciably effected by the type of natural bank material and the amount and type of bank vegetation. Most of these canals, excluding those found in sand, had sides that were very steep near the water surface (this was possible because of the reinforcement provided by the plant roots) and that were asymptotic to the channel bed.

The shape of these 24 canals, with some exceptions, conform reasonably well to the theoretical regime channel shapes as described by King Yu (70) and Glover (24).

It was pointed out in Chapter II that Lane (32) and others have investigated the possibility of designing channels to such shape and dimensions that the entire wetted perimeter is in a state of incipient motion. None of the canals investigated have adjusted to the foregoing shape implying that it is perhaps necessary to construct to this form initially if it is desired. It seems that this aspect of design is worthy of a more thorough investigation.

Transition Function

The transition function as described by Albertson (1) illustrates the transition from smooth to rough boundaries in wide, alluvial channels. This is a modification of the Nikuradse function prepared for pipes in terms of sand roughness.

In Fig. 95 the points corresponding to all canals excluding the Imperial Valley canals have been superimposed on the transition function plot presented by Albertson. The majority of points from the Punjab canals, the Sind canals, and the canals investigated by Simons and Bender fall in a large cluster near the upper portion of the figure. The U. S. Bureau of Reclamation data fall near the horizontal uniform roughness line and points representing canal Nos. 12 and 13 fall intermediate to the foregoing two groups of data in such a way that a straight line can be drawn through all the three groups of points.

A third variable, mean size of bed material, has been introduced and it is noteworthy that these values of d increase rather uniformly from left to right along the straight line.

The above data fail to conform to the limiting curves of the Albertson and Ali transition function (2), also superposed on Fig. 95, nevertheless the plot may prove to be very useful in the analysis of various design situations. Estimating values involved in the correlated parameters by means of the preceding relationship between Q, V, R, D, W, --, a value of S can be estimated by trial and error from Fig. 95. The major limitations of the method are:

1. A rather loose correlation between variables exist limiting the accuracy of the estimate.

2. The procedure that must be followed to determine the numerical value of S is rather cumbersome.

Modified Einstein Theory

According to the basic theory of sediment transport in open channels as proposed by Einstein (16) and reported by the Sedimentation Section of the Hydrology Branch of the U. S. Bureau of Reclamation (67)

$$\sqrt{RS} = \frac{V}{32.63 \ \mathrm{Log}_{10} \dfrac{12.27 \ x \ D}{K_S}} \qquad (159)$$

where S = slope of energy gradient,

R = hydraulic radius,

x = corrective parameter for the transition smooth to rough,

D = mean depth of cross-section modified to mean depth on the bed in this report,

K_S = the roughness of the bed assumed equal to mean diameter of bed material in this report,

V = average velocity.

The value of x is evaluated by means of Fig. 96 taken from reference (16). In this figure

$$\delta = \frac{11.6 \ \nu}{U^*}$$

where δ = thickness of the laminar sublayer,

ν = kinematic viscosity,

U^* = shear velocity.

In Fig. 97, $(RS)^{1/2}$ has been plotted against

$$\frac{V}{32.63 \operatorname{Log}_{10} \frac{12.27 \times D}{d}} .$$

All groups of canal data have been utilized excluding the Imperial Valley canal data.

A good correlation results. Two lines have been drawn, one representative of canals in sand material and finer, the other holds coarse non-cohesive material. Note that as one would anticipate the latter line connects the points corresponding to the Simons and Bender data for canals 12 and 13 with the points representing the U. S. Bureau of Reclamation data. Although this function is of rather complex form it shows considerable potential as a means of evaluating design slope.

Channel Roughness

Several different coefficients have been proposed to serve as an index of channel resistance. Some of the more important ones are

f = resistance coefficient

n = Manning coefficient

n_a = Lacey coefficient

$C/\sqrt{g}$ = Chezy coefficient in dimensionless form.

These coefficients are interrelated to one another, the latter being the one most commonly used currently.

In terms of uniform channels of non-circular cross-section

$$h_f = f \frac{L}{4R} \frac{V^2}{2g} \tag{160}$$

and solving for V

$$V = \sqrt{\frac{8g}{f}} \sqrt{RS} \tag{161}$$

or

$$V = C \sqrt{RS} \tag{162}$$

and

$$C = \sqrt{\frac{8g}{f}} \tag{163}$$

or

$$\frac{C}{\sqrt{g}} = \sqrt{\frac{8}{f}} \ . \tag{164}$$

The Chezy C is related to the Manning n by writing the Manning equation in the form

$$V = \frac{1.49\ R^{1/6}}{n} \sqrt{RS} \tag{165}$$

or

$$C = \frac{1.49\ R^{1/6}}{n} \ . \tag{166}$$

The Lacey roughness coefficient is also related to the Chezy C. The Lacey equation

$$V = \frac{1.346}{n_a} R^{3/4}\ S^{1/2} \tag{167}$$

can be written as

$$V = \frac{1.346\ R^{1/4}}{n_a} \sqrt{RS}$$

and

$$C = \frac{1.346\ R^{1/4}}{n_a} \ . \tag{168}$$

The values of n have been plotted against dune height in Fig. 98, and weed effect has been introduced as a third variable considering Simons and

Bender data only. A dune heighth of zero corresponds to a plane bed such as was observed in canal Nos. 4, 5, 20, and 21. The effect of weeds on n is at best only roughly indicated.

In Fig. 99, Manning's n has been correlated with size of bed material and bed condition. Three lines have been drawn, one for canals with pronounced dunes, one for canals with ripples and small dunes, and one for plane beds. Data do not conform completely to these lines but the trend is readily apparent.

In reference (4) it has been pointed out that

$$\frac{C}{\sqrt{g}} = \frac{V}{U_*} = f\ (R_e\ ,\ \text{relative roughness},\ \ R_i)$$

where R_e = Reynolds number

R_i = Richardsons number = $\dfrac{V_s\ c}{U_*\ S}$

V_s = fall velocity of median sediment size

c = concentration of sediment by dry weight in per cent of sample weight.

In Table 35 additional values of $C/\sqrt{g}$ and Ri are given. The values listed under the heading "Cody Report" are based on field data taken on the Niobrara River by the U. S. Geological Survey and presented in the foregoing report. The values given under the heading "Colorado State University Data" were obtained directly from reference (2) These three groups of data were used to prepare Fig. 100. In this figure the canals and rivers group in accordance with bed condition, those having plane beds fall in the upper group, and those with rough beds in the lower group.

The new data, particularly the Niobrara River data, were incorporated and used because the channel involved carried a larger sediment load than the canals investigated by Simons and Bender and it was anticipated that they might help develop a clearer insight to sediment effect on stability. Actually, little was gained in this respect but it can be concluded from the figure that magnitude of sediment load has little or no effect on the magnitude of roughness from this approach.

Chapter VIII

DESIGN PROCEDURES

Discussion of Correlations Presented in the Preceding Chapter

Keeping the primary objective in mind, which is design of stable channels, some of the correlations presented in the preceding chapter may seem superfluous. On the other hand situations may arise where they will be of value both in the design field and in guiding related phases of future research.

Scope of Recommended Design Procedures

The relationships of the previous chapter, regardless of their limitations, allow considerable latitude in design procedure. The objective of this chapter is to discuss these procedures and to point out their respective limitations and advantages.

In most cases, because of the general scatter of data, the complexity of the relations, and the time involved, curves have been fitted to the data visually. Where the scatter of the points about the trend line is not excessive, equations describing the relations have been determined.

Selecting W/D or P/R Ratios

It is apparent, based on existing literature and the correlations of the preceding chapter, that W/D and/or P/R can only be arbitrarily selected when sediment load is negligible and resultant shears exerted on the sides and bed are not sufficient to erode them. In effect then the designer can only impose his will on shape as long as he conforms to the preceding limitations. This approach is simply that recommended by Lane (35).

When dealing with fine non-cohesive materials, the foregoing procedure would involve using a very flat gradient which requires a large cross-section and/or a wide shallow channel to control magnitude of shear on the banks.

The problem is much more complex when sediment transport is involved. The channel must now be stable considering both the stability of the material forming its periphery and its ability to transport the sediment charge without deposition.

In nature if a canal or channel is designed properly, constructed, and then subjected to the action of the proposed flow, no adjustment of W , D , and S will occur. Conversely a channel improperly designed will adjust its form to achieve stability. The figures of Chapter VII, see Appendix A, are based on data taken in stable canals. Stability in these canals, excluding the U. S. Bureau of Reclamation group is probably a function of sediment transport to a minor extent in the canals investigated by Simons and Bender, and at least to a moderate extent in the Punjab and Sind canals.

Estimating W Knowing P or Visa Versa

Wetted perimeter and top width are closely related as illustrated in Fig. 46. Based on this relation either P or W can be estimated for stable canals provided one or the other is known. The wetted perimeter P would undoubtedly correlate equally well with top width. The wetted perimeter estimated in this manner should be more representative of true conditions than if it were computed based on some initial trapezoidal shape.

Estimating D When R is Known or Visa Versa

Corresponding values of D and R are closely related to one another in stable canals as illustrated in Fig. 54. In this case D is the average bed depth. A similar correlation could be established relating average depth to hydraulic radius or average depth could be correlated directly with bed depth. The primary use of this relation thus far has been to extend the scope of the India data. However, knowledge of D in terms of R or visa versa is of value in design as will be illustrated later.

Estimating W/D or P/R for Design

Figs. 47, 48, and 49 are probably best suited for tentatively estimating W/D ratios.

In Fig. 53 some estimate of effect of sediment load on shape is indicated. In Fig. 49 W/D can be determined independently in terms of discharge capacity and type of bank material.

As another possibility, Fig. 51 relates P/R and Q . This is probably not as fundamental an approach as the foregoing ones. However, magnitude of P/R is indicated with considerable certainty within the limits of the data. In order to express P/R in terms of W/D , refer to Fig. 52. The values of W/D thus obtained are definitely only approximate and should be considered further after W and D and/or P and R have been evaluated individually.

Selection of P and/or W

In Fig. 57, P , Q , and type and condition of bed and bank material have been related. The four parallel curves presented are representative of:

1. Sand beds and banks.

2. Sand beds and slightly cohesive to cohesive banks.

3. Cohesive beds and banks.

4. Coarse non-cohesive beds and banks.

Although data for canals having sand banks are limited, Curve 1 provides a means of estimating P for this condition except possibly in the very small, and also in the very large, ranges of Q . Curve 2 is valid for the complete range of Q covered by the basic data and has been described mathematically by Eq 139.

Curve 3 is based on very limited data and should be employed with this fact in mind.

Curve 4 is recommended as a means of estimating the magnitude of P in the coarse non-cohesive range of bed and bank materials.

At this point, knowing the wetted perimeter, the average stable channel width could be determined from Fig. 46.

A procedure paralleling the foregoing, but involving average width instead of wetted perimeter, can be employed. In this case use of the three curves presented in Fig. 59 is recommended. Note that the curve representative of cohesive beds and banks coincides with the one covering the coarse non-cohesive range of bed and bank materials.

With regard to preference of above methods, one approach is about as desirable as the other. Generally it might be more convenient to work directly in terms of W . On the other hand values of W used in the basic correlation were estimated from P using Fig. 46 for the Punjab canals. This constitutes something of a restriction but it appears to be of negligible significance. The net result as far as accuracy is concerned is about the same in either case.

Selection of D and/or R

Values of D and R for stable canals are closely related as has been shown, see Fig. 45. The values of both D and R correlate well with discharge and type of bank material much as P and W did in the preceding paragraph.

Referring to the relationships between discharge and bed depth, Fig. 61, values of D corresponding to Q can be obtained directly from the appropriate curve or may be computed by equation if, in the sand bed-cohesive bank or coarse non-cohesive range of materials. From the preceding chapter these equations are:

$$D = 0.685\ Q^{0.314} \tag{141}$$

for sand beds and cohesive banks, and

$$D = 0.408\ Q^{0.314} \tag{142}$$

for coarse non-cohesive materials.

Equations were not developed for the other two curves because these trends are based on rather limited information.

Rate of discharge could be correlated with average depth if the need developed. However, the writer feels that bed depth is a more meaningful measure for design purposes.

The hydraulic radius R is related to Q and soil type in the same way that D is. That is, relationships for the foregoing four classes of materials in terms of R are given in Fig. 62. The use of this approach is essentially equivalent to working in terms of D from all view points, and since R and D are related in Fig. 45 determination of D fixes R, or conversely determination of R fixes D.

The only advantage of determining both R and D by the preceding relations is that these values could both be referred back to Fig. 45 to see if they give a point on the R versus D curve. This would constitute a double check on the above values and if a discrepancy occurred an adjustment could be made.

Checking W/D Against the W/D Ratio Indicated by Independent Values of W and D

Methods of estimating an initial value of W/D were discussed. In these cases the W used was top width and D was bed depth. The magnitude of this estimated ratio should now be compared with the W/D ratio indicated by independent values of W and D determined from the relationships involving D and W with Q and type of material, see Figs. 59 and 61. It is important to recall that W in the latter case is average width and hence it is necessary to convert from average width to top width before the equivalent W/D can be evaluated for comparison. This conversion can be accomplished by Fig. 60 which relates these variables.

In general the W/D ratio based on individual values of W and D is the more meaningful of the two because of superior correlation in the relations yielding these values. It is important to keep in mind, however, that W/D is related to suspended sediment load and from this viewpoint the original relations yielding W/D directly should not be overlooked.

Computing W and D Based on the Blench Regime Equations

It was pointed out in Chapter IV that the accuracy with which W and D can be determined using the Blench regime equations is solely a function of how accurately the bed and side factor can be determined.

It appears that b and s can be evaluated rather accurately for design of canals that are to be part of an existing system. In other cases the determination of b and s is largely dependent on experience and independent rules of thumb. These facts tend to complicate the issue. The possibility of establishing accurate independent equations for b and s was investigated. The results of the investigation, Figs. 64 through 69, inclusive show that to date no precise reliable method of evaluating b and s exists. Because of this the writer feels that currently the regime equations are not superior to the preceding methods, and will not become so until it is possible to evaluate the bed and side factors more accurately.

Selection of A Based on Q and Soil Type

As a partial alternative to the foregoing it may be expedient to determine A based on Q and soil type. Knowing A and the value of W from Fig. 59 the bed depth could be selected, or knowing A and the value of D based on Fig. 61 the average width could be determined. The value of A can be determined from the curves of Fig. 70 knowing Q and soil type or it can be solved directly if Eqs 146 or 147 (which depend on soil type) apply. As before, because of limited data, no equation was written for canals with both sand beds and sand banks.

The area required to transport a given discharge is maximum for sand banks and beds, somewhat less for slightly cohesive to cohesive banks inclusive and a minimum for coarse non-cohesive banks and beds. The explanation of the preceding is primarily a difference in stability of the different bank materials.

Determination of Design Slope

The value of average velocity can be estimated from Fig. 72 based on a knowledge of Q and soil type or it can be determined from values of Q and A , the magnitude of the area being determined as indicated in the preceding paragraph. Having evaluated V by one means or the other, knowing the value of D from Fig. 61, convert it to equivalent R by means of Fig. 45 or evaluate R directly from Fig. 62. Knowing V and R it is possible to evaluate slope by referring to Fig. 74 which correlates V and R^2S

The foregoing process is made more direct by evaluating S from the equations relating V , R , S , and soil type presented in the preceding chapter. That is, for coarse non-cohesive materials.

$$V = 17.9\ (R^2S)^{0.286} \tag{152}$$

and for canals with sand beds and cohesive banks

$$V = 16.0\ (R^2S)^{1/3} \tag{153}$$

Eq 153 is the same as Eq 151 suggested by Lacey. For canals with sand beds and banks

$$V = 13.86\ (R^2S)^{1/3} \tag{154}$$

Using the same procedure, Fig. 75 provides another means of estimating S . The advantage of this figure is that the data plot more nearly on a straight line. Two curves are given, Eqs 155 and 156 which express the two relationships mathematically. These equations cover a wide range of design conditions. Values of Q between the limits of 5 and 9000 cfs are represented as well as soil conditions ranging from fine cohesive to and including coarse non-cohesive materials.

The limitations of the method are of course obvious. Points scatter appreciably about the major trend lines indicating that slopes computed from these relationships might vary appreciably from actual slopes used to establish the plot. The relation is also limited by the fact that it in no way considers variation in charge although the sediment load carried by the canals used to establish the relation varied rather widely indicating that, at least within the range of concentrations considered sediment, transport did not play a major role.

The above procedure would also apply if Fig. 76 were used. However, because of a less significant relation between parameters, the method is not recommended.

<u>Slope Determined by the Correlation of S and $f^{5/3}/Q^{1/6}$</u>

A study of Fig. 78 relating S and $f^{5/3}/Q^{1/6}$ indicates that slopes for canals having sand beds that are a function of the sediment load being transported can be estimated from such a relationship. The way the Punjab and Sind canal data plot verifies this. On the other hand, considering the rather wide scatter exhibited by the Simons and Bender data the correlation has its limitations.

To estimate slope, evaluate V and R occuring in the expression $f = {}^{3/4}\, V^2/R$ using Figs. 62 and 70. Knowing Q and f, compute the parameter $f^{5/3}/Q^{1/6}$ and enter the figure to estimate the slope.

<u>Slope Determined by the Correlation of S and $d^{0.86}/Q^{0.21}$</u>

Fig. 80 shows that good correlation exists for the India data where bed material is a function of sediment transport. The scatter is rather extreme for the Simons and Bender data in the several cases where bed condition was not a function of the sediment being transported. When applying the results of this figure to design problems, the designer should bear this fact in mind.

Application of this correlation requires knowledge of the magnitude of Q and a means of estimating mean diameter of future bed material. The latter can be estimated in most cases by studying river conditions and the natural bank and bed material. However, more precise methods of predicting d are needed.

Slope Determination by the Blench-King Slope Formula

The Blench-King slope formula when applied in dimensionless form to the Simons and Bender and the India canal data yielded Fig. 81. The correlation is quite significant for values of $\frac{VW}{\nu} = R_e < 8,000,000$ particularly for the India data. Beyond this point it seems logical to use some other method, such as illustrated in Fig. 75, or possibly one of the following methods -- since even the India data scatter badly when $R_e > 2x10^7$.

To evaluate slope estimate W, D, and V using such Figs. as 59, 61, and 70. Next compute the parameter VW/ν using an appropriate value for the viscosity. Then enter Fig. 81 and obtain a value for V^2/gDS. Knowing V and D, the slope can be determined.

Determination of S by the Tractive Force Method

The basic method of determining slope using the tractive concept was outlined in Chapter VII. In this case shape was imposed and slope selected so that stable conditions existed in the canal. This method is only valid for clear water conditions. In the case of sediment transport a lower limit on slope must be established such that harmful deposition will not occur.

The scope of the original d vs. τ relation proposed in reference (35) has been broadened to include conditions encountered in the canals investigated by Simons and Bender and the India canals, see Fig. 92. Using this family of curves an estimate of S can be made by first estimating mean size of bed material, hydraulic radius, type of bank conditions that will result, and by knowing Q.

The major limitations of this method are lack of knowledge of size of bed material and the scatter occuring in the plot -- which is of course related to the accuracy with which slope can be estimated.

Slope Determined in Accordance With the Transition Function

A plot of the transition function for smooth to rough boundaries as it applies to wide alluvial canals in terms of the basic canal data is given in Fig. 95. The function is rather complex making it more difficult to work with than preceding methods. In this case $C/\sqrt{g}$ can be expressed in terms of D and S and the values of D, W, V, and R can be estimated as previously described. A slope can be assumed and then both ordinate and abscissa values can be evaluated. If they indicate a point on the figure consistent with expected mean diameter of the material the selected slope was correct otherwise revision of S and calculation must be repeated until the preceding condition is satisfied. The slope yielding this condition is theoretically the correct design slope.

This method is not recommended at present because of the appreciable scatter occuring in the plot -- indicating that S thus selected might be in considerable error.

Slope Based on the Modified Einstein Equation

A plot of the basic canal data in terms of the modified Einstein equation is given in Fig. 97. Two major lines have been drawn, one for canals in sand size material and smaller and the other for coarse non-cohesive material. This is the only plot involving slope, with the exception of V vs. R^2S, that is consistently good over the complete range of conditions. Solving for slope involved the following:

1. A value of X must be estimated based on Fig. 96. Considerable error in X does not effect materially the net result since X occurs in a log function.

2. The magnitudes of average velocity based on Figs. 70 and 75 and bed depth based on Fig. 61 must be estimated.

3. The anticipated mean diameter of bed material must be approximated.

4. Knowing the preceding values the magnitude of
$$\frac{V}{32.63 \text{ Log } 12.27 \frac{X\,D}{d}}$$
can be computed and the corresponding value of $(RS)^{1/2}$ can be taken from the Fig.

5. Estimating the magnitude of R from Fig. 62, or using the D value already established and converting to R, the value of S can be computed.

6. As a check evaluate X and if necessary repeat the preceding procedure until the assumed X equals the computed X.

The major limitations of this procedure are the accuracy, or lack thereof, with which one can estimate d, D, R, and V, and the complexity of the computational process.

Correlation of Richardsons Number and $C/\sqrt{g}$

As discussed in Chapter VII the Richardsons number has been computed for the Simons and Bender data and two reaches in the Niobrara River. These values of R_i and corresponding values of $C/\sqrt{g}$ were employed along with additional data from reference (4) to construct Fig. 100.

A study of this figure shows that $C/\sqrt{g}$ and hence S, within the range of the canal data, when plotted against R_i is fairly constant having a value on the order of 10 for canals with dune beds. In the same manner $C/\sqrt{g}$ is fairly constant for canals with plane beds having a value on the order of 16.0.

One might conclude from the foregoing that design slope within certain limits of R_i for a given type of bed roughness tends to be independent of sediment effect as represented by the Richardson number which is not reasonable. Certainly this plot will not yield slope with sufficient accuracy for design purposes. However, it may be useful for situation analysis.

Summary

I. A summary of the range of the more important variables follows:

Q varies from 5 to 9000 cfs
Slope varies from 0.000058 to 0.000388
Average width varies from 2 ft to 264 ft
Depth varies from 2.8 ft to 10.5 ft
Sediment concentration varies from 50 ppm to 500 ppm excluding four canals which have concentrations ranging from 2500 to 8000 ppm

In conclusion it may be stated that within the limits of the canal data presented:

1. Both P and W can be estimated with fair accuracy by using Figs. 57 and 59 and/or the corresponding equations.

2. Both D and R can be estimated with fair accuracy by means of Figs. 61 and 62 and/or the corresponding equations.

3. A reasonable estimate of design slope can be obtained by using one or more of the following:

    a. Figs. 74 or 75 correlating V and R^2S.

    b. Fig. 81 representing the Blench-King regime equation in dimensionless form.

c. Fig. 80 relating slope, mean diameter of bed material, type of bank material, and discharge.

d. Fig. 97 based on the modified Einstein equation.

The relative merits of the respective methods available to help estimate design slope can be comprehended and appreciated fully by referring to the following chapter where actual design problems are considered.

Chapter IX

APPLICATION TO DESIGN

In the preceding chapter possible design procedures were outlined. As a means of further explaining and clarifying these suggested methods, four canals will be designed.

Considering these four canals, assume that all have the same capacity but that each is to be constructed in a different type of natural material as indicated.

Q = 500.0 cfs

Soil Types

(1) Coarse non-cohesive material

(2) Sandy material

(3) Cohesive banks and sand bed

(4) Cohesive banks and beds

The specific sediment load to be carried is not given but it is assumed since the preceding quantitative correlations have been developed for canals carrying a suspended sediment load that the relations are valid for sediment concentrations ranging from a negligible quantity up to 500 ppm and possibly more, depending on whether or not wash load concentrations are negligible or appreciable. That is, considering the Sind canals utilized in this study, concentrations are on the order of 1000 to 3000 ppm for at least limited time periods and yet they grouped rather well geometrically with the other canal data where concentrations are generally much smaller.

Design (1)

Given:

a. Q = 500 cfs

b. Coarse non-cohesive bed and bank material having a mean diameter of one inch.

c. Sediment load 100 to 500 ppm

Determine:

a. Mean width

b. Bed depth

c. Slope

Solution:

Referring to Fig. 70, the required area of water cross-section can be determined either graphically or by Eq 147. Using the equation,

$$A = 0.45\ Q^{0.873}$$

$$A = 0.45\ (500)^{0.873} = A = 102.5\ ft^2\ .$$

The average velocity based on continuity is

$$V = \frac{Q}{A} = \frac{500}{102.5} = 4.87\ ft/sec\ .$$

Referring to Fig. 62,

$$R = 0.247\ Q^{0.361}$$

so that

$$R = 0.247\ (500)^{0.361} = 2.32\ ft.$$

Then by definition

$$P = \frac{A}{R} = \frac{102.5}{2.32} = 44.2\ ft\ .$$

From Fig. 61, the bed depth D can be estimated as follows:

$$D = 0.408\ Q^{0.314}$$

or

$$D = 0.408\ (500)^{0.314} = \underline{2.88}\ \text{ft}$$

Using the definition that

$$WD = A$$

Average width is

$$W = \frac{A}{D} = \frac{102.5}{2.88} = \underline{35.6}\ \text{ft}$$

In Fig. 10, the angle of repose of coarse non-cohesive material having a mean diameter of 1 in. is approximately equal to 39 degrees. This should be reduced about 5 degrees to compensate for the action of the flowing water. Based on these values it appears that side slope of 34 degrees (side slope of about 1.5:1) is reasonable. The geometry of the cross-section has now been evaluated and its shape and dimensions are shown in Fig. 101.

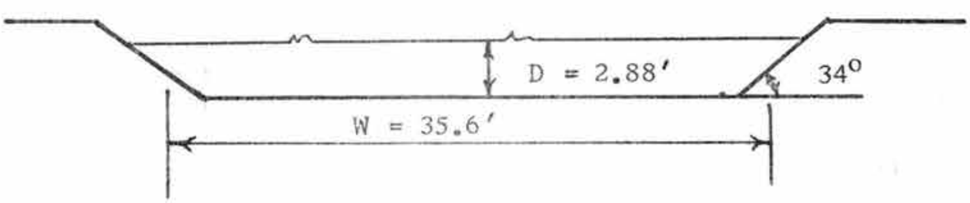


Fig. 101 Channel Shape, Design I

Considering the various correlations presented involving slope, it appears that those of the type prescribed by Lane, see Fig. 9, and the relationship of Fig. 74 are superior. Using the latter of the two

$$V = 17.9\ (R^2S)^{0.286}$$

or

$$S = \frac{1}{R^2}\left[\frac{V}{17.9}\right]^{\frac{1}{0.286}}$$

$$= \frac{1}{(2.32)^2}\left[\frac{4.87}{17.9}\right]^{3.50} = \underline{0.00195}$$

If the Lane theory is used the question arises: What is the mean diameter of the material on the bed after it has been subjected to the transporting and sorting action of the water? It is apparent that the mean size of exposed material will be increased. Consequently, using a mean diameter equal to that of the natural material introduces error on the safe side. To illustrate, based on Fig. 74, for a mean diameter of bed material equal to that of the natural material, 1 in., the value of γDS is 0.22 and

$$S = \frac{0.22}{\gamma D} = \frac{0.22}{(62.4)(2.88)} = \underline{0.00123}$$

Design No. 2:

Given:

a. Q = 500.0 cfs

b. Sandy bank and bed material

c. Sediment load 100 to 500 ppm

Determine:

a. Mean width

b. Bed depth

c. Slope

Solution:

As before referring to Fig. 70, the required area of water cross-section can be determined. In this case graphically

$A = 290.0$ sq ft .

The average velocity based on continuity is

$$V = \frac{500}{290.0} = \underline{1.75 \text{ ft/sec}} \quad .$$

Referring to Fig. 62,

$R = 3.40$ ft .

Using the relationship $R = A/_P$

$$P = \frac{A}{R} = \frac{290.0}{3.40} = \underline{85.3 \text{ ft}} \quad .$$

From Fig. 61, the value of bed depth can be estimated, that is,

$D = \underline{3.90 \text{ ft}}$.

Using the expression, $A = WD$, the average width is

$$W = \frac{A}{D} = \frac{290.0}{3.90} = \underline{74.4 \text{ ft}} \quad .$$

This width can also be verified by referring to Fig. 59. The desirable side slope of the channel should be slightly flatter than the angle of repose indicated by Fig. 10. Considering the sand range this should be on the order of 27 degrees -- that is, 32 - 5 = 27 degrees (a 2:1 side slope). As the channel ages it is anticipated that the sides will fill in near the bed and vegetation will stabilize the top portion of the bank such that it is nearly vertical giving a final shape that is elliptical or perhaps parabolic. The initial stable section is indicated in Fig. 102.

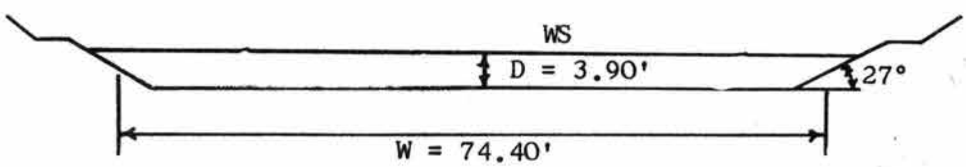


Fig. 102 Channel Shape, Design II

The design slope can be estimated by various relations given in Appendix A. The problem is to determine the most reliable correlation for the problem at hand. If one favors a relationship that is independent of size of bed sediment, Fig. 75 probably serves as good a means as any method presented. That is, for sand bed and banks

$$V = 8.53\ (R^2S)^{0.18} - 1$$

substituting

$$1.75 + 1 = 8.53\ (3.40)^2\ (S)^{0.18}$$

and solving for S

$$S = 0.000162\ .$$

A second possibility involves use of Fig. 81. In this case assuming an average water temperature during the period of operation of 70°F.

$$\frac{VW}{\nu} = \frac{(1.75)(74.4)}{1.059}\ (10)^5 = 1.23 \times 10^7$$

and

$$\frac{V^2}{gDS} = 136.0$$

then

$$\frac{1.75^{-2}}{(32.2)(3.9)(S)} = 136$$

and

$$S = \underline{0.000185}\ .$$

These two values of slope are reasonably close to one another. It should be emphasized, however, that none of the canals studied by Simons and Bender with sand beds and banks had capacities of 500 cfs, hence these results are based on extrapolated values. It is also the writer's opinion that the magnitude of S is a function of type of bed configuration. If conditions were favorable toward development of an extremely rough bed, it may be that this value of S should be increased.

Design No. 3

Given:

a. $Q = 500.0$ cfs

b. Sand bed and cohesive banks

c. Sediment load 100 to 500 ppm

Determine:

a. Mean width

b. Bed depth

c. Slope

Solution:

Based on Fig. 70

$$A = 1.076\ Q^{0.873}$$

or

$$A = 1.076\ (500)^{0.873} = 245.0 \text{ sq ft} .$$

The average velocity based on continuity is

$$V = \frac{Q}{A} = \frac{500}{245} = 2.04 \text{ ft/sec} .$$

Referring to Fig. 62

$$R = 0.43\ Q^{0.361}$$

and

$$R = 0.43\ (500)^{0.361} = 4.05\ .$$

Using the relationship $R = \frac{A}{P}$

$$P = \frac{A}{R} = \frac{245.0}{4.05} = 60.50\ .$$

From Fig. 61, bed depth is

$$D = 0.685\ Q^{0.314}$$

or

$$D = 0.685\ (500)^{0.314} = \underline{4.82}\ \text{ft}\ .$$

Using the expression $A = WD$

$$W = \frac{245}{4.82} = \underline{50.9}\ \text{ft}\ .$$

This value for W can be verified directly by referring to Fig. 59. The stable side slope of slightly cohesive to cohesive material is on the order of 40 degrees. Reducing this slightly to compensate for reduced stability due to wave action, seepage forces, and effect of the flowing water a slope of about 35 degrees (about 1.4:1 side slope) is recommended.

Based on the above computations the shape of initial water cross-section is shown in Fig. 103.

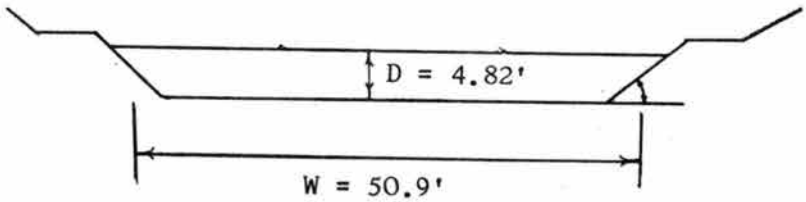


Fig. 103 Channel Shape, Design III

If it was deemed desirable to estimate top width this can be obtained by referring to Fig. 60. That is,

$$W_T = 59.0 \text{ ft} \quad .$$

To estimate slope Fig. 75 will be used and the results checked by means of Fig. 81. It is also noteworthy that if mean diameter of bed material can be established accurately based on existing conditions, such as sediment load and data taken from similar existing canals, the relationship indicated in Fig. 80 (based on Punjab and Sind data) or Eq 25 should give excellent results. From Fig. 75

$$V = 9.3\ (R^2S)^{0.18} - 1$$

from which

$$R^2S = .00183$$

and

$$S = \frac{0.00183}{(4.05)^2} = \underline{0.000112} \quad .$$

Assuming an average temperature of water equal to 70°F.

$$\frac{VW}{\nu} = \frac{(2.04)(50.9)}{1.059} \times 10^5 = 9.81 \times 10^6 \quad .$$

Utilizing the above value in Fig. 81

$$\frac{V^2}{gDS} = 200.0$$

and

$$S = \frac{2.04}{(32.2)(4.82)(200)} = 0.000134$$

As before reasonable agreement exists between the two computed values.

Design No. 4

Given:

a. $Q = 500.0$ cfs

b. Cohesive bank and bed material

c. Sediment load 100 to 500 ppm (no deposition on bed).

Determine:

a. Mean width

b. Bed depth

c. Slope

Referring to Fig. 70 the required area of water cross-section can again be estimated by the equation

$$A = 1.076\ Q^{0.873}$$

or directly from the graph, that is

$$A = 1.076\ (500)^{0.873}$$

or

$$A = 245.0 \text{ sq ft} .$$

Both the method involved and the magnitude of A correspond to that of the preceding example. This situation exists because canals having cohesive beds and banks fall on the same curve as those canals having sand beds and cohesive banks. Note in particular the location of the points 4, 5, 20, and 21 in the relation. These points represents canals having cohesive banks and beds.

The average velocity is also the same as that established in the above example.

$$V = \frac{Q}{A} = \frac{500}{245} = 2.04 \text{ ft/sec} .$$

Referring to Fig. 62, the value of R corresponding to the prescribed conditions is

$$R = 4.70 \text{ ft} .$$

Then

$$P = \frac{A}{R} = \frac{245.0}{4.70} = 52.1 \text{ ft} .$$

From Fig. 61, referring to the line representing cohesive banks and beds

$$D = \underline{6.70} \text{ ft} .$$

Using the relation

$$A = WD$$

$$W = \frac{A}{D} = \frac{245.0}{6.70} = \underline{36.6} \text{ ft} .$$

The estimated top width based on Fig. 60 and the preceding value of W is

$$W_T = \frac{W + 2.0}{0.92}$$

or

$$W_T = 42.0 \text{ ft} .$$

Based on observation, and the theory of channel shapes (70) canals constructed in this type of material can be given side slopes of as much as 1:1 if the level of the water in the canal is held fairly constant. The shape of the required cross-section is shown in Fig. 104.

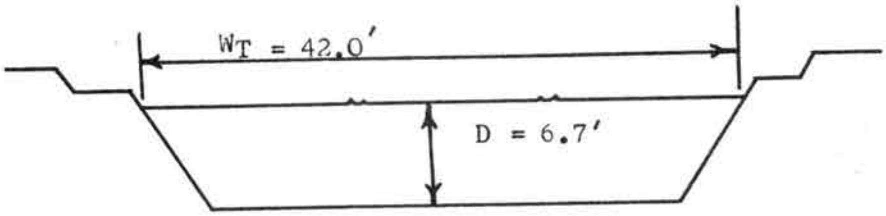


Fig. 104 Channel Shape, Design IV

To determine slope refer to Fig. 81. Assuming a value of corresponding to T = 70° F.

$$\frac{VW}{\nu} = \frac{(2.04)(36.6)}{1.059} \times 10^5 = 7.06 \times 10^6$$

and

$$C^2/g = \frac{V^2}{gDS} = 303.0$$

or

$$S = \frac{(2.04)^2}{(32.2)(6.7)(303.)} = \underline{0.0000636}.$$

This design corresponds closely to conditions found in canals 4 and 5. A comparison of the above computed slope with the measured slope in the two similar canals indicated general agreement.

Only a limited number of the relations developed and presented have been applied to determine solutions to the foregoing design problems. Those utilized, however, yield results that are as good as or superior to those given by the majority of the unused relations for these problems. It should not be assumed on the basis of the foregoing, however, that the unused relations are unimportant. Considering other problems it may be that better results can be obtained by using different combinations of the relationships of Appendix A.

The importance of charge on the stability of channels should be re-emphasized. Using the relations based on the Imperial Valley canals as shown by the arbitrary trend lines of Figs. 45, 46, 57, 62, 70, and 74 considerable insight as to the effect of increasing charge is gained. Even though these trends are based on very limited data they are extremely important. For example, assuming a discharge of 1000 cfs, a sand bed, and cohesive banks the qualitative effect of a sediment load of magnitude on the order of 5000 ppm as compared to the effect of a sediment load ranging from 0 - 500 ppm is to reduce average width W by 28 per cent, reduce the depth by 23 per cent, increase the velocity by 86 per cent, and increase the slope by 84 per cent.

Chapter X

SUMMARY AND CONCLUSIONS

Two basically different theories are currently recognized because of their superiority over other available existing methods used to approximate the design of stable channels. These concepts are:

1. The Regime Theory of India as developed by Kennedy, Lindley, Lacey, Bose, Blench, and others and,

2. The Limiting Tractive Force Theory as proposed by Lane and others.

In accordance with the objectives of the proposed research, see Chapter I, the validity of the regime theory, the validity of the limiting tractive force theory, and the interrelationship between these two methods of design have been investigated and both theories have been expanded to a certain extent.

An investigation of the regime theory verifies that the regime equations of India are only valid for the limited range of conditions upon which they are based as follows:

1. Channels having sand beds, and slightly cohesive to cohesive banks, the banks of which are usually formed by the berming action of the suspended sediment.

2. Channels that are not required to carry a heavy charge of sediment for sustained periods of time. That is, the canals yielding the data upon which the India regime theory is based have their magnitude of charge controlled by sediment exclusion and/or ejection structures so that it is generally less than 500 ppm.

The range of conditions to which this theory applies has been expanded as a result of this study so that canals in each of the following groups can be designed by this method.

1. Canals formed in coarse non-cohesive material of the type studied by the U. S. Bureau of Reclamation(35) (charge $<$ 500 ppm)

2. Canals formed in sandy material with sand beds and banks (charge $<$ 500 ppm)

3. Canals possessing sand beds and slightly cohesive to cohesive banks (Good results when charge $\leq$ 500 ppm, qualitative results when charge $>$ 500 ppm)

4. Canals having cohesive beds and banks (charge $\leq$ 500 ppm)

Within each of the preceding four classifications it is possible to evaluate area, average width, top width, bed depth, average depth, hydraulic radius, wetted perimeter, and average velocity and side slopes with ease and a practical degree of accuracy. This is accomplished by means of the regime type correlations involving these parameters as previously discussed, see Figs. 45 to 85 inclusive in Appendix A.

The regime slope equations as they apply to this sub-classification of canals are of two types:

1. Those relating V, R, and S, and,

2. Those which relate slope, size of bed material and other variables.

Those of the first type, as illustrated in Fig. 74 have the advantage that they can be applied directly after estimating V and R and the disadvantage that values of S computed by this type of relation can vary as much as 30 percent from the original values. The advantage of the second type is increased accuracy provided the mean size of bed material can be pre-determined and its disadvantages are:

1. Inability to pre-determine accurately mean diameter of bed material in many instances and,

2. Equations of this type only seem to apply with accuracy to those channels having sand beds.

As a result of utilizing all of the data presented in this report, the relations shown in Figs. 74, 75 and 81 are recommended for estimating slope in those canals falling within the sub-classifications numbered 2, 3, and 4. Considering coarse non-cohesive materials the original relation presented by Lane (35) relating τ and d as shown in Fig. 9, or the relations of Figs. 89 and 97 are recommended for estimating regime slope. In this latter case it is definitely necessary in all instances to estimate the mean diameter of bed material before the slope can be evaluated.

With the exception of Fig. 74 none of the slope equations or relations presented in this report properly reflect the effect of sediment load on slope. The major reason why the Simons and Bender data have not cast more light on this problem is that the sediment load measured in these canals proved to be fairly constant varying only within very narrow limits -- thereby making it virtually impossible to determine any meaningful effect.

The limiting tractive force concept of design in its current form, as presented by Lane, has the advantage over other methods that it is theoretically sound -- being based entirely on the fundamentals of fluid mechanics and soil mechanics once the hypothesis is accepted that the tractive force concept applies. The major drawback as previously cited is that it has thus far only been developed adequately to apply quantitatively to those channels constructed in coarse non-cohesive materials.

Utilizing all of the basic data, an attempt to extend the range of applicability of the tractive force method to include all types of canals was investigated. The results of this study are fairly well summarized in Fig. 92. In terms of this it is immediately obvious that canals formed in materials in the sand range and finer constitutes a group within which conditions are significantly more complex than in the coarse non-cohesive range. Note that five different curves have been drawn, each representative of a different sub-group of canals, and that Q increases moving from left to right along any curve. Estimating a design slope in the range of sand and finer by means of these curves is in no sense a precise approach, but the figure is extremely useful in that within limits slopes can be estimated and the presentation gives an insight to the complexity of conditions within this range of operation heretofore unrecognized by the tractive force approach.

//Summarizing, the tractive force method of design seems to be valid for the coarse non-cohesive range, however, it is recommended that equations of the regime type relating such terms as W and Q and D and Q, should be used to estimate width-to-depth ratio in preference to arbitrarily selecting W and D and then computing a slope consistent with stability of sides and bed, / see Figs. 57, 59, 61, 62, and 70.

//Because of the less significant correlation between tractive force, mean diameter of bed material and etc., as depicted by Fig. 92 within the sand and cohesive range of particle sizes, other relations of the regime type are perhaps equal or superior to the tractive force method for estimating design slope. In any event it seems logical, based on the validity of regime type area, width, and depth relations that they should be used to establish W/D regardless of whether regime or tractive force equations are used to estimate design slope.

The disadvantage of imposing an arbitrary W/D ratio on a design problem is that when narrow widths are selected (that is, a small W/D ratio) the magnitude of slope must be limited to avoid bank erosion. This also means a small average velocity and an inability to transport appreciable sediment.

The above brings out the advantages of combining the strong points of the two theories, as was illustrated in Chapter IX, except possibly in those cases where coarse non-cohesive materials, limited slope, and small sediment load are involved.

As an independent function relative to regime and tractive force theories the correlation illustrated by Fig. 97 is worthy of attention. It is, however, of a form involving both S and d, and consequently is related to post-design conditions. This graphical presentation based on the Modified Einstein Theory(18) provides a means of estimating slope for all of the types of canals considered. The results are particularly good in the coarse non-cohesive range. It should be noted also that the Sind data tend to plot to the right of the Simons and Bender and the Punjab data and that this group carries a larger than average sediment load and has, in terms of averages, a mean size of bed material smaller than any of the other groups.

Chapter XI

PROPOSED FUTURE STUDIES

An analysis of the status of stable channel theory verifies that rapid progress has been made in this field during the past two decades. There are, however, a multitude of shortcomings in existing theories that should be given additional consideration. As a means of gaining a more comprehensive insight to stability of channels than this report has provided, the following studies are proposed:

1. A thorough investigation of the influence of the Imperial Valley canal data presented in reference (21) and the Nile canal data from reference (37) on the correlations presented in this report.

2. The effect of magnitude of sediment load on W/D and slope.

3. How W/D, slope, and ability to transport sediment are influenced by varying percent of wash load.

4. The mechanics of ripple and dune formation and their influence on channel roughness and slope.

5. The influence of natural soil type on stable shape -- that is, how it relates to W/D.

6. The influence of wave action on the stability of channel banks and beds.

7. Secondary circulation and its effect on sediment transport, expenditure of energy, and distribution and magnitude of the tractive force exerted on the periphery of channels.

8. Relationship connecting characteristics of the natural soils, the sediment being transported, and the size of bed material.

9. A study of the factors influencing magnitude of bed factors and side factors with the ultimate goal in mind of describing them more accurately in terms of known variables so as to increase the usefulness of the regime theory as proposed by Blench.

10. Investigate the distribution of tractive force in channels of different shapes and the influence of tractive force distribution on the ultimate stable shape of cross-section.

11. Consider the influence of particle shape and size distribution on armor plating, and allowable magnitude of critical tractive force.

12. Study the influence of clays on channel stability.

13. Consider effect of vegetation on bank stability, and vegetal growth as related to type of bank material and method of canal operation.

14. Investigate the magnitude and distribution of the tractive forces exerted on the channel sides and bed at bends; also, methods of bank stabilization in these regions, the effect of spiraling the curves, and effect of superelevating the channel bed.

A rather intimate relationship exists between some of the preceding research proposals. Consequently, it is conceivable that several of these problems could be incorporated into one study.

As pointed out in Chapter 10, it is apparent that the most significant shortcoming in the existing theories is the lack of an adequate slope formula capable of accounting for the effect of type and magnitude of sediment load. The foregoing studies should alleviate this situation and at the same time strengthen methods of selecting W/D and give a means of predicting the influence of bends on overall stability and maintenance. Such information would round out the existing theory making design of stable channels still more of a science and less of an art.

BIBLIOGRAPHY

Bibliography

1. Albertson, Maurice L. An outline of recent developments in the theories of sediment transportation. Fort Collins, Colo., Civil Engineering Department, Colorado A and M College, 1955. 13 p. processed.

2. Ali, Said M. and Albertson, L. M. Boundary layer approach to roughness in alluvial channels; revised. Fort Collins, Colo., Department of Civil Engineering, Colorado A and M College, 1956. 20 p. processed.
   Originally issued under title: Some aspects of roughness in alluvial channels.

3. American Geophysical Union. Subcommittee on Sediment Terminology. Report. American Geophysical Union. Transactions, 28:936-38, December 1947. E. W. Lane, Chairman.

4. Barton, J. R. and Pin-Nam Lin. A study of the sediment transport in alluvial channels. Fort Collins, Colo., Civil Engineering Department, Colorado A and M College, 1955. Various pages, processed. (Report no. 55JRB2).

5. Bender, D. L. Suspended sediment transport in alluvial irrigation channels. Master's thesis, 1955. Colorado A and M College. 86 p. typewritten.

6. Blench, Thomas. Hydraulics of sediment bearing canals and rivers. Vancouver, B.C., Evans Industries Limited, 1951. unpaged.

7. Blench, Thomas. Regime formulas for bed-load transport. Edmonton, Alberta, Department of Civil and Municipal Engineering, University of Alberta, 1955. 19 p. mimeographed.

8. Blench, Thomas. Regime theory for self-formed sediment bearing channels. American Society of Civil Engineers. Proceedings, 77:Separate no. 70: 1-18, May 1951.

9. Bose, N. K. and Malhatra, J. K. Investigation of interrelation of silt indicies and discharge elements for some regime channels in Punjab. Punjab Irrigation Research Institute. Research publication, 2(23):1-70, 1939.

10. Brown, Carl S. Sediment transportation. (In Hydraulics Conference, Iowa City, 1949. Engineering hydraulics; Proceedings of the Fourth Hydraulics Conference. New York, John Wiley and Sons, 1950. p. 769-857.)

11. Carlson, Enos J. and Miller, C. R. Research needs in sediment hydraulics. Denver, Colo., U. S. Bureau of Reclamation, 1955. 28 p. processed.
Also in American Society of Civil Engineers. Proceedings, 82:HY2:Paper 952:1-33, April 1956.

12. Chang, Y. L. Laboratory investigation of flume traction and transportation. American Society of Civil Engineers. Transactions, 104:1246-84, 1939.

13. Chatley, Herbert. Regime and rythm in waterways; Are rivers subject to rules? London, 1951. 8p.
Reprinted from The Dock and Harbour Authority, August 1951.

14. Chien, Ning. A concept of Lacey's regime theory. American Society of Civil Engineers. Proceedings, 81:Separate no. 620: 1-15, 1955.

15. Colby, B. R., Matejka, D. Q., and Hubbell, D. W. Investigations of fluvial sediments of the Niobrara river near Valentine, Nebraska. U. S. Geological Survey. Circular, 205:1-57, 1953.

16. Einstein, Hans A. The bed-load function for sediment transportation in open channel flows. U. S. Department of Agriculture. Technical bulletin, 1026:1-71, 1950.

17. Einstein, Hans A. Formulas for the transportation of bed load. American Society of Civil Engineers. Transactions, 107:561-97, 1942.

18. Einstein, Hans A. and Barbarossa, N. L. River channel roughness. American Society of Civil Engineers. Proceedings, 77:Separate no. 78: 1-12, 1951.

19. Etcheverry, E. A. Irrigation practice and engineering, Vol. II Conveyance of water. New York, McGraw Hill Book Co., 1915. 364 p.

20. Erb, Bryon R. Regime theory of sediment transport. Master's thesis, 1955. University of Alberta. typewritten.

21. Fortier, Samuel and Blaney, H. F. Silt in the Colorado river and its relation to irrigation. U. S. Department of Agriculture. Technical bulletin, 67:1-94, 1928.

22. Fortier, Samuel, and Scobey, F. C. Permissable canal velocities. American Society of Civil Engineers. Transactions, 89:940-84, 1926.

23. Ganguillett, E. and Kutler, W. R. A general formula for the uniform flow of water in rivers and other channels. New York, John Wiley and Sons, 1889. 240 p.

24. Glover, R. E., and Florey, O. L. Stable channel profiles. U. S. Bureau of Reclamation. Hydraulics laboratory report, Hyd-325:, 1955.

25. Goldstein, S., Editor. Modern developments in fluid dynamics. Oxford, Clarendon Press, 1938. 2 v.

26. Hirandani, M. G. Remarks on note C-295/CEE, dated July 1941. India. Central Board of Irrigation. Annual report (Technical), 1942:73-76. (India. Central Board of Irrigation. Publication no. 29).

27. Hiranandani, M. G. Remarks on the note "Effects of dynamic shape on Lacey's relations. India. Central Board of Irrigation. Annual report (Technical), 1942:68-72. (India. Central Board of Irrigation. Publication no. 29.)

28. Inglis, Sir Claude Cavendish. The behavior and control of rivers and canals (with the aid of models). Poona, India, 1949. 2 v. (India. Central Waterpower, Irrigation and Navigation Research Station. Research publication no. 13.)

29. Kalinske, A. A. Role of turbulence in river hydraulics. Hydraulic Conference, Iowa City. 2:266-79, 1942. (Iowa University. Studies in Engineering. Bulletin 27.)

30. Keulegan, G. H. Laws of turbulent flow in open channels. U. S. National Bureau of Standards. Journal of research, 21:707-41, December, 1938.

31. Lane, E. W. Charge as a factor in stable irrigation canals. Fort Collins, Colo., The Author, 1954. 9 p. processed. Reprint from Irrigation and Power, vol. XII, no. 2, 1955.

32. Lane, E. W. Design of stable channels. American Society of Civil Engineers. Transactions, 120:1234-60, 1955.

33. Lane, E. W. The importance of fluvial morphology in hydraulic engineering. American Society of Civil Engineers. Proceedings, 81: Separate no. 745:1-17, 1955.

34. Lane, E. W. Progress report on results of studies on design of stable channels. U. S. Bureau of Reclamation. Hydraulics laboratory report, Hyd352:1-36, 1952.

35. Lane, E. W. Progress report on studies on the design of stable channels by the Bureau of Reclamation. American Society of Civil Engineers. Proceedings, 79:Separate no. 280:1-31, 1953.
Shortened form of Reference 34.

36. Lane, E. W., Carlson, E. J., and Hanson, O. S. Low temperature increases sediment transport in the Colorado river. Civil Engineering, 19:45-6, September 1949.

37. Leliavsky, Serge. An introduction to fluvial hydraulics. London, Constable and Company, 1955. 257 p.

38. Liu, Hsin-Kuan. Mechanics of sediment-ripple formation. American Society of Civil Engineers. Proceedings, 83:Hy2:Paper 1197:1-23, April 1957.

39. Madan, M. L. Mean velocity and mean silt points. India. Central Board of Irrigation. Annual report (Technical), 1943:85-88. (India. Central Board of Irrigation. Publication no. 31.)

40. Madan, M. L. Verification of Lacey's modified basic equation. India. Central Board of Irrigation. Annual report (Technical), 1942: 76-78. (India. Central Board of Irrigation. Publication no. 29.)

41. Manning, Robert. Transactions of the Institution of Civil Engineers of Ireland, 1890.
Cited by Rouse (53).

42. Manning, Robert. Flow of water in open channels and pipes. Transactions of the Institution of Civil Engineers of Ireland, Vol. 20, p. 161, 1891. Vol. 24, p. 179.
Cited by Rouse (53).

43. Milne Thompson, L. M. Theoretical hydraulics. New York, The MacMillan Company, 1950. 600 p.

44. Nebraska. Bureau of Irrigation, Water Poser and Drainage. 29th biennial report 1951-1952. Lincoln, Neb., 1952. 725 p.
Vol. II of Nebraska. Department of Road and Irrigation. Biennial report.

45. Posey, C. J. Measurement of surface roughness. Mechanical Engineering, 68:305-6, 338, April 1946.

46. Powell, R. W. Flow in a channel of definite roughness. American Society of Civil Engineers. Proceedings, 70:1521-44, December 1944.

47. Powell, R. W. Resistance to flow in rough channels. American Geophysical Society. Transactions, 31:575-82, August 1950.

48. Powell, R. W. Resistance to flow in smooth channels. American Geophysical Union. Transactions, 30:875-78, December 1949.

49. Punjab Irrigation Research Institute. Report for the year ending April 1941. Lahore, Punjab, Superintendent of Government Printing, 1943. 234 p.

50. Raju, B. Chandrasekhara. Correlation of regime theory and tractive force theories of stable channel design. Master's report, 1955. Colorado A and M College. 66 p. typewritten.

51. Ree, W. O. and Palmer, V. J. Flow of water in channels protected by vegetative linings. U. S. Department of Agriculture. Technical Bulletin, 967:1-115, 1949.

52. Robinson, A. R. and Albertson, M. L. Artificial roughness standard for open channels. American Geophysical Union. Transactions, 33:881-88, December 1952.

53. Rouse, Hunter. Elementary mechanics of fluids. New York, John Wiley and Sons, 1946. 376 p.

54. Rouse, Hunter. Evaluation of the boundary roughness. Hydraulics Conference, Iowa City. Proceedings, 2:105-16, 1943. (Iowa University. Studies in engineering. Bulletin 27.)

55. Rouse, Hunter. Fluid mechanics for hydraulic engineers. New York, McGraw Hill Book Co., 1938. 422 p.

56. Schlichting, Hermann. Boundary layer theory. New York, McGraw Hill Book Co., 1955. 535 p.

57. Schoklitsch, Armin. Hydraulic structures. New York, American Society of Mechanical Engineers, 1937. 2 v.

58. Schroeder, K. B. and Raitt, D. B. Total suspended sediment load from vertical transport distribution. Denver, Bureau of Reclamation, 1955. 57 p. processed.

59. Scobey, F. C. The flow of water in irrigation and similar channels. U. S. Department of Agriculture. Technical bulletin, 652:1-79, 1939.

60. Simons, D. B. Angle of repose of non-cohesive materials. Fort Collins Colo., 1956. 64 p. typewritten
Report presented in CE 292 at Colorado A and M College.

61. Simons, D. B. Forces of wave motion which affect canal stability. Fort Collins, Colo., 1956. 67 p. typewritten.
Report presented in CE 292 at Colorado A and M College.

62. Skinner, Morris M. The influence of tractive shear on the design of stable channels. Master's thesis, 1955. University of Wyoming. 100 p. typewritten.

63. Strickler, A. Beiträge zur Frage der Geschwindigkeitsformel under der Rauhigkeitszahlen fur Strome, Kanale und geschlossens Leitungen. Mitt. Amtes für Wasser Wirtschaft. No. 16, 1923.
Cited by Schoklitsch (57).

64. Tennessee Valley Authority, and others. Measurement of the sediment discharge of streams. Iowa City, Iowa, St. Paul District Sub-Office, Corps of Engineers, 1948. 92 p. processed. (Tennessee Valley Authority and others. A study of methods used in measurement and analysis of sediment loads in streams, Report no. 8.)

65. Terrell, Pete W. and Borland, Whitney M. Design of stable canals and channels in erodible material. Denver, Colo., Bureau of Reclamation, 1954. 15 p. processed.

66. U. S. Bureau of Reclamation. Proceedings of the Federal Inter-Agency Sedimentation Conference, May 6-8, 1947. Washington, Bureau of Reclamation, 1948. 314 p. processed.

67. U. S. Bureau of Reclamation. Step method for computing total sediment load by the modified Einstein procedure. Denver, 1955. various pages. processed.

68. Vanoni, Vito A. Transportation of suspended sediment by water. American Society of Civil Engineers. Transactions, 111:67-133, 1946.

69. Vennard, John K. Elementary fluid mechanics. New York, John Wiley and Sons, 1954. 401 p.

70. Yu, King. The design of stable channels in erodible material. Master's report, 1949. Colorado A and M College. 79 p. typewritten.

APPENDIX A

FIGURES

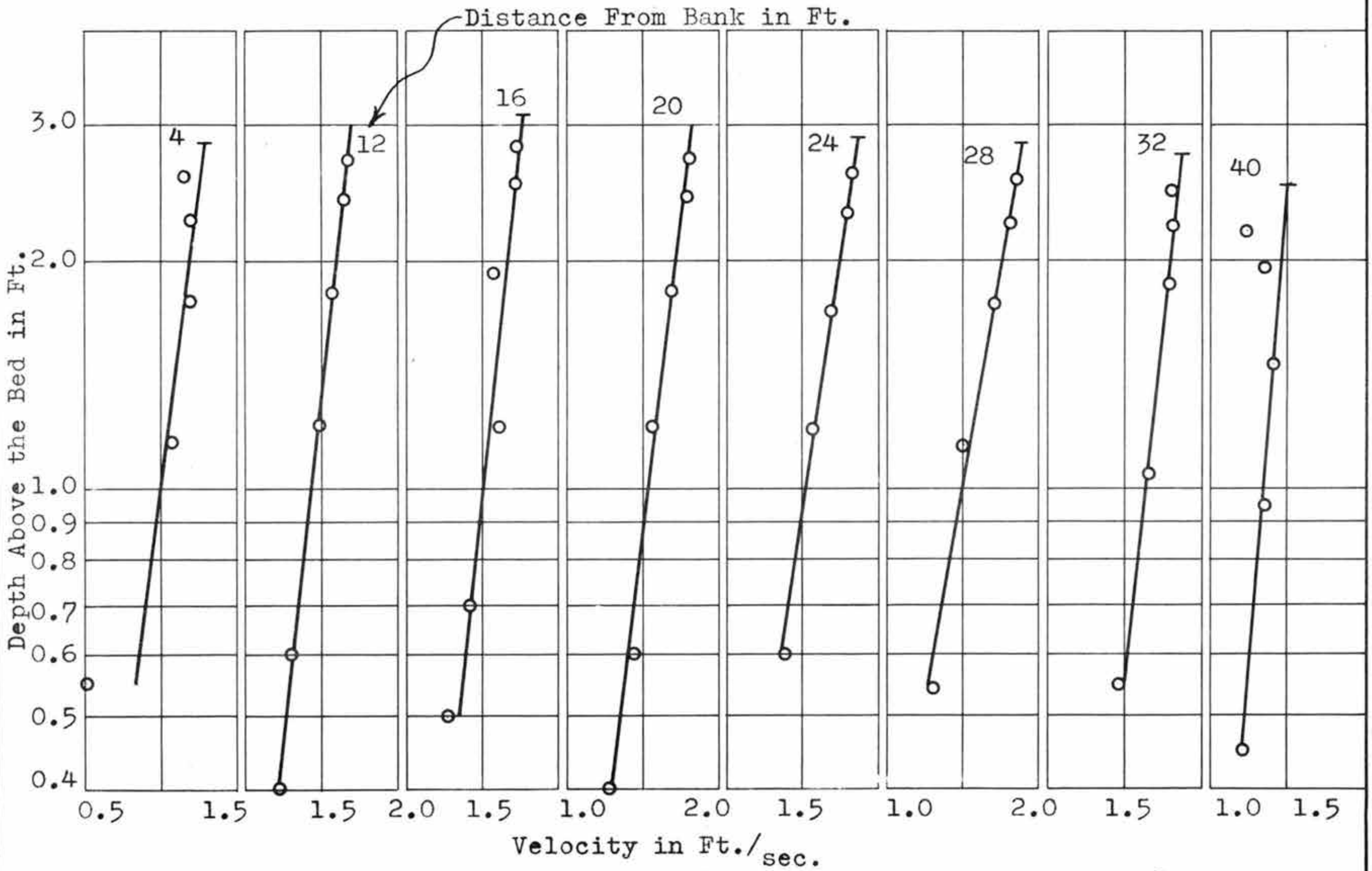
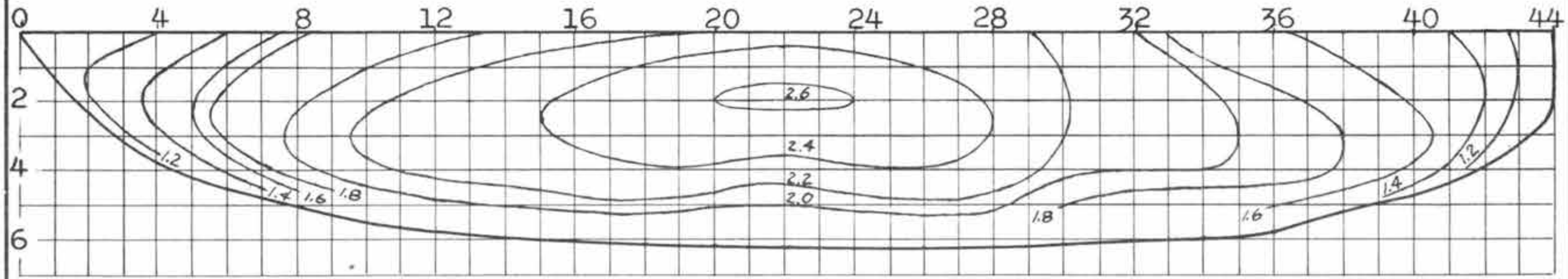
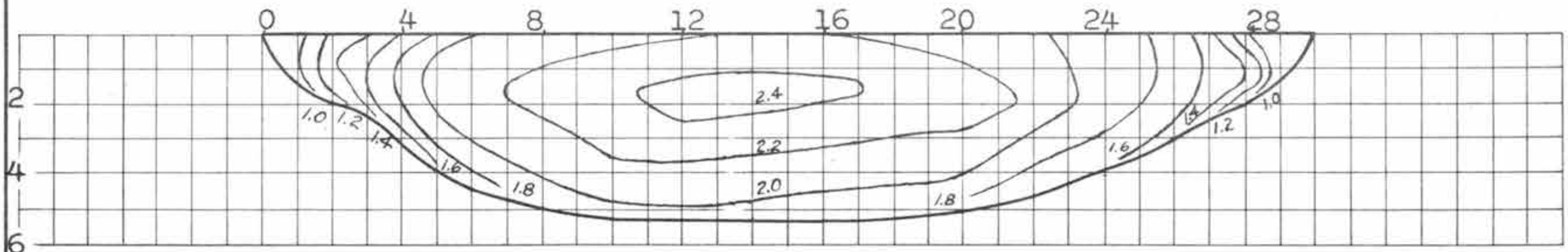


Fig.35 Typical Variation of Velocity With Depth, Canal No. 9

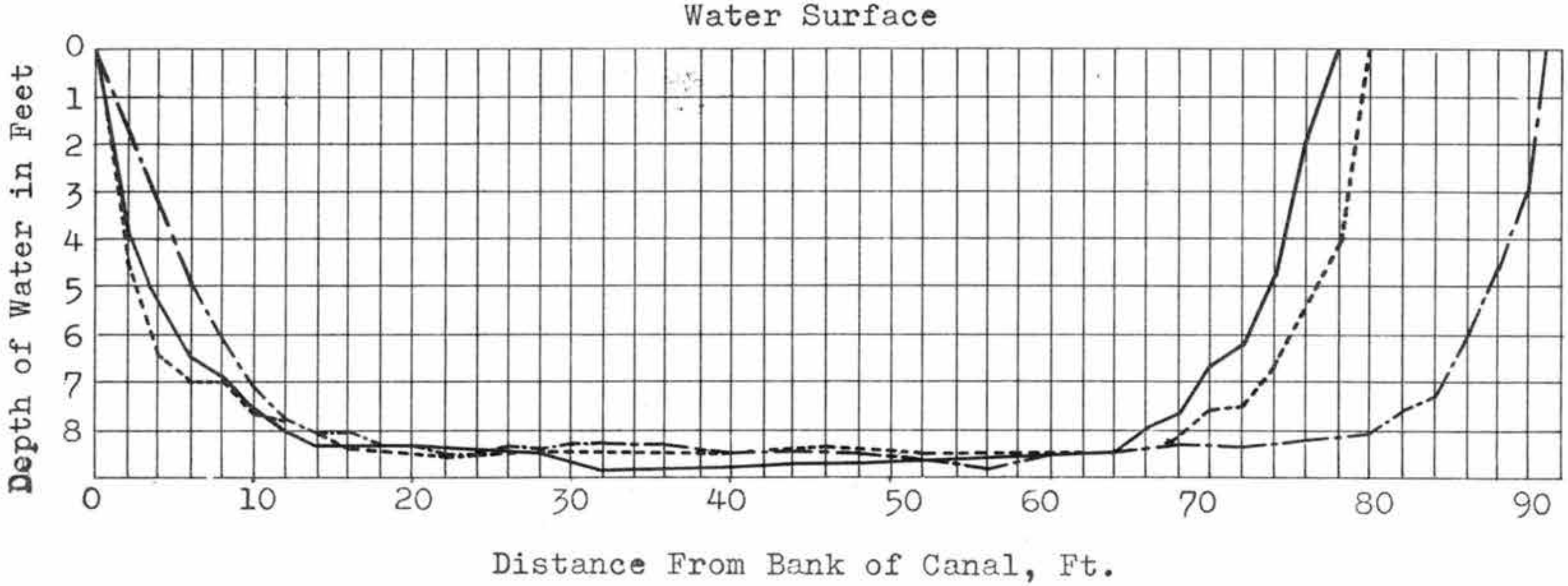


Canal No. 4



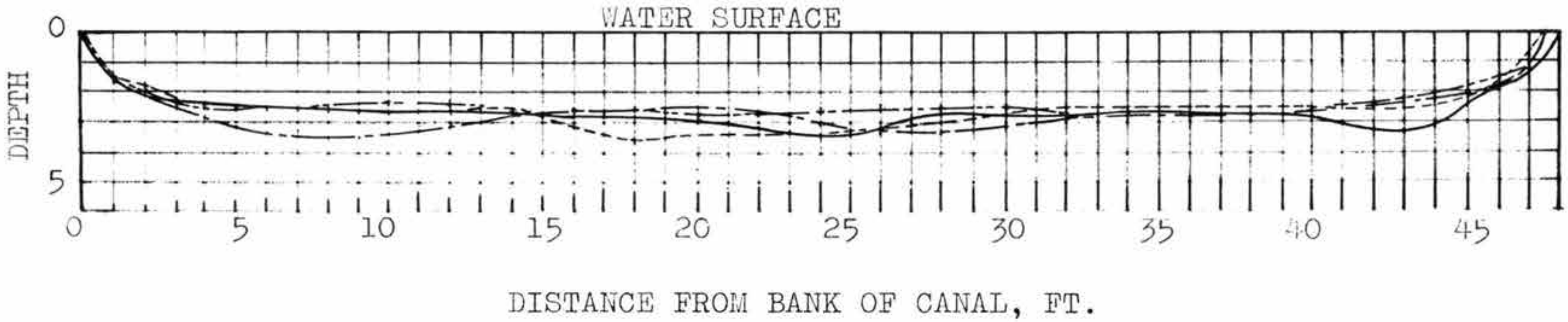
Canal No. 20

Fig.36 Typical Isovels



Station	P	A	R
2	83.7	567.9	6.78
5	87.5	602.9	6.87
5+70	97.6	610.58	6.26
Ave	89.6	593.8	6.64

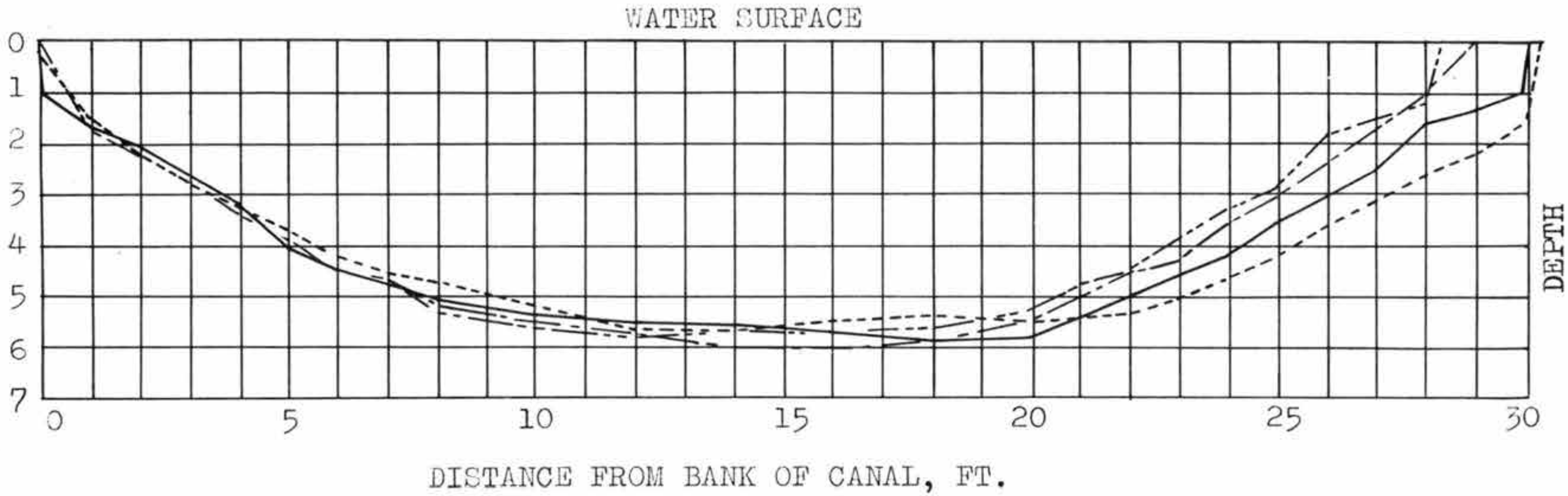
Fig.37 Comparison of Cross Sections, Canal No. 2



STATION	P	A	R
3+00	50.2	131.3	2.62
4+00	49.6	127.0	2.56
6+00	50.0	131.5	2.63
8+00	49.6	119.6	2.41
AVE.	49.85	127.35	2.55

STA. 3+00 ————————
STA. 4+00 - - - - - - - -
STA. 6+00 ——·——·——
STA. 8+00 ——··——··——

FIG.38 COMPARISON OF CROSS SECTIONS, CANAL No. 11



STATION	P	A	R
1	33.6	124.99	3.72
2	33.5	124.64	3.72
5	31.9	118.50	3.72
7	31.5	116.11	3.69
AVE.	32.6	121.06	3.71

STA. 1+00

STA. 2+00

STA. 5+00

STA. 7+00

FIG.39 COMPARISON OF CROSS SECTIONS, CANAL No. 20

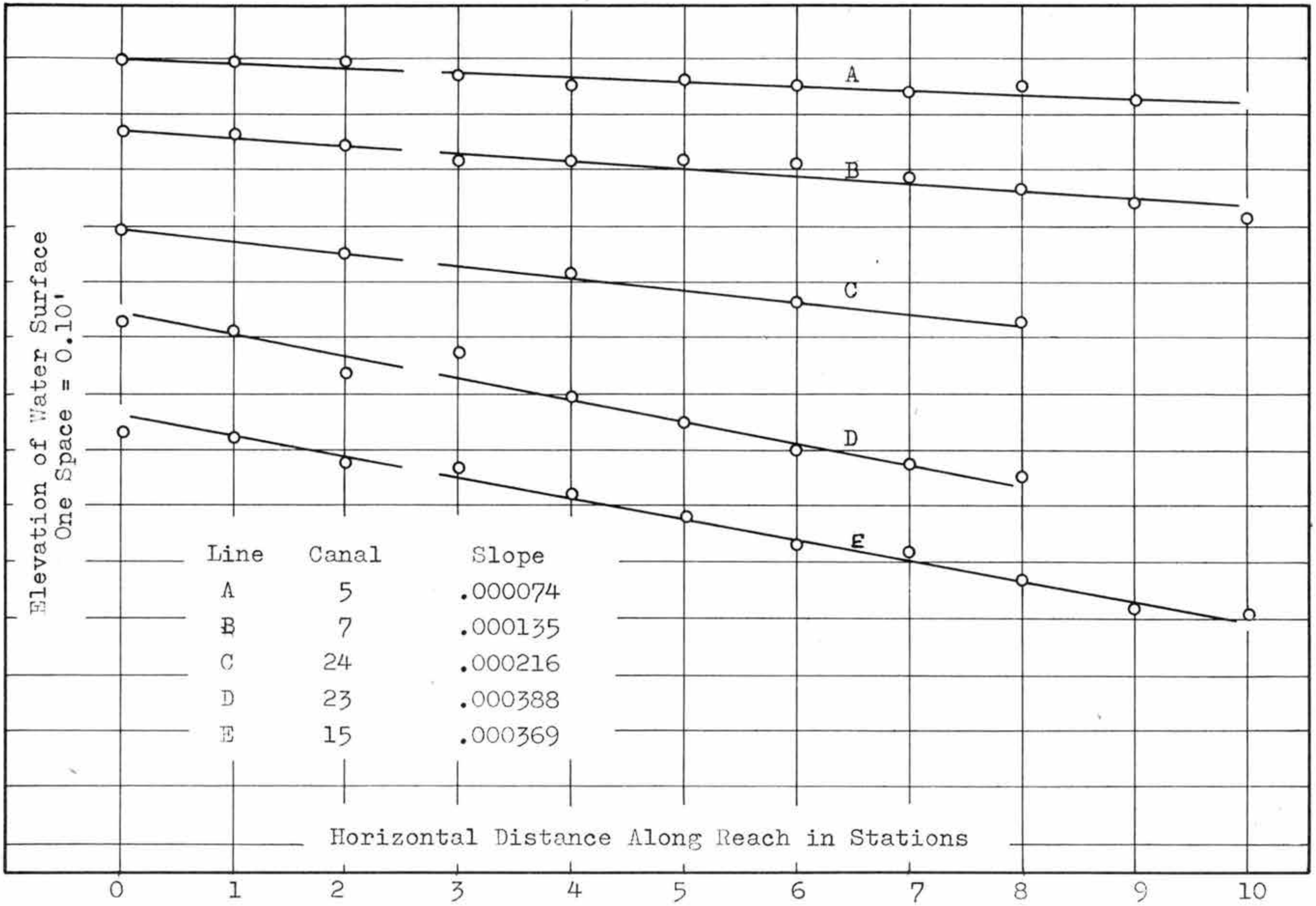


Fig. 40 Typical water surface slopes

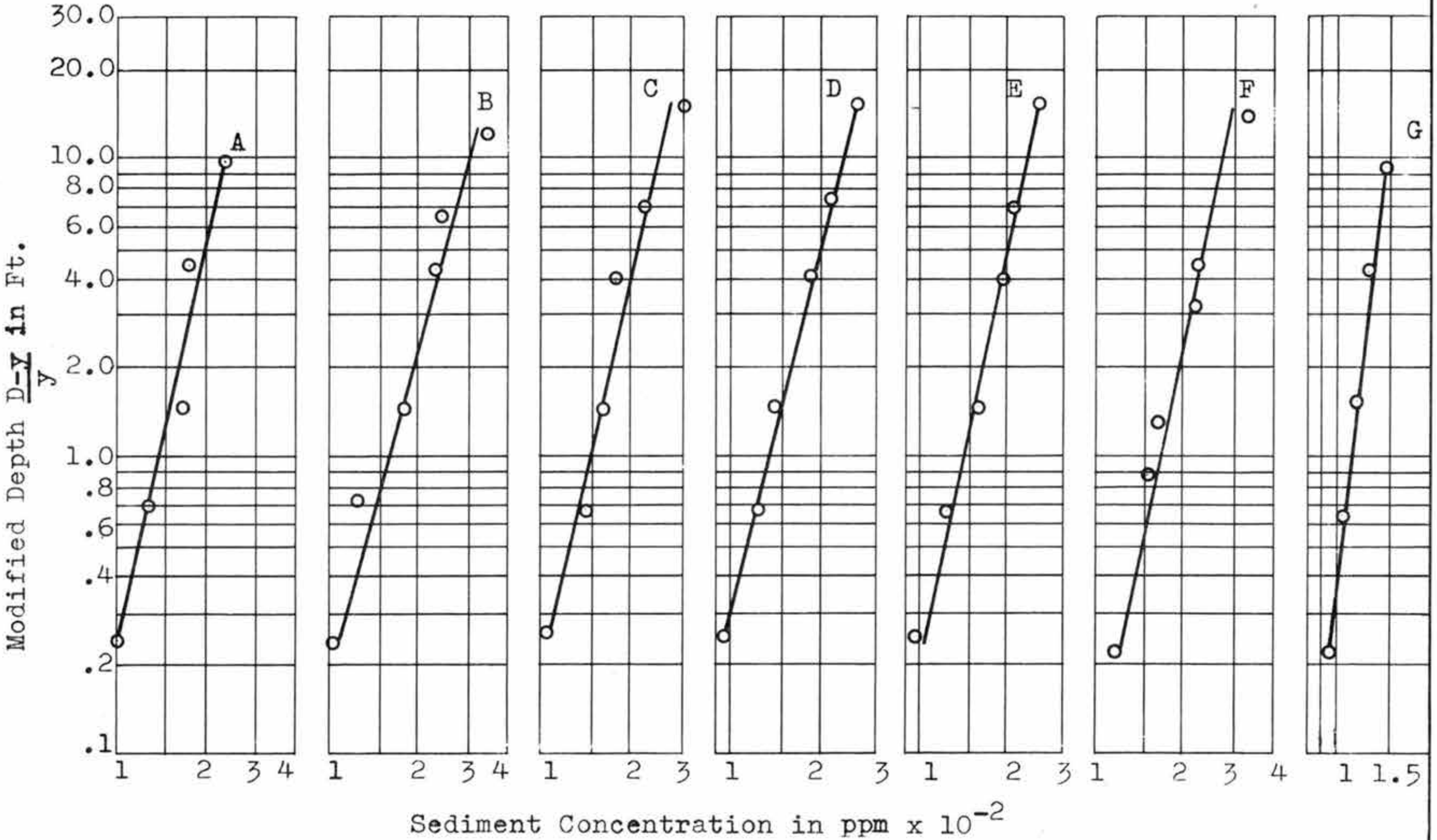


Fig. 41 Typical Variation of Sediment Concentration With Depth, Canal No. 2

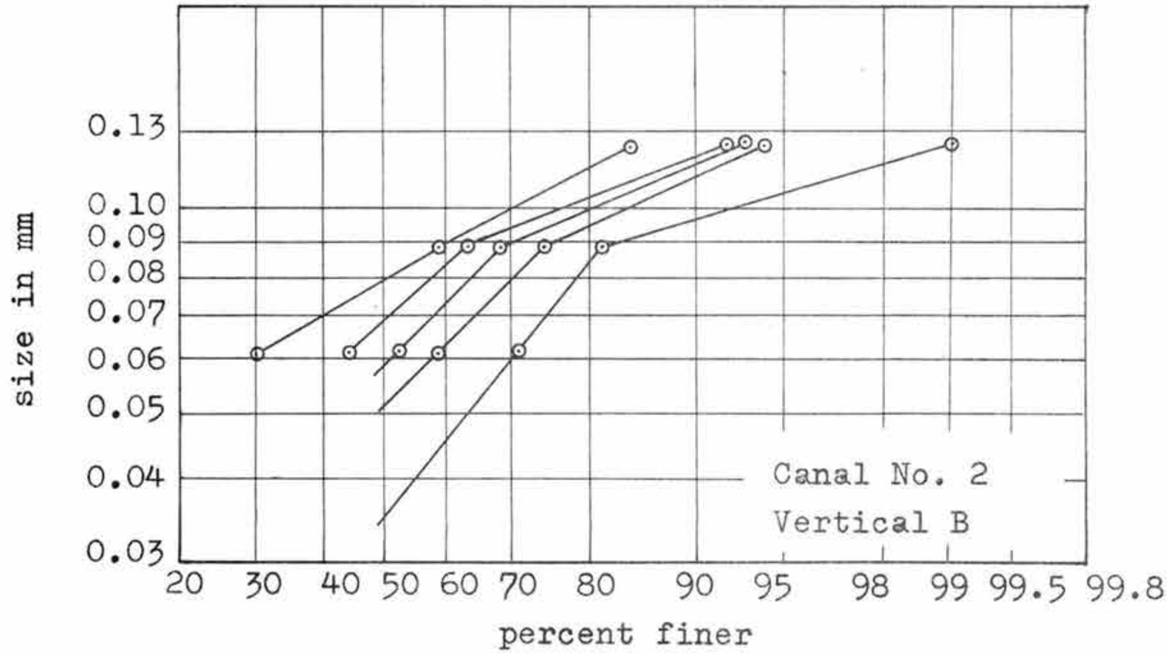


Fig. 42a Typical Sediment Size Distribution

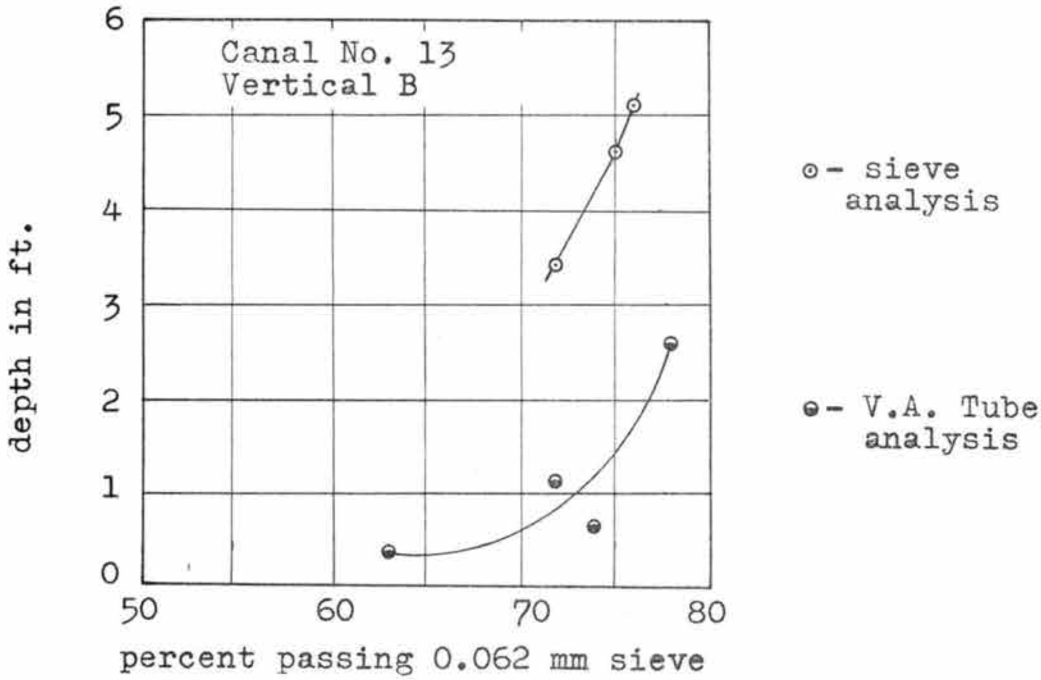


Fig. 42b Typical Variation of Sediment Size with Depth

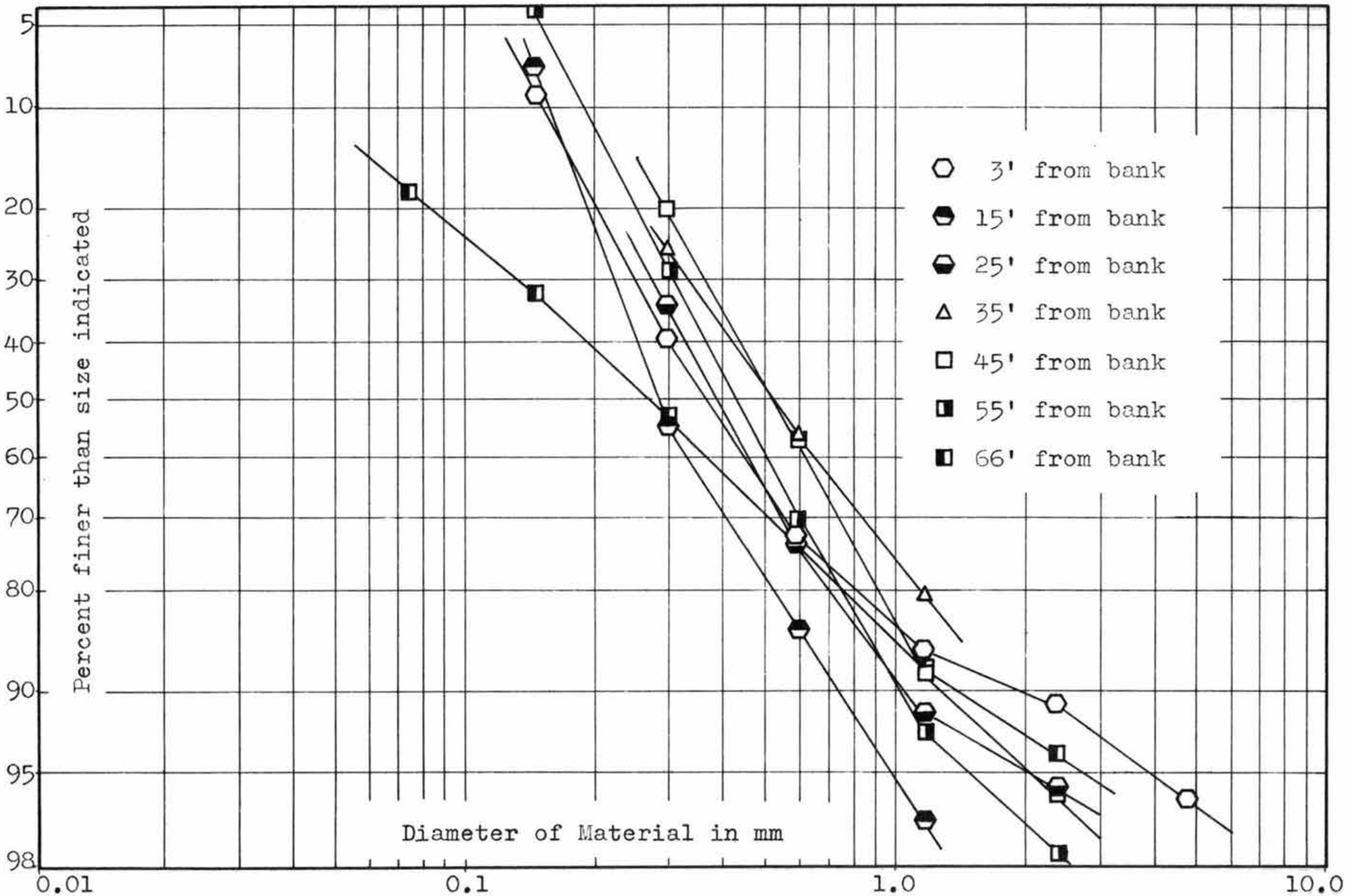


Fig. 43 Percent finer curves for the bed and side material of Canal No. 23

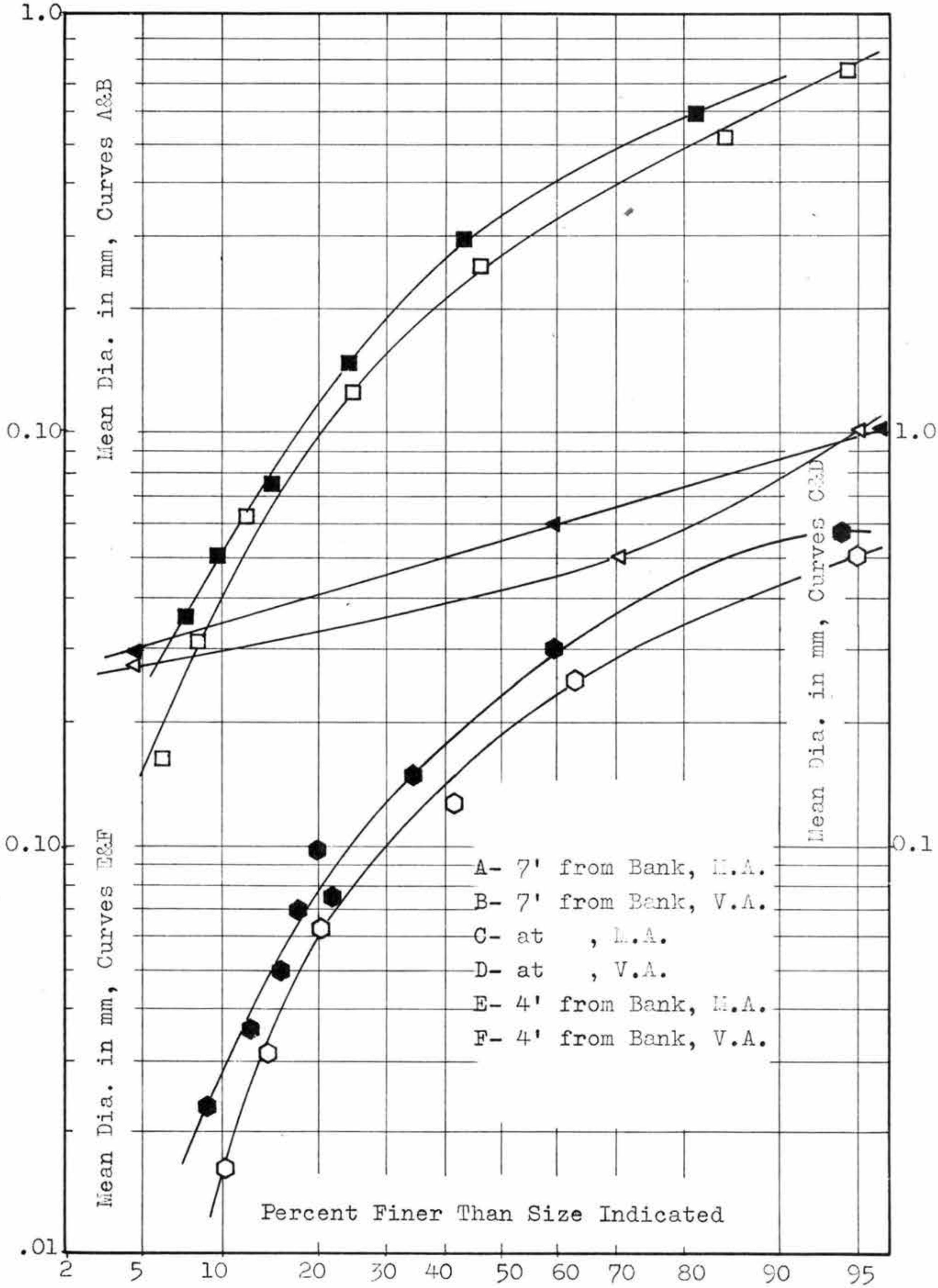


Fig. 44 Comparison of percent finer curves resulting from V.A. tube and mechanical methods of analysis

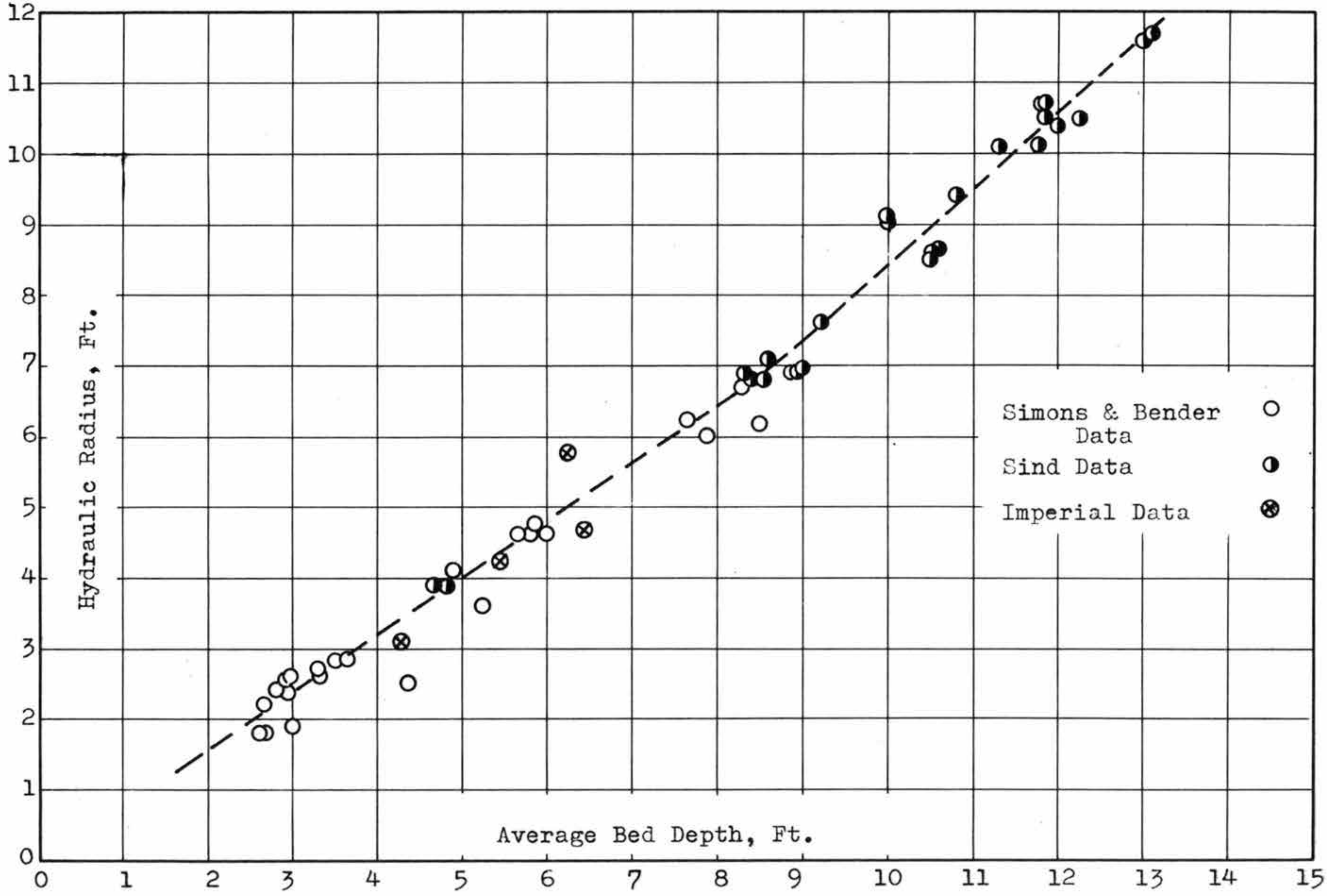


Fig. 45 Variation of hydraulic radius R with depth D

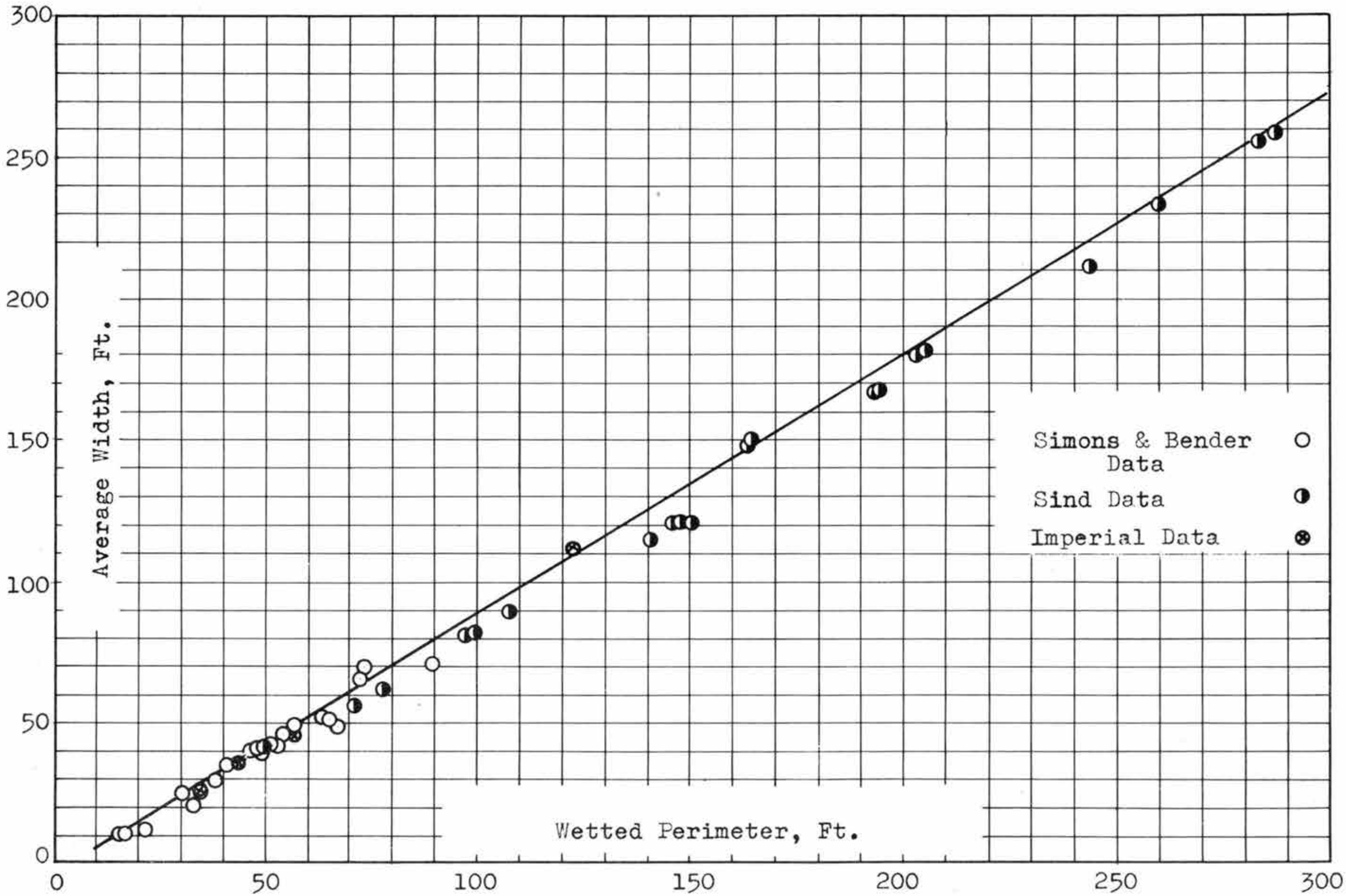


Fig. 46 Variation of average width W with wetted perimeter P

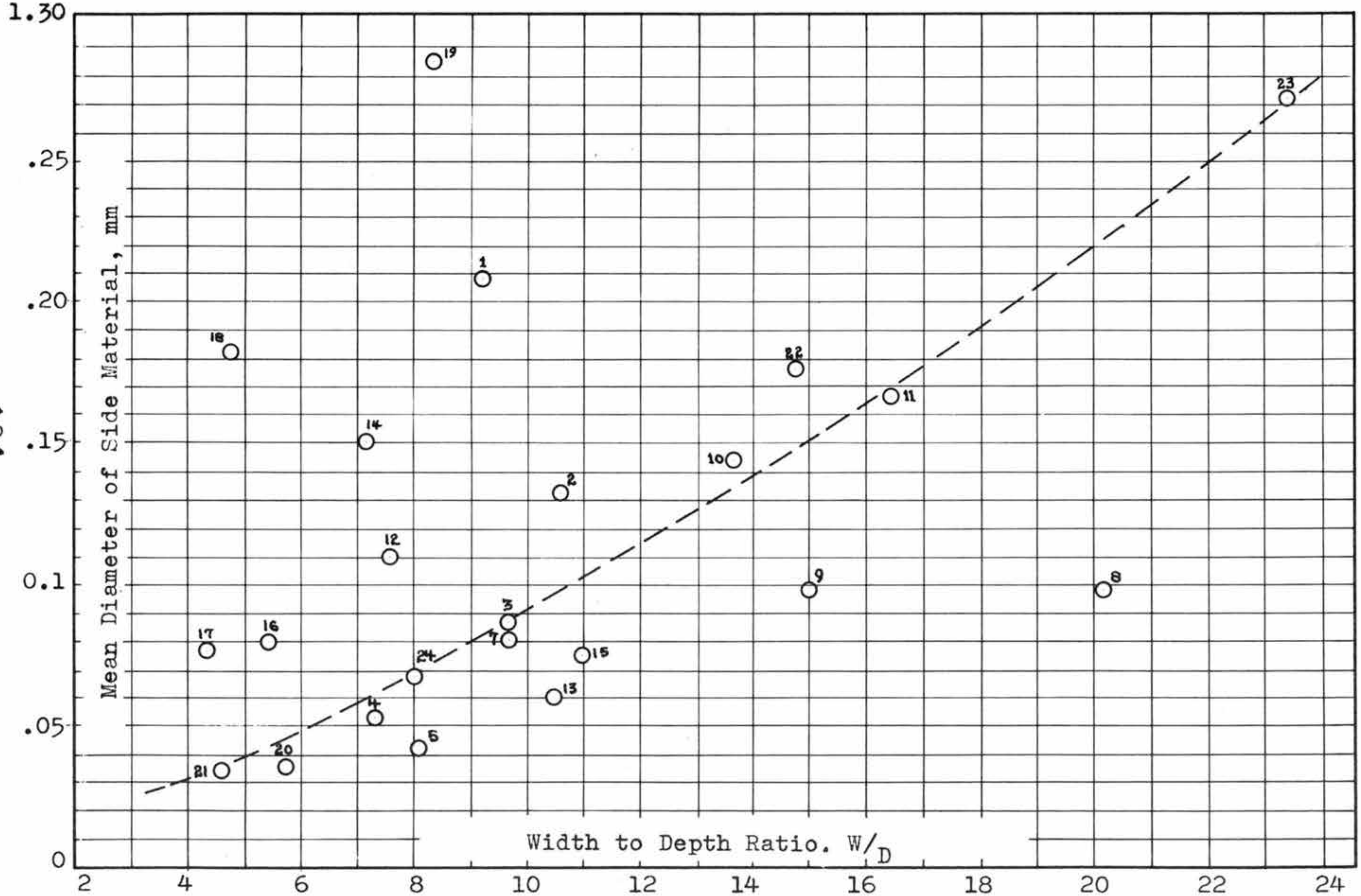


Fig. 47 Variation of side material d with width-depth ratio W/D

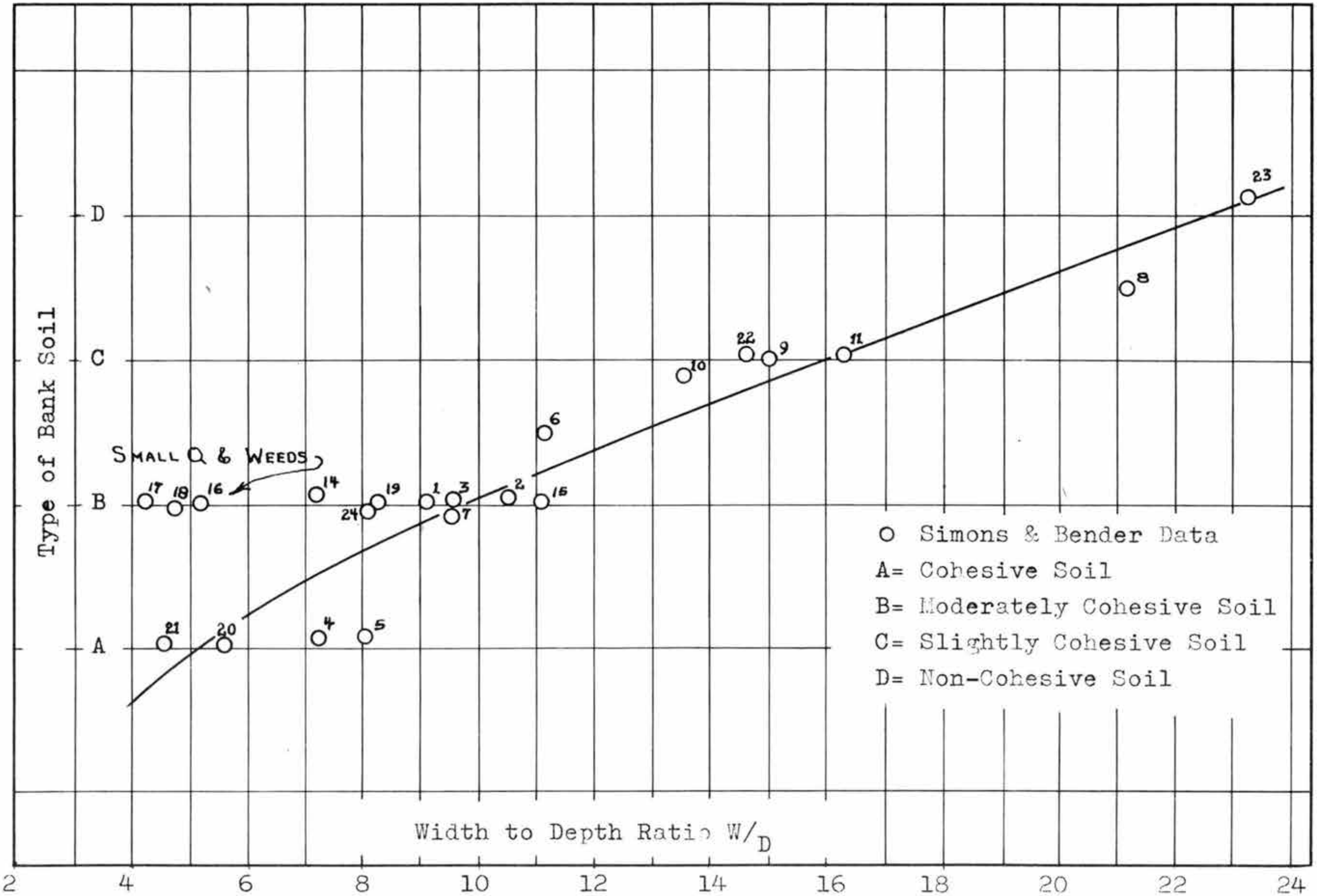


Fig. 48 Variation of bank soil with width-depth ratio W/D

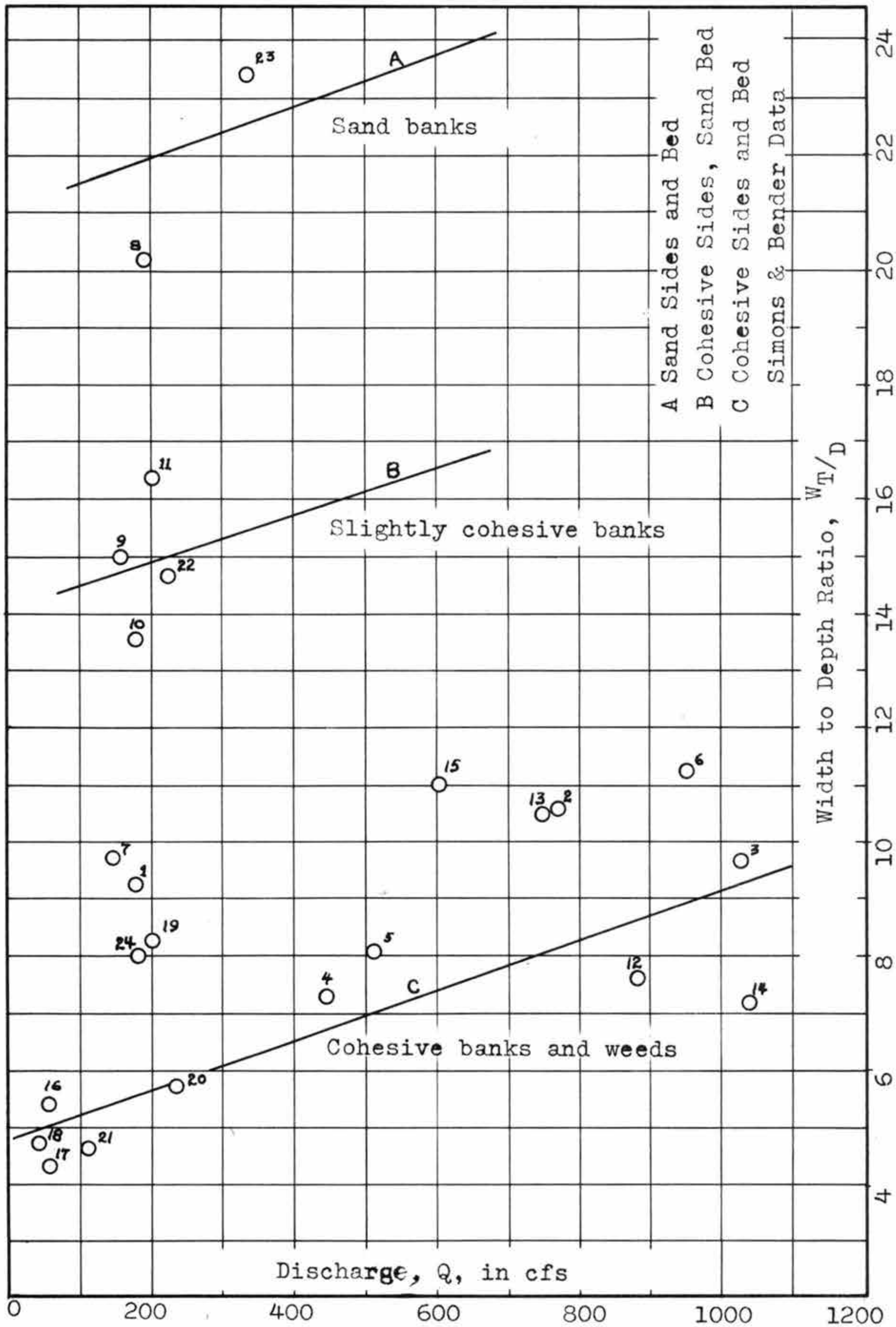


Fig. 49 Variation of top width-depth ratio W_T/D with discharge Q and type of bank material

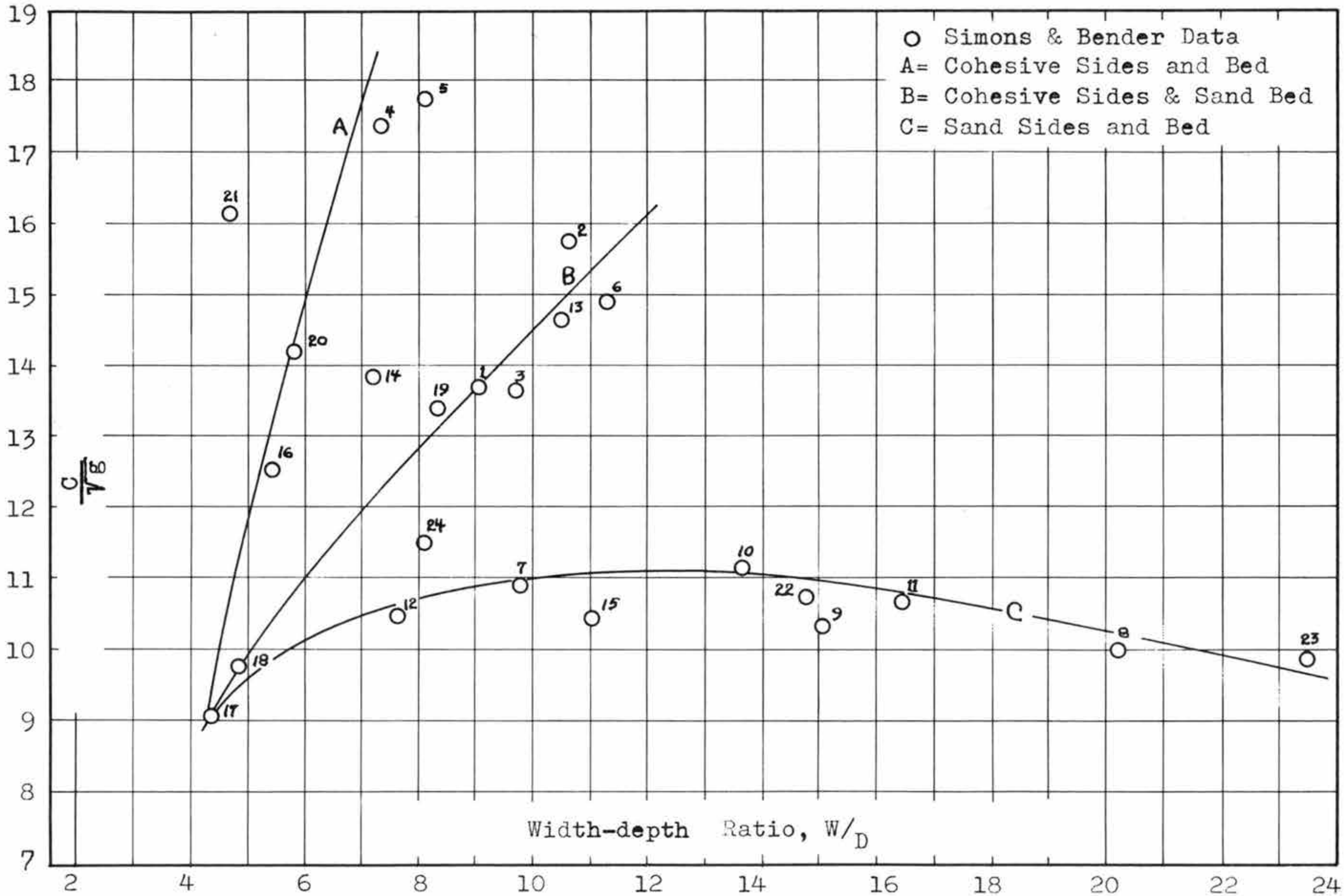


Fig. 50 Variation of roughness $C/\sqrt{g}$ with width-depth ratio W/D

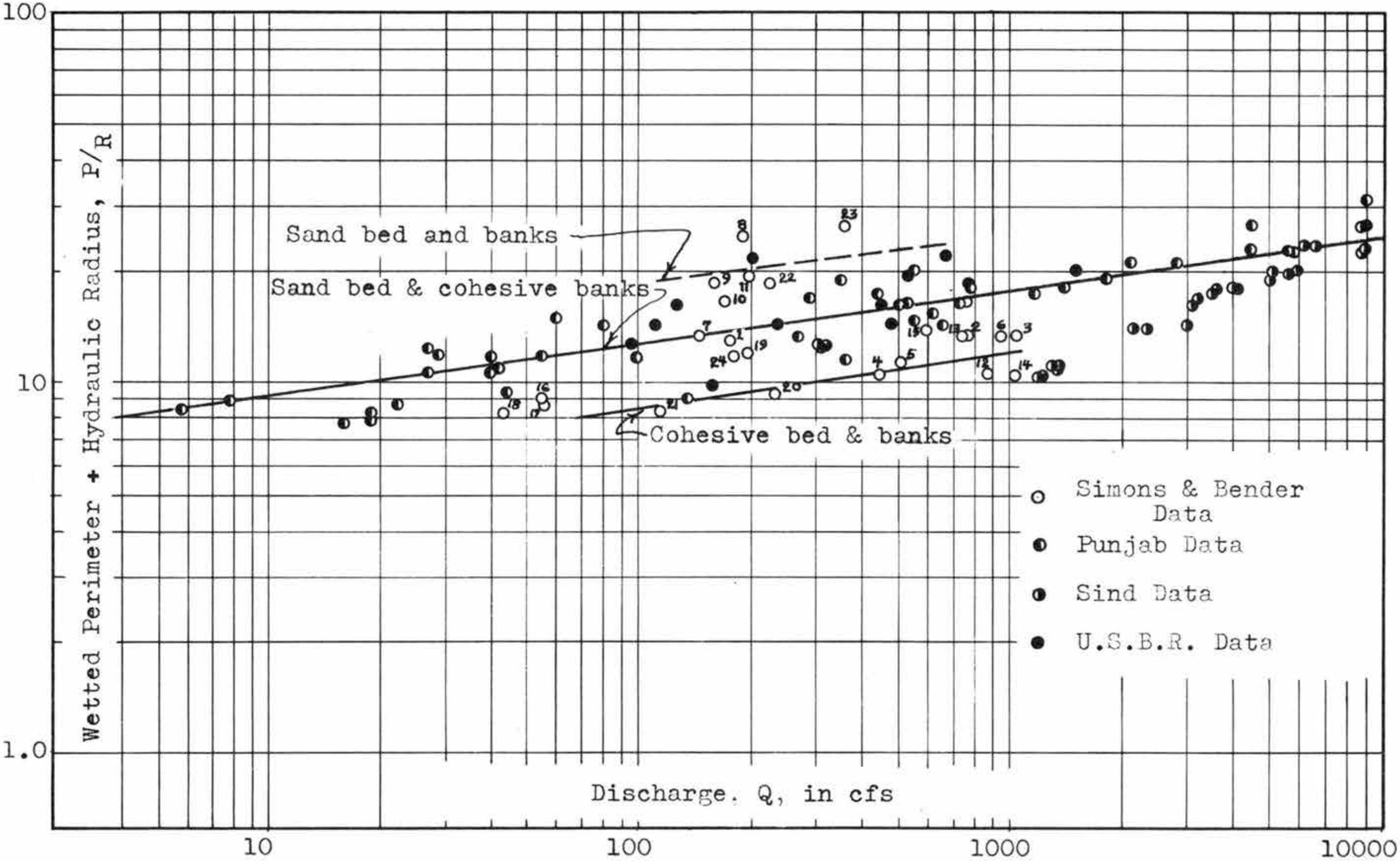


Fig. 51 Variation of shape factor P/R with discharge Q and type of bank and bed material

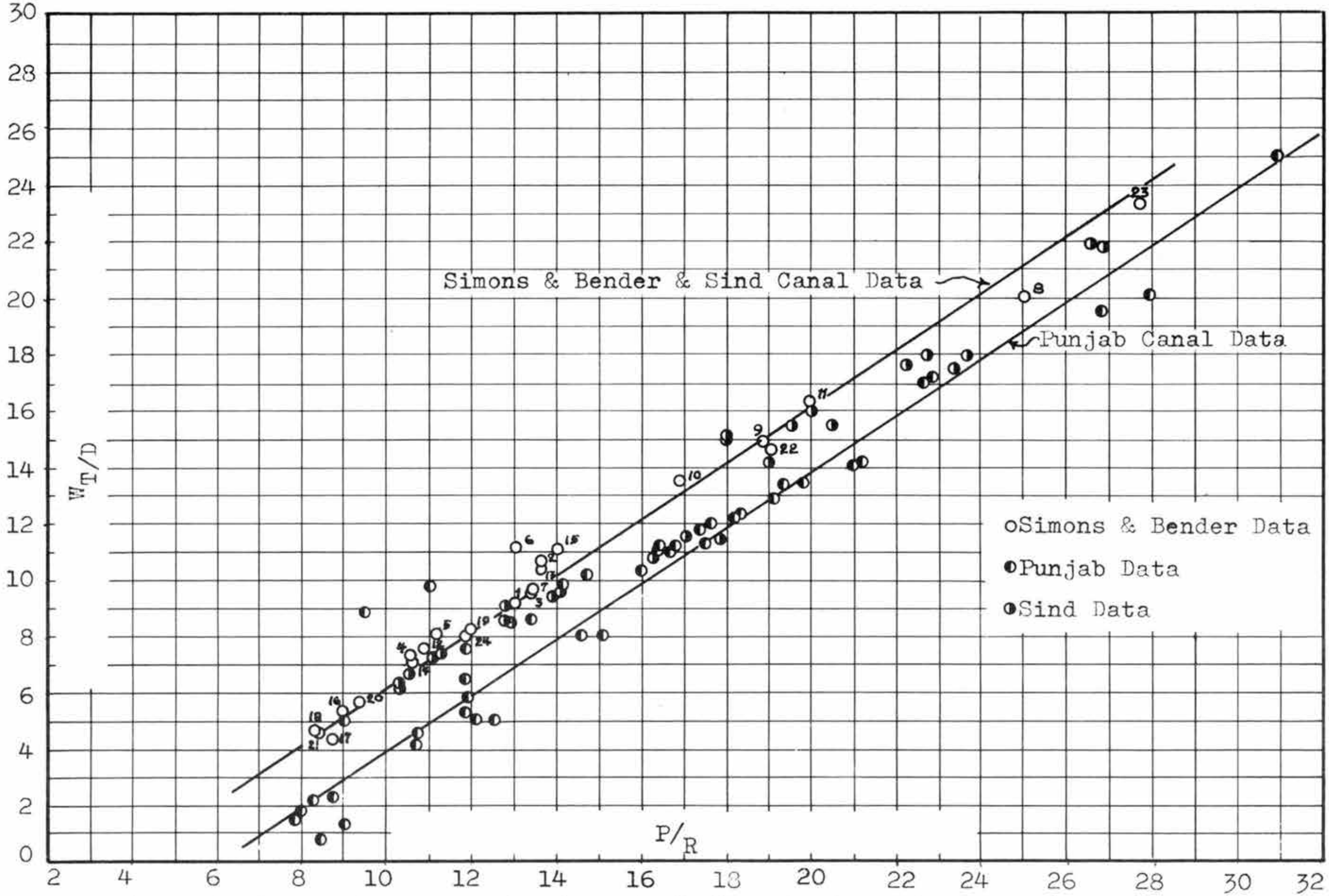


Fig. 52 Variation of top width-depth ratio W_T/D with shape factor P/R

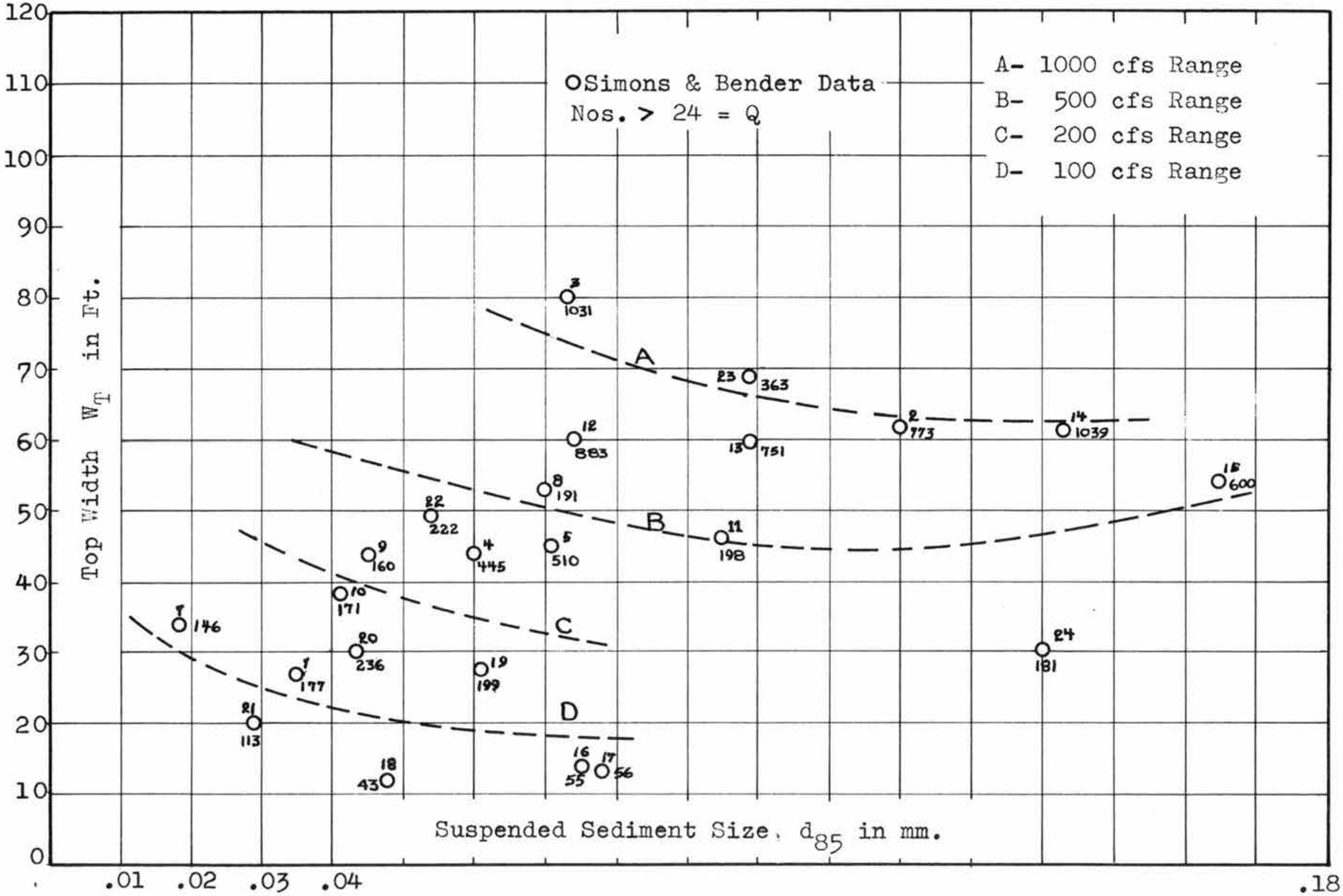


Fig. 53 Variation in top width W_T with suspended sediment d_{85} and discharge Q

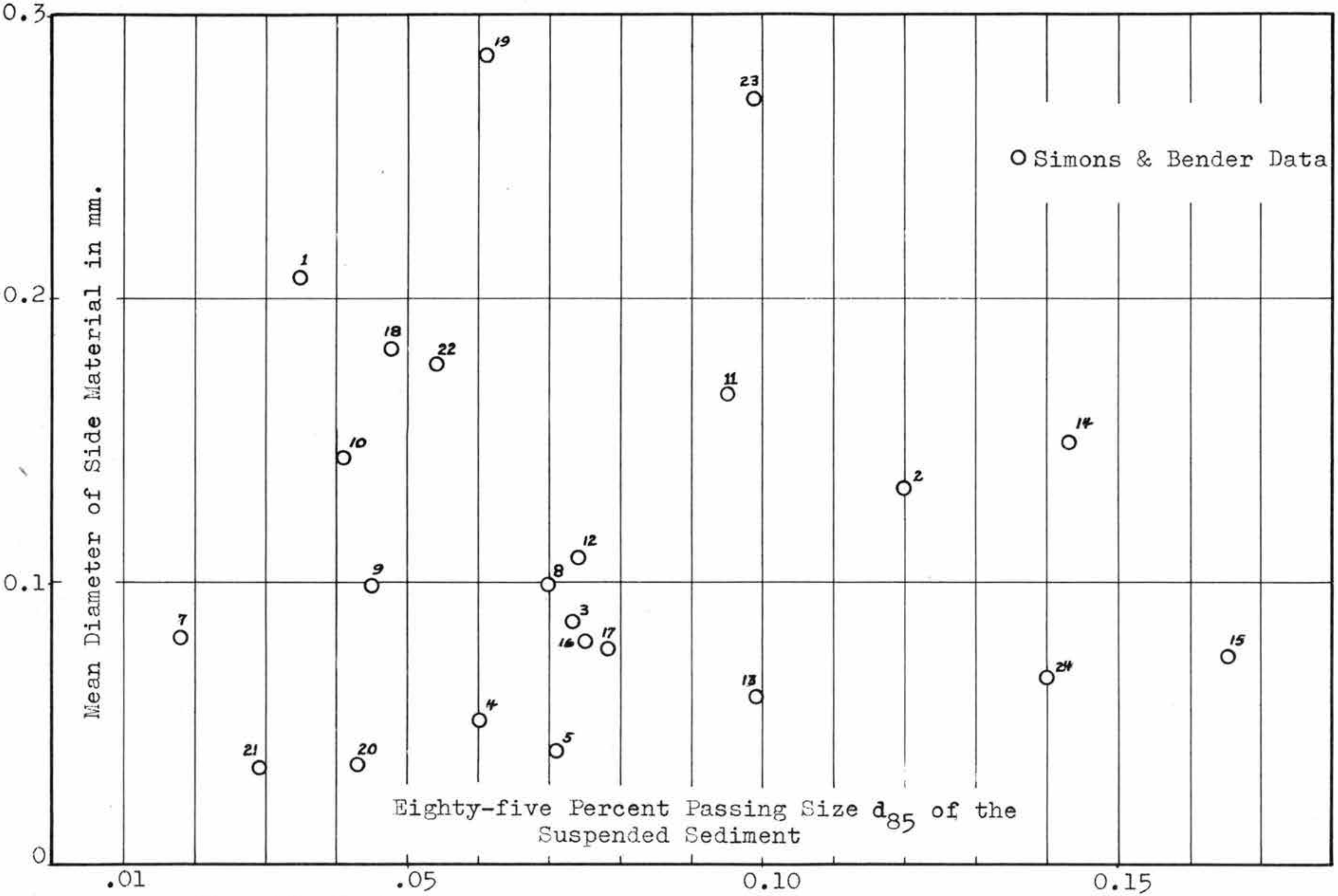


Fig. 54 Variation of side material d with suspended sediment d_{85}

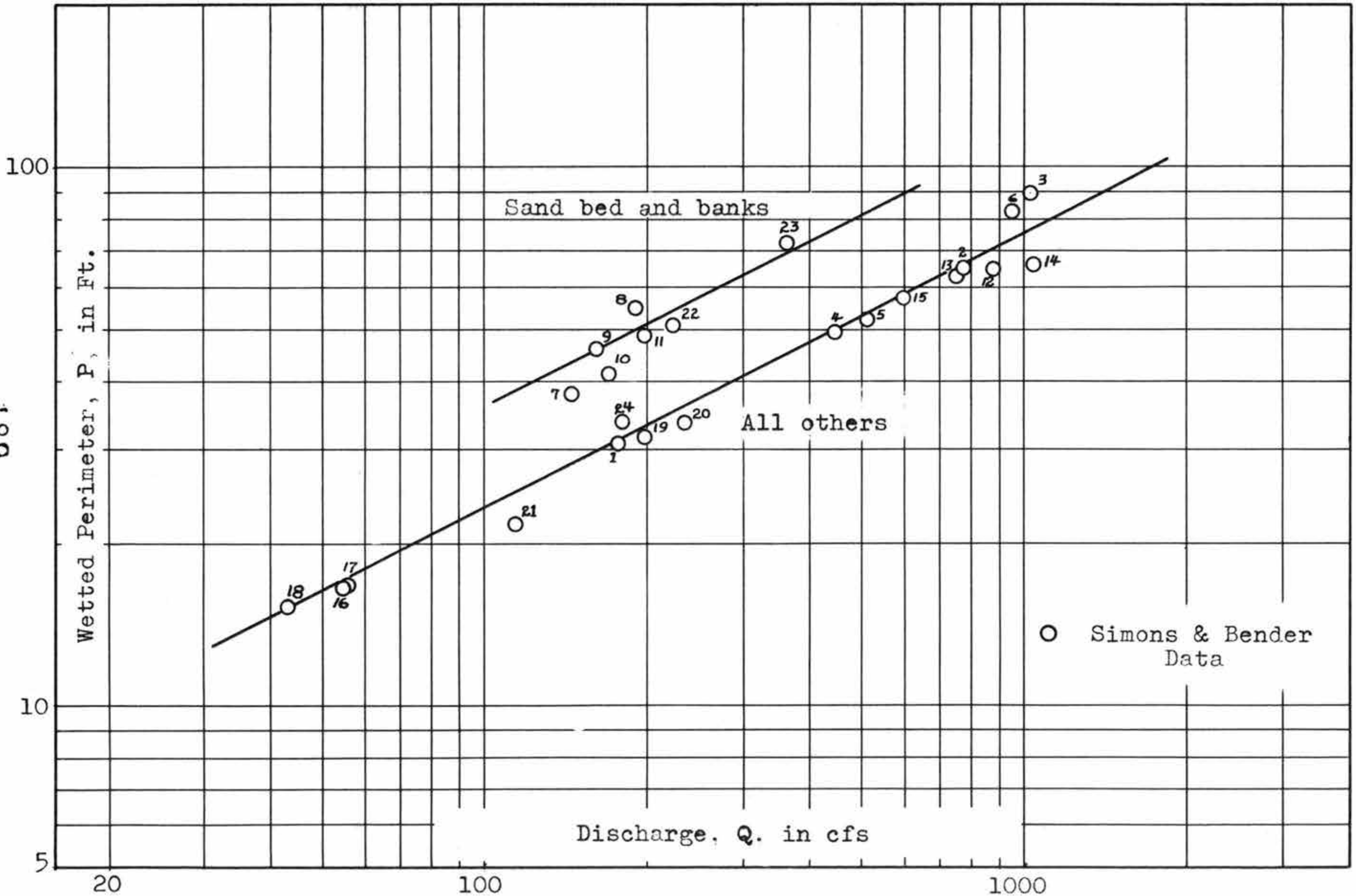


Fig. 55 Variation of wetted perimeter P with discharge Q and type of channel

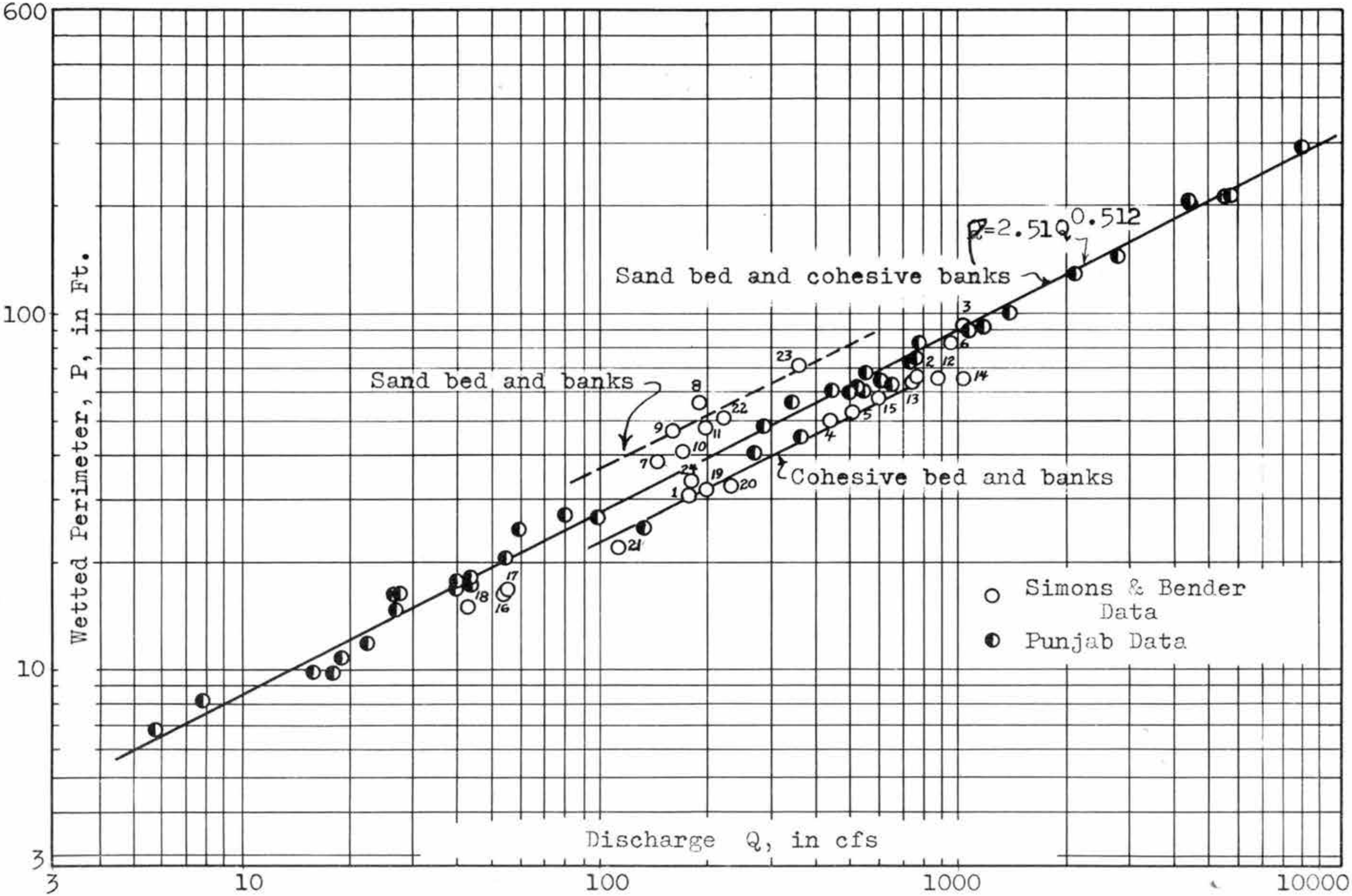


Fig. 56 Variation of wetted perimeter P with discharge Q and types of channel

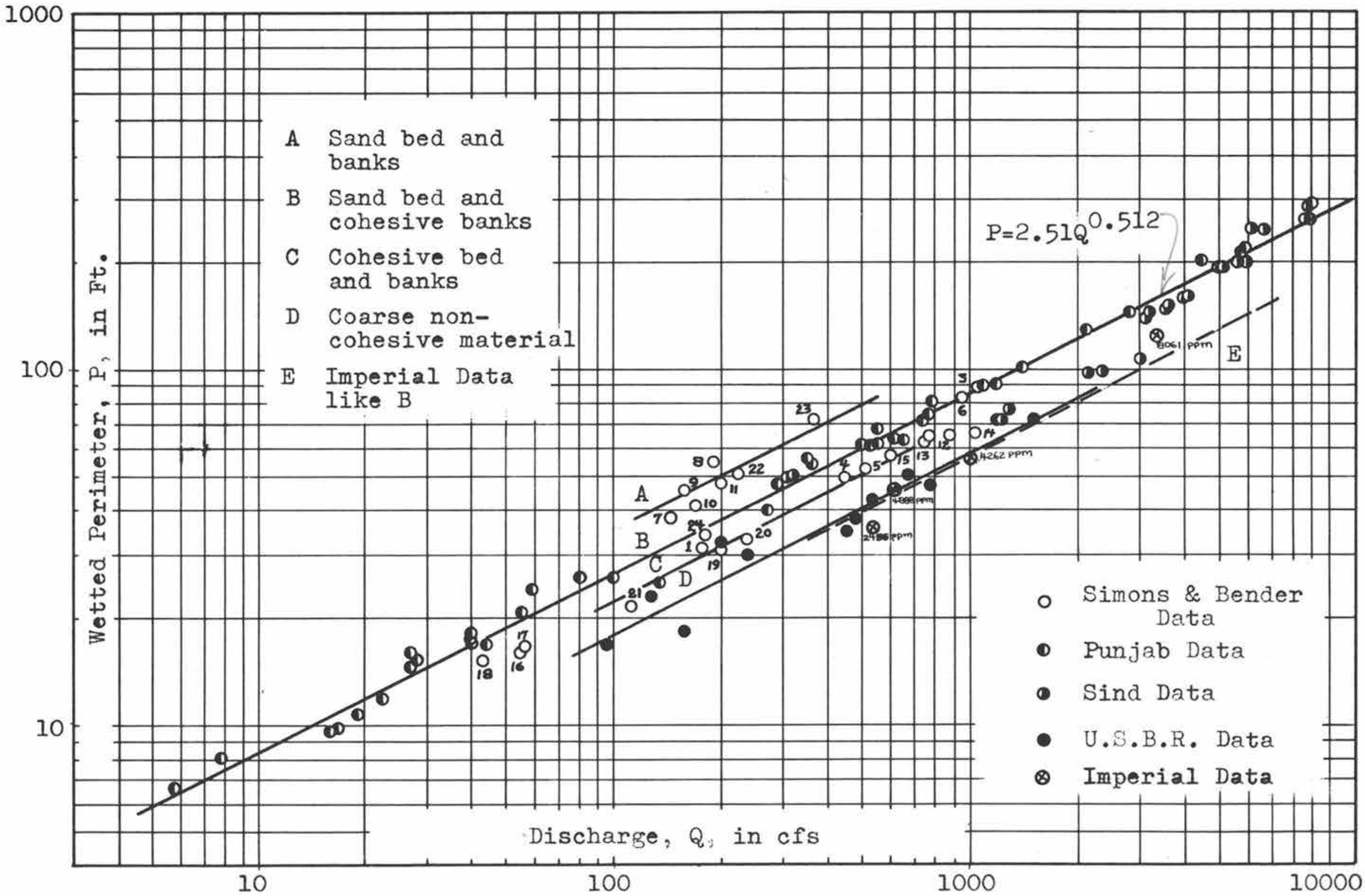


Fig. 57 Variation of wetted perimeter P with discharge Q and type of channel

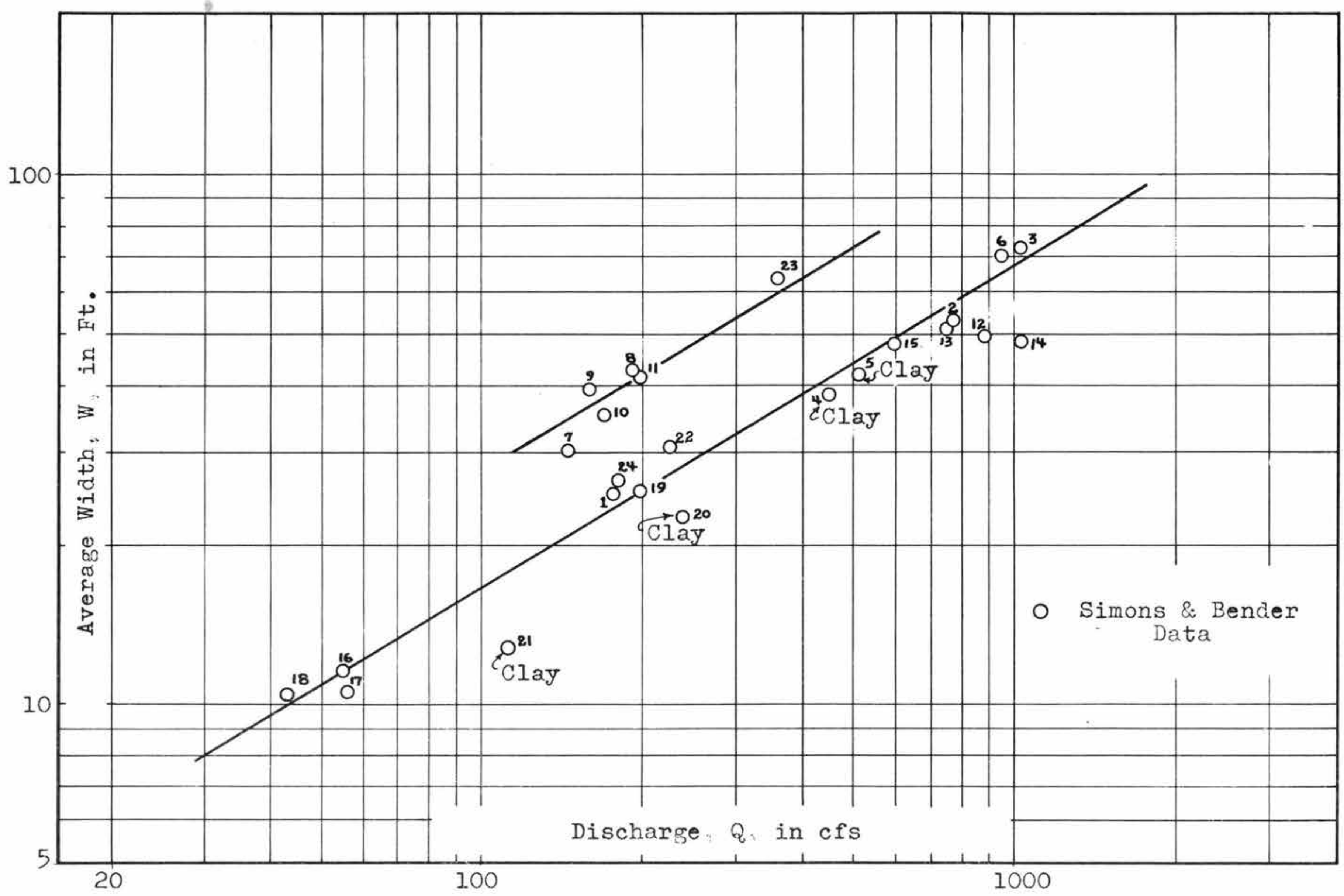


Fig. 58 Variation of average width W with discharge Q and type of channel

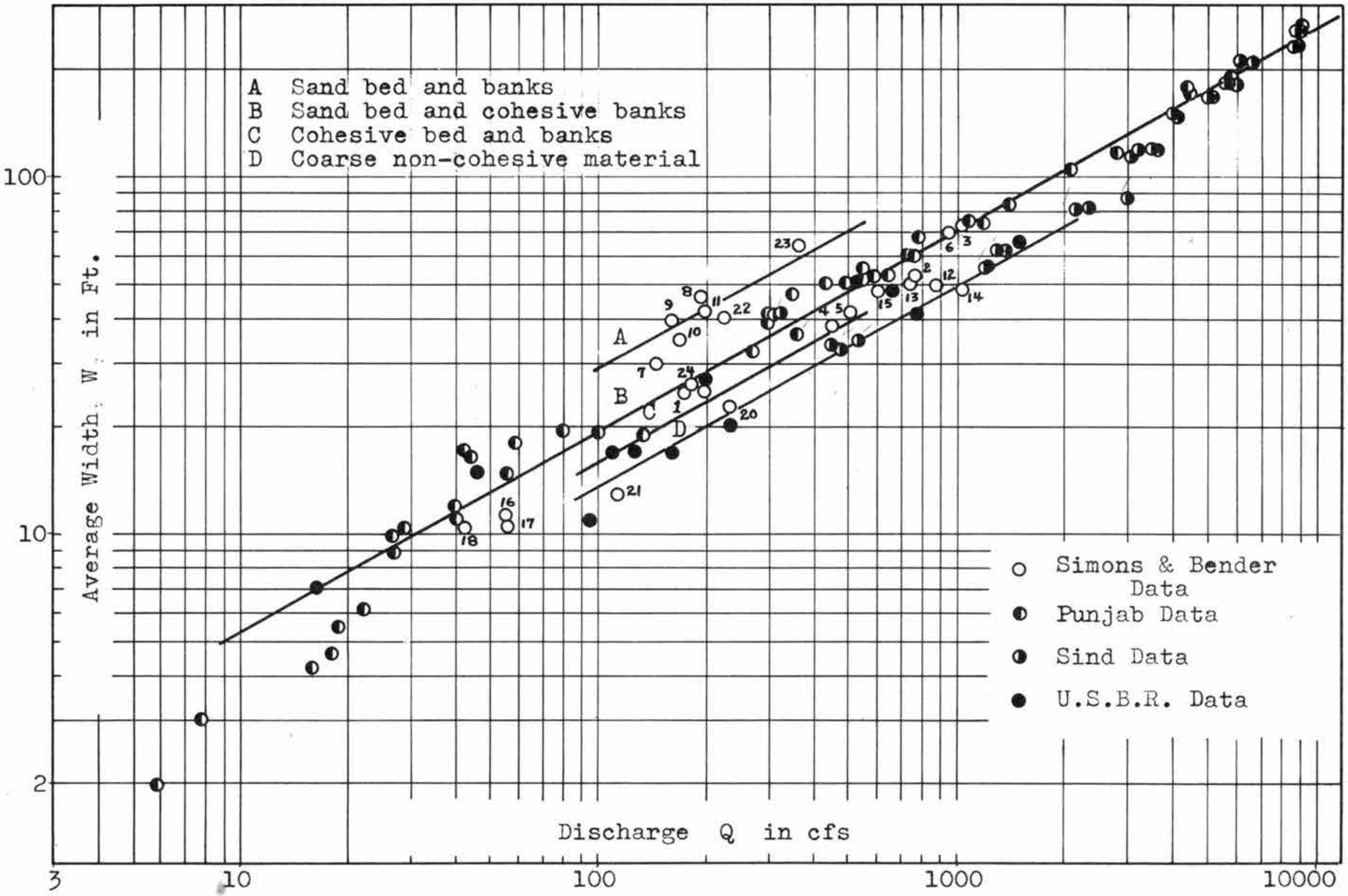


Fig. 59 Variation of average width W with discharge Q and type of channel, all data

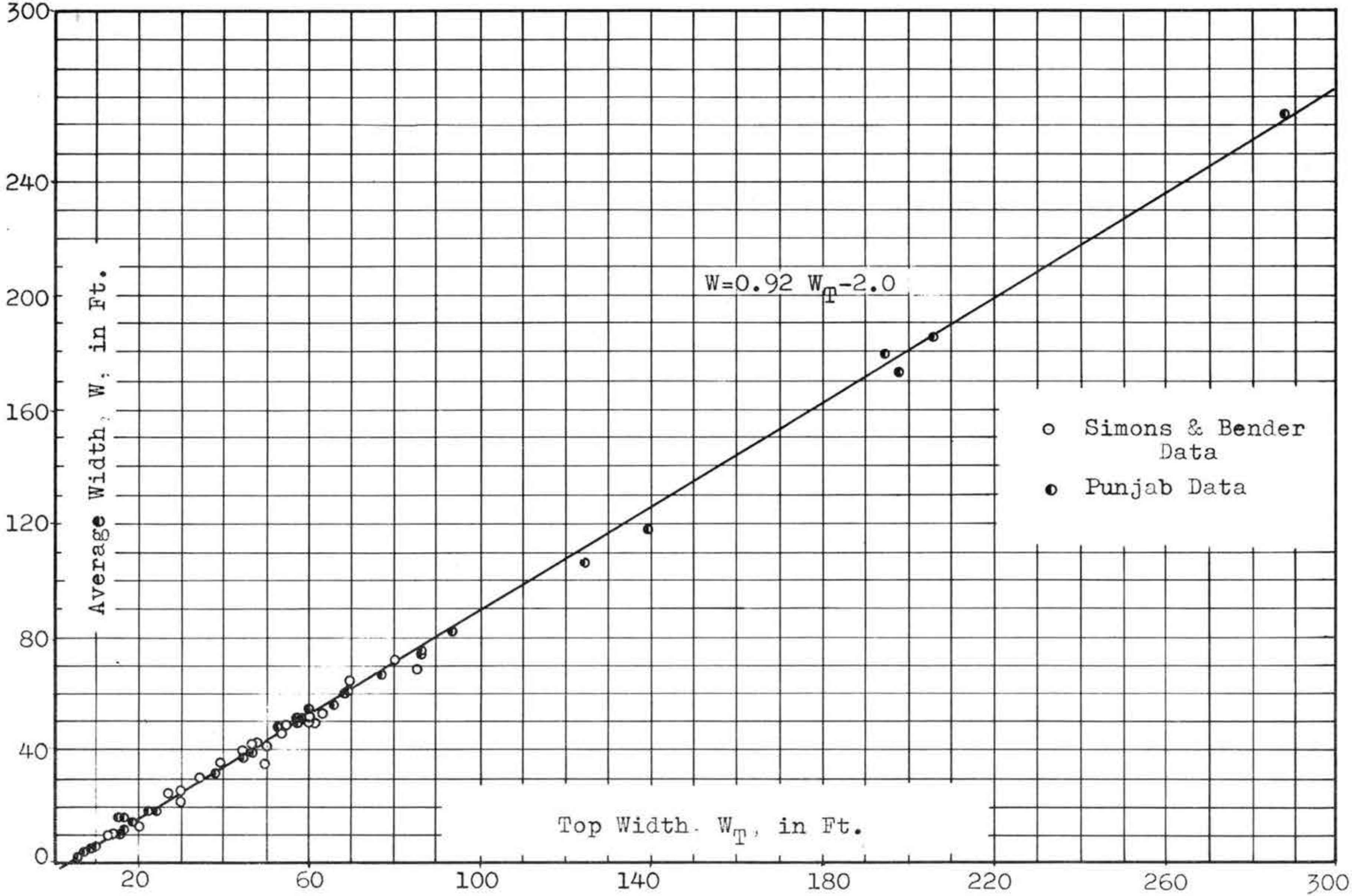


Fig. 60 Variation of average width W with top width W_T

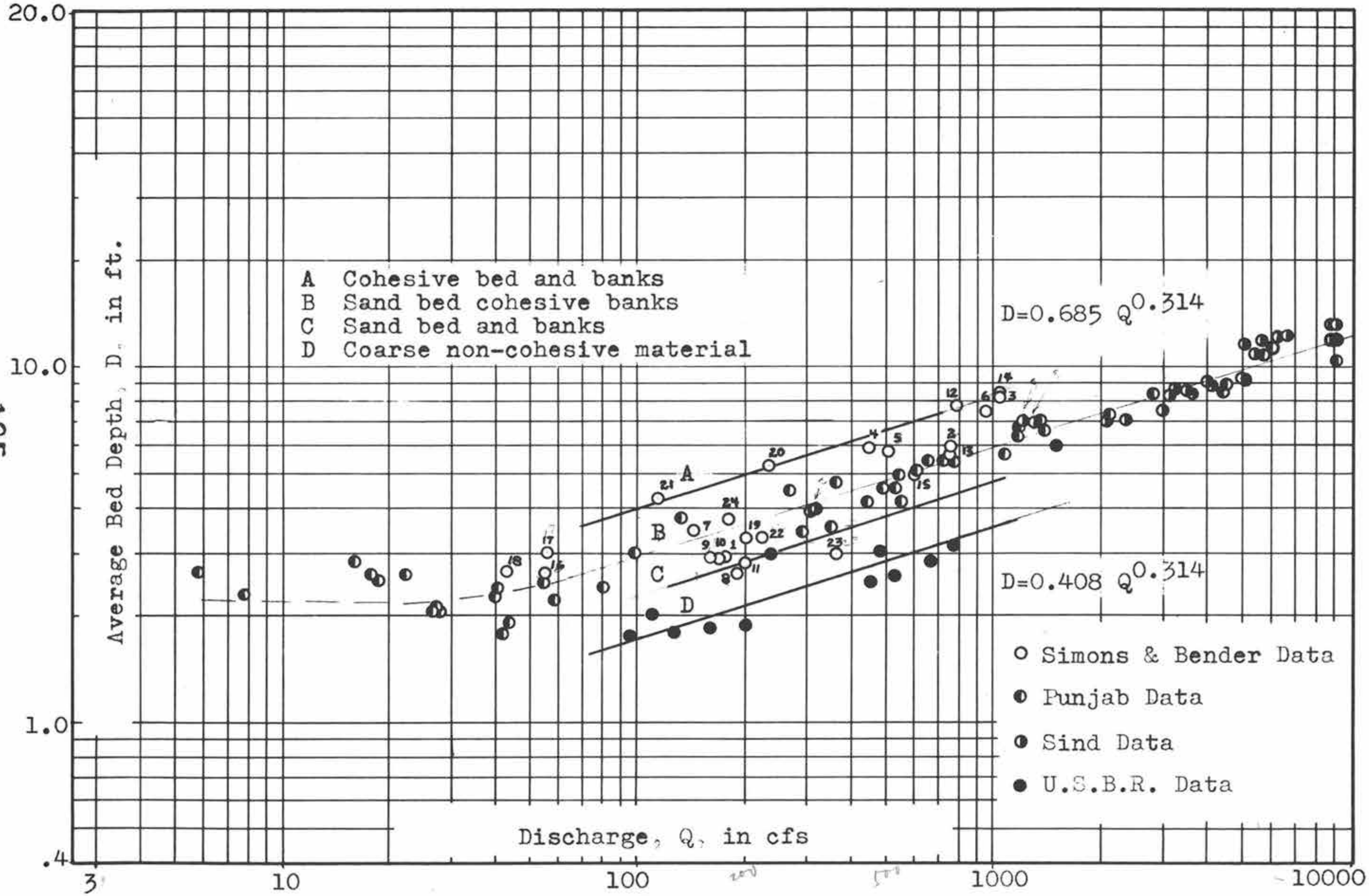


Fig. 61 Variation of bed depth D with discharge Q and type of channel, all data

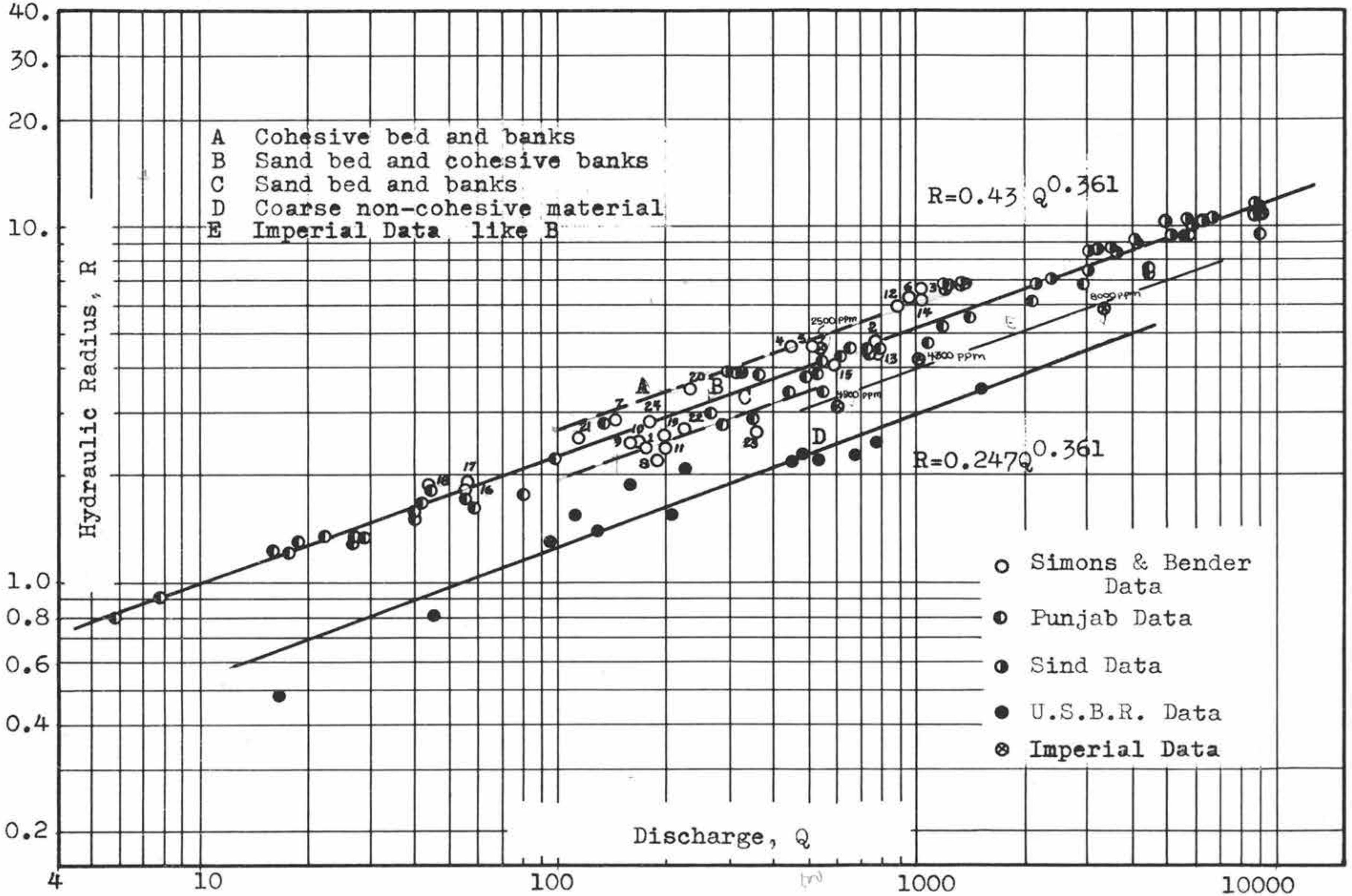


Fig. 62 Variation of hydraulic radius R with discharge Q and type of channel, all data

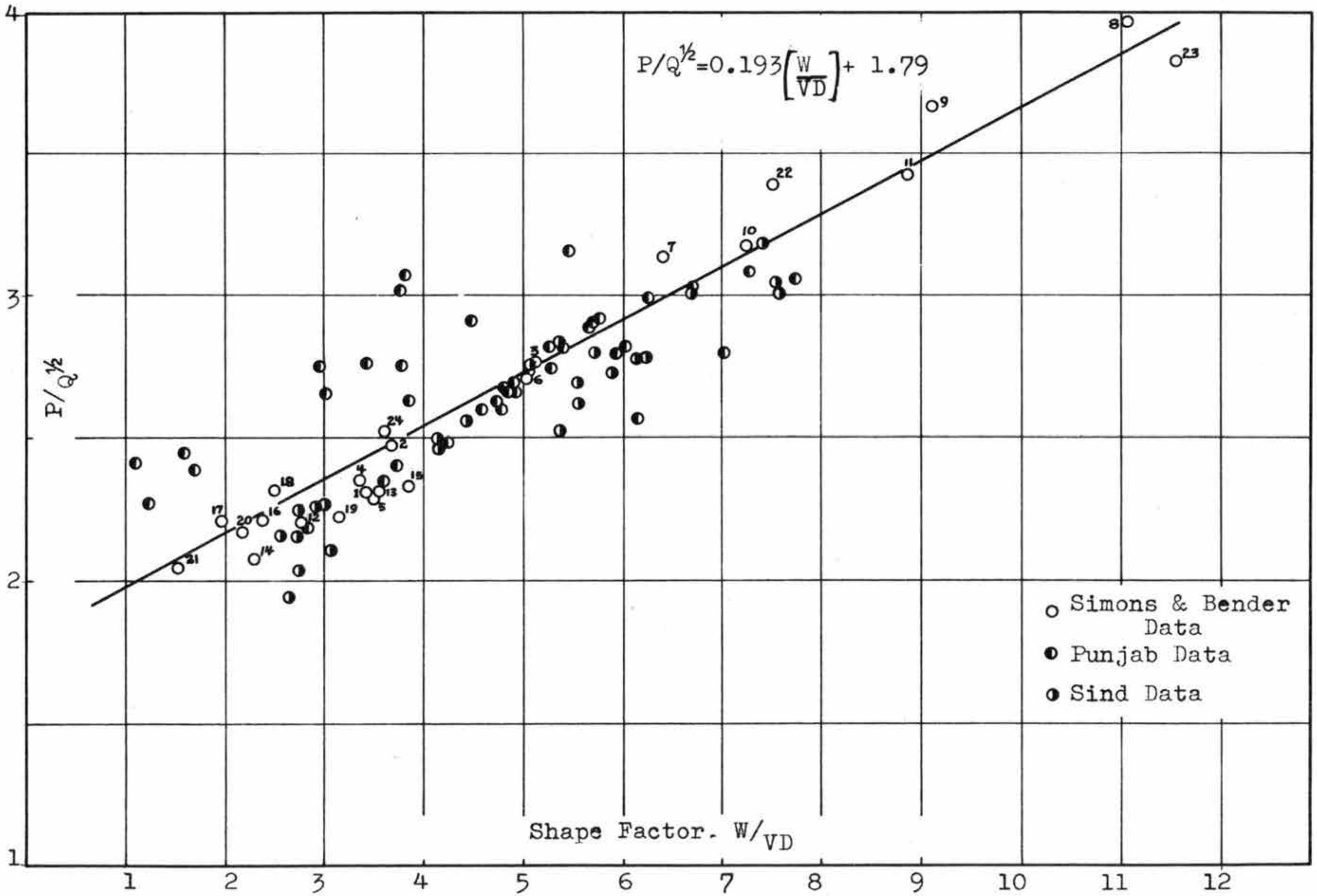


Fig. 63 Variation of $P/_{Q}{}^{1/2}$ with Blench shape factor W/VD

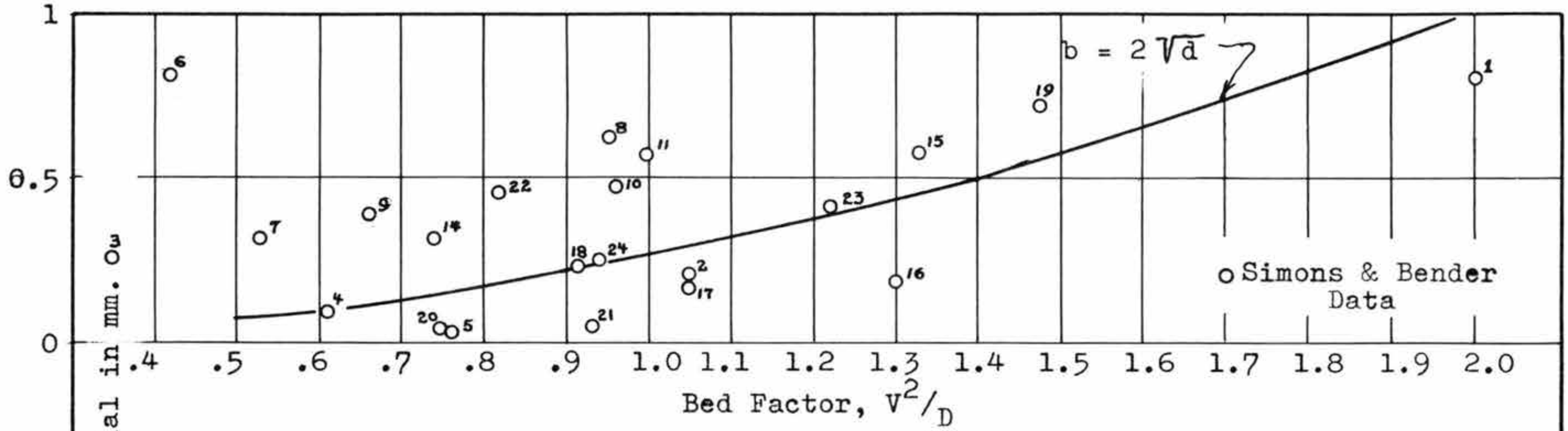


Fig. 64 Variation of bed factor V^2/D with bed material d

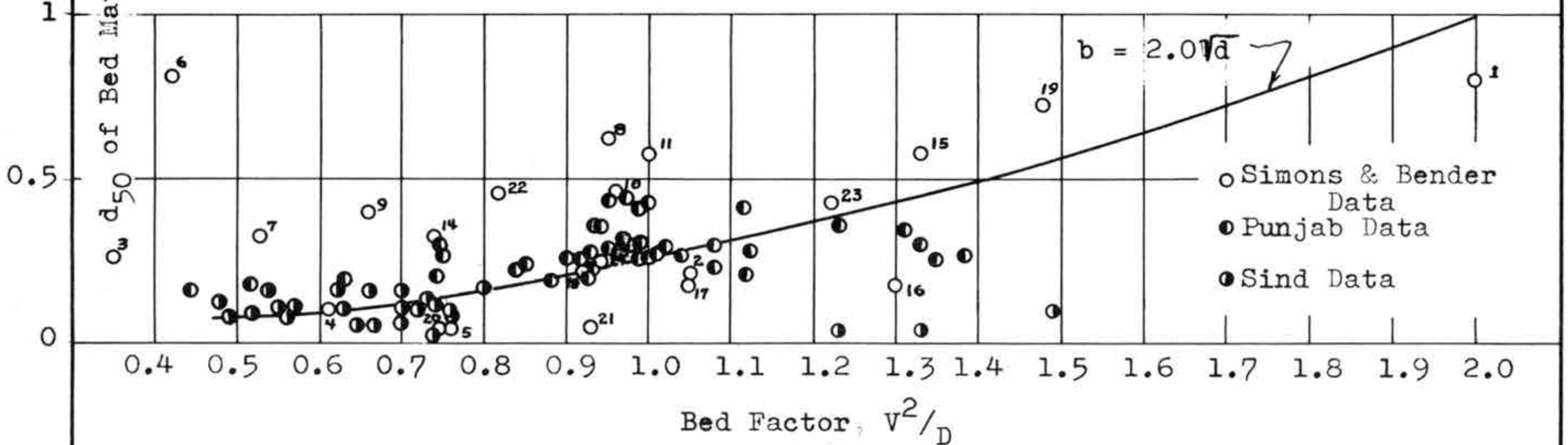


Fig. 65 Variation of bed factor V^2/D with bed material d, all data

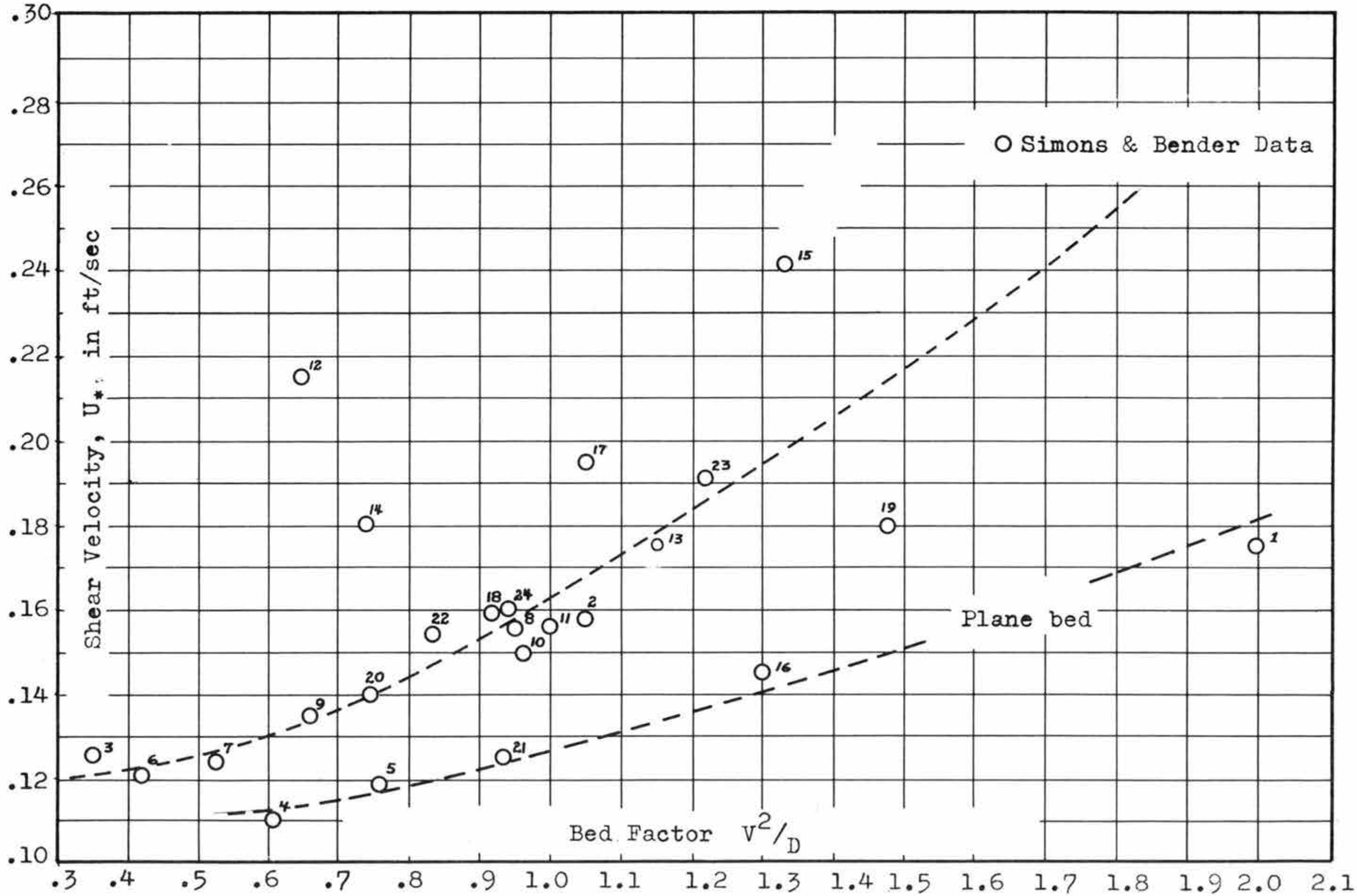


Fig. 66 Variation of shear velocity U_* with bed factor V^2/D

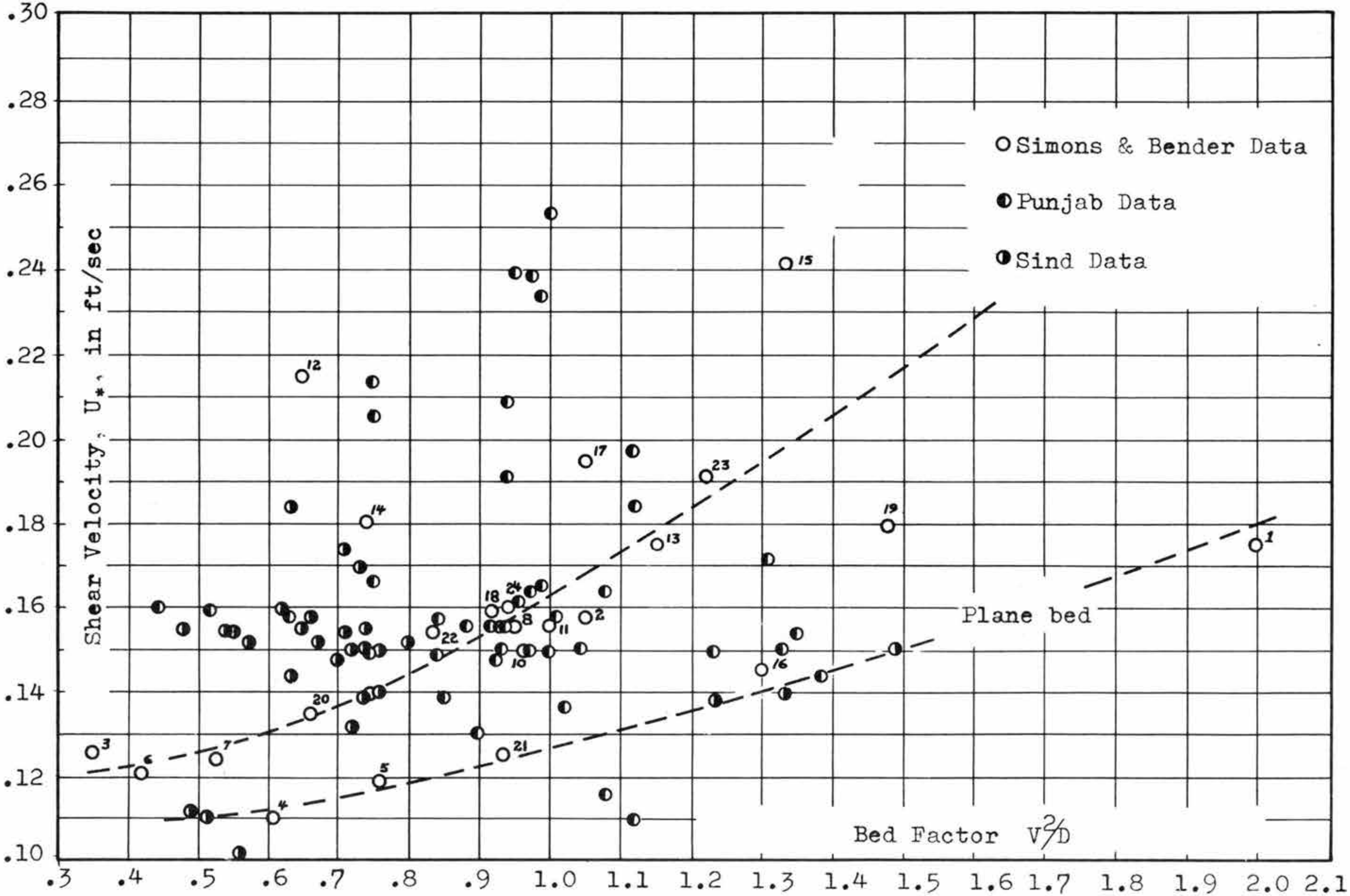


Fig. 67 Variation of shear velocity U_* with bed factor V^2/D, three groups of data

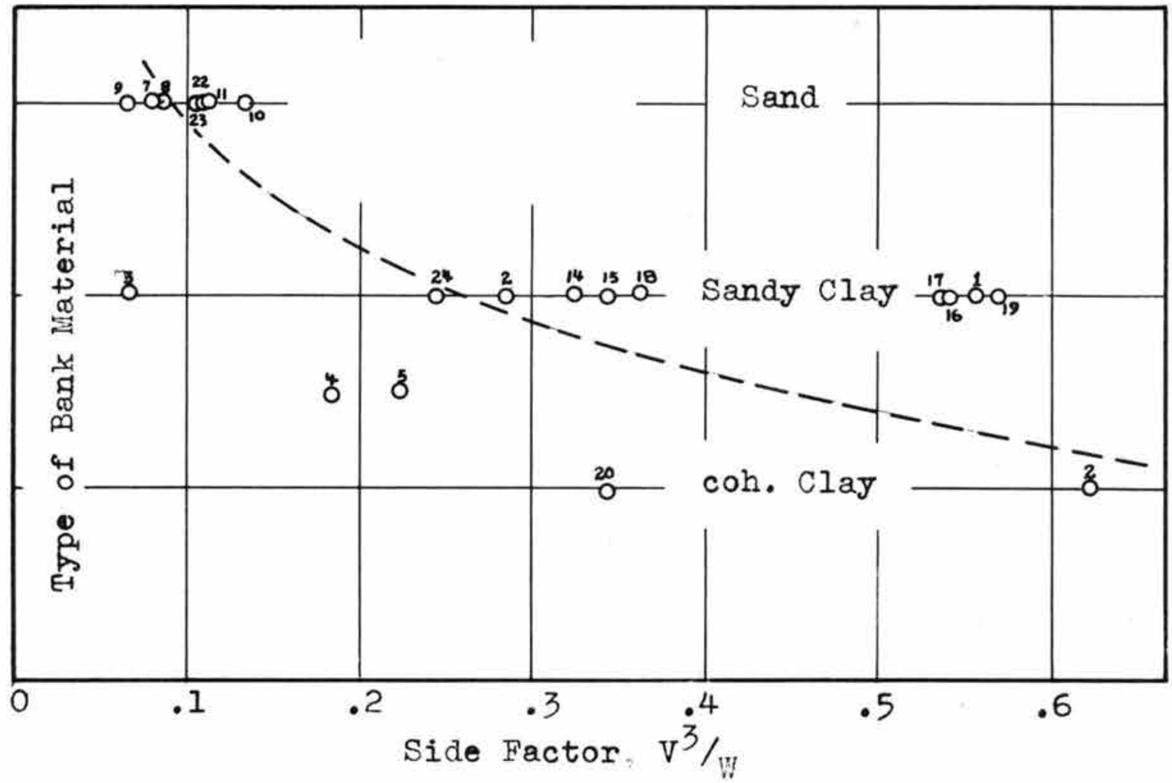


Fig. 68 Variation of type of bank material with side factor V^3/W

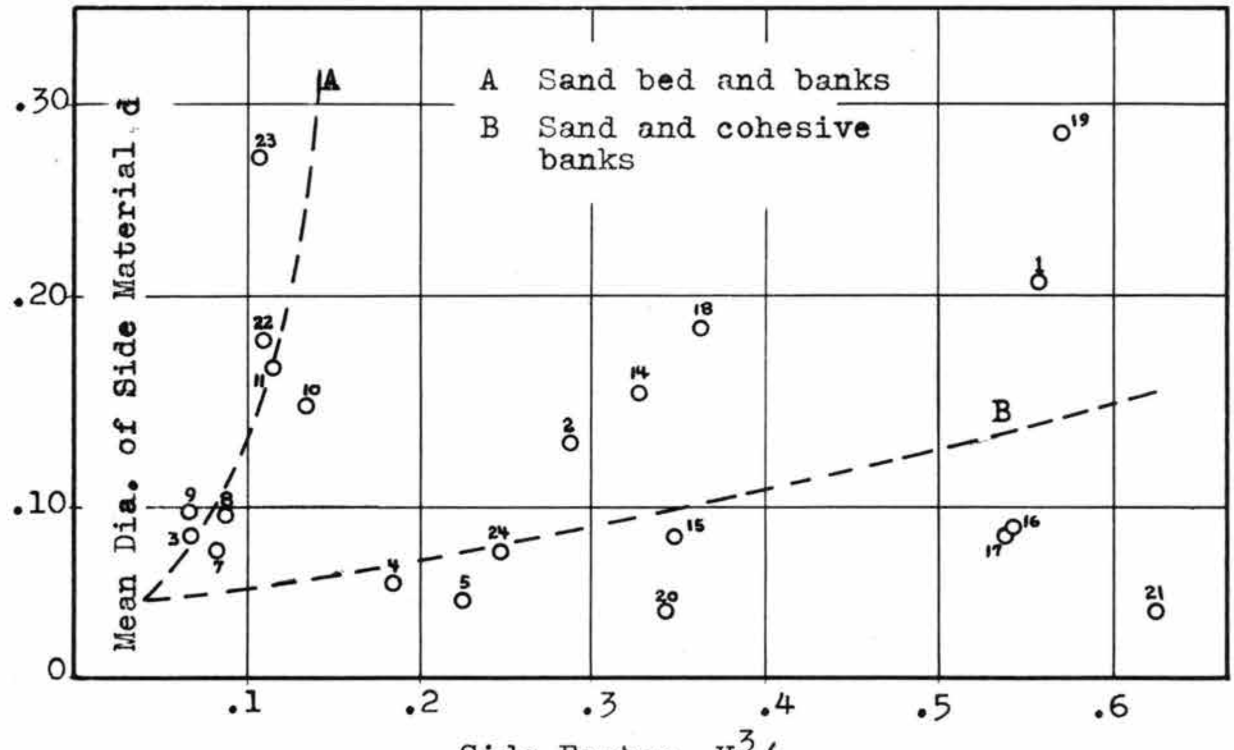


Fig. 69 Variation of side material d with side factor V^3/W

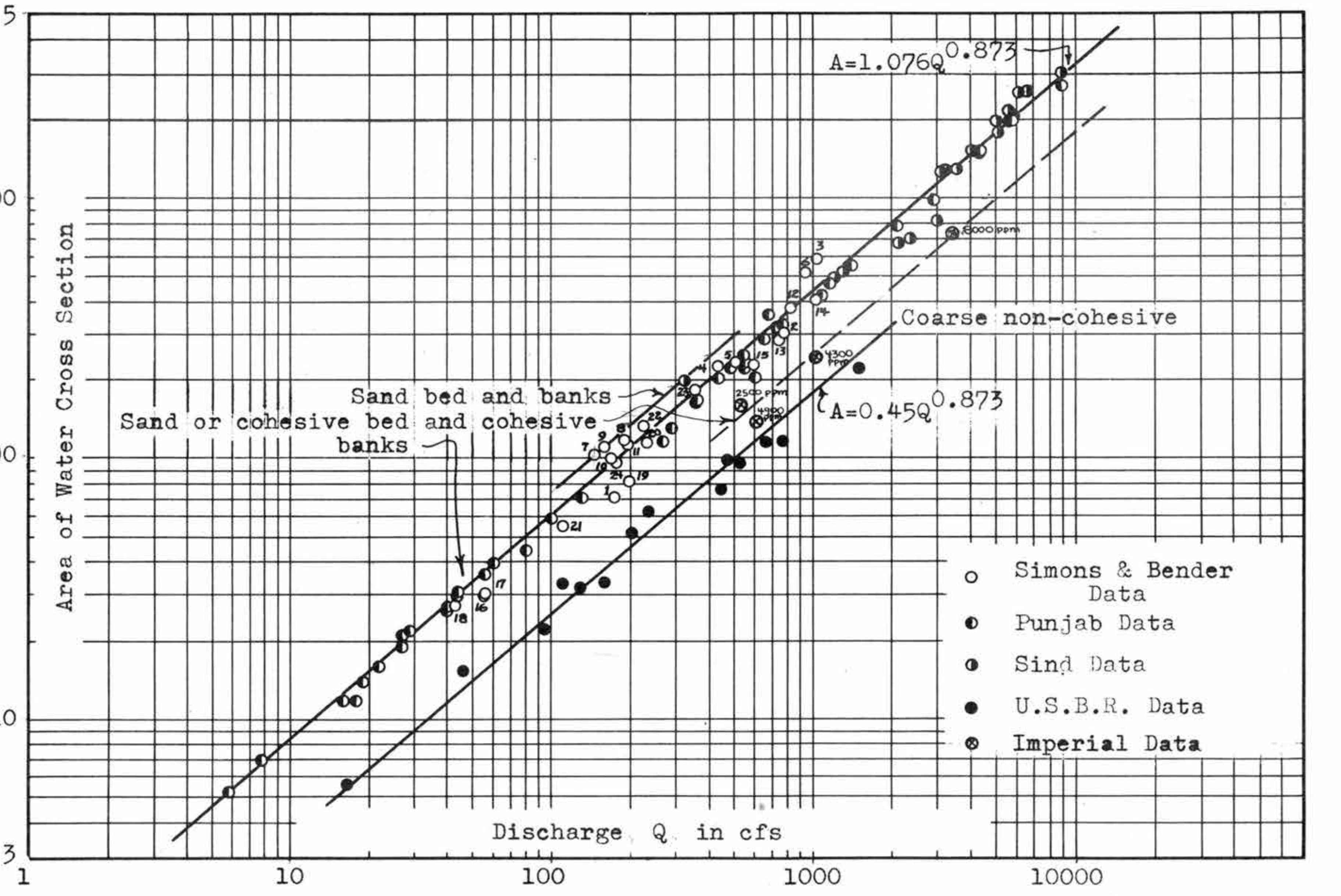


Fig. 70 Variation of area of water cross-section A with discharge Q and type of channel

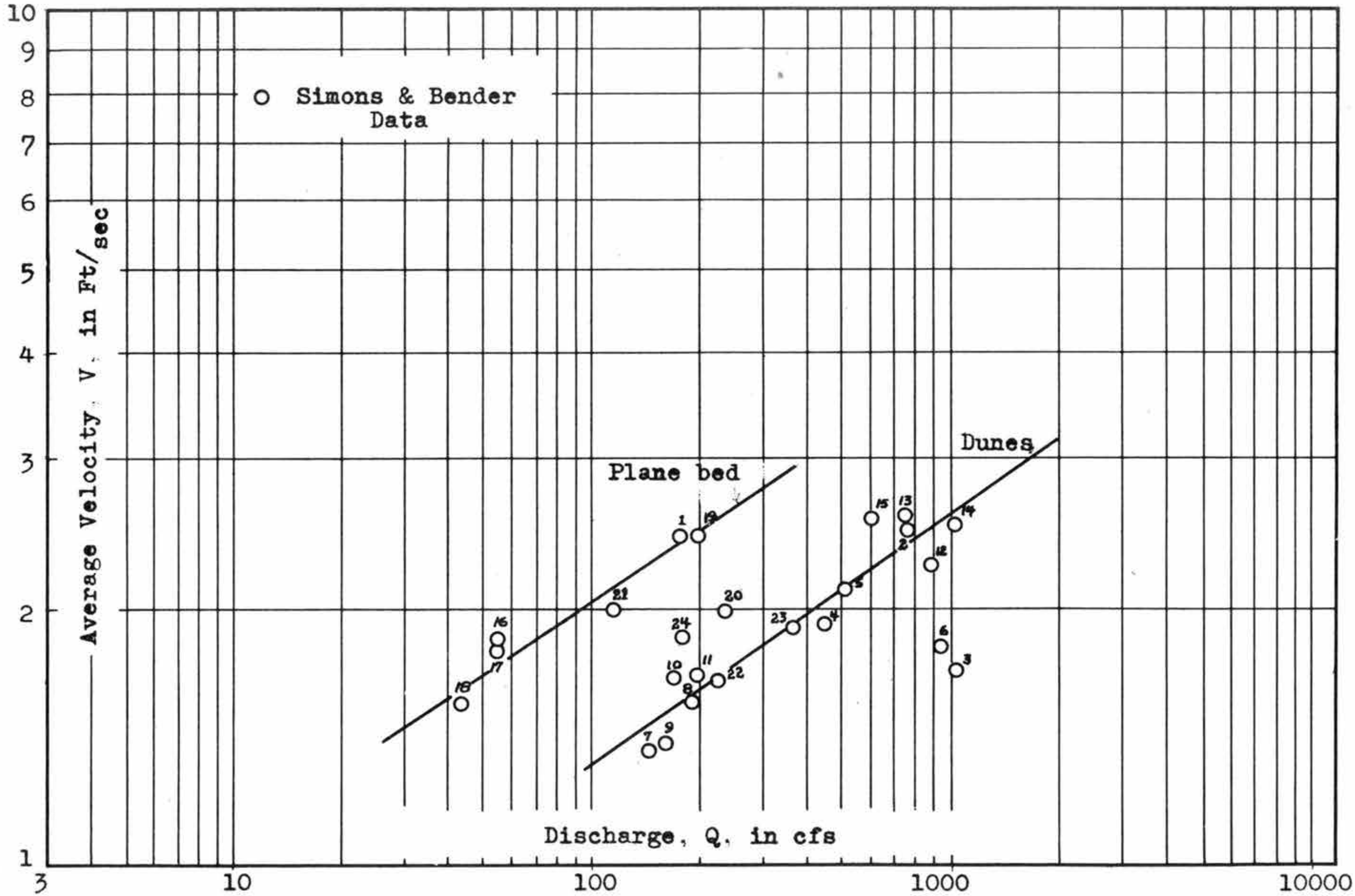


Fig. 71 Variation of average velocity V with discharge Q and type of bed roughness

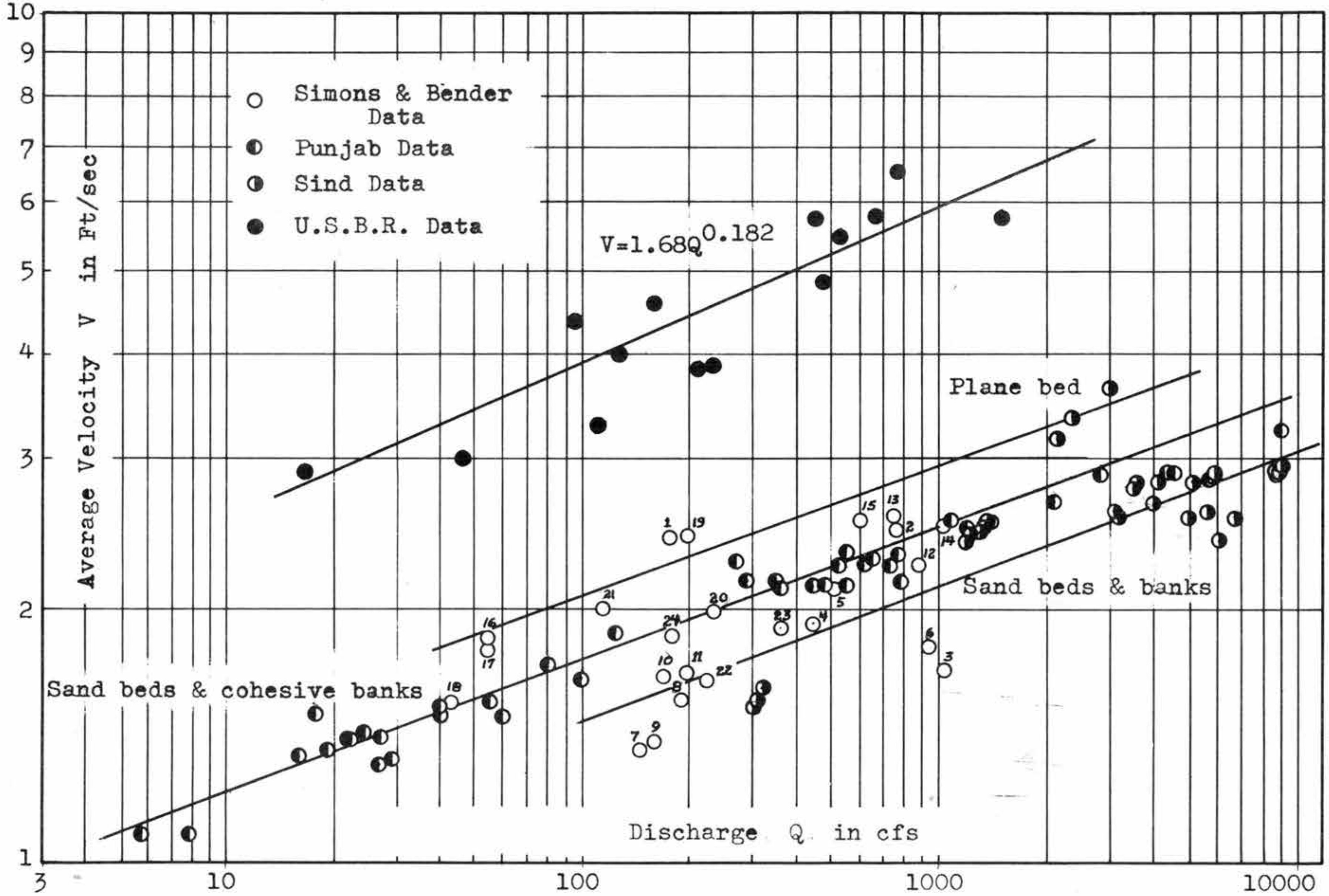


Fig. 72 Variation of average velocity V with discharge Q and type of channel, all data

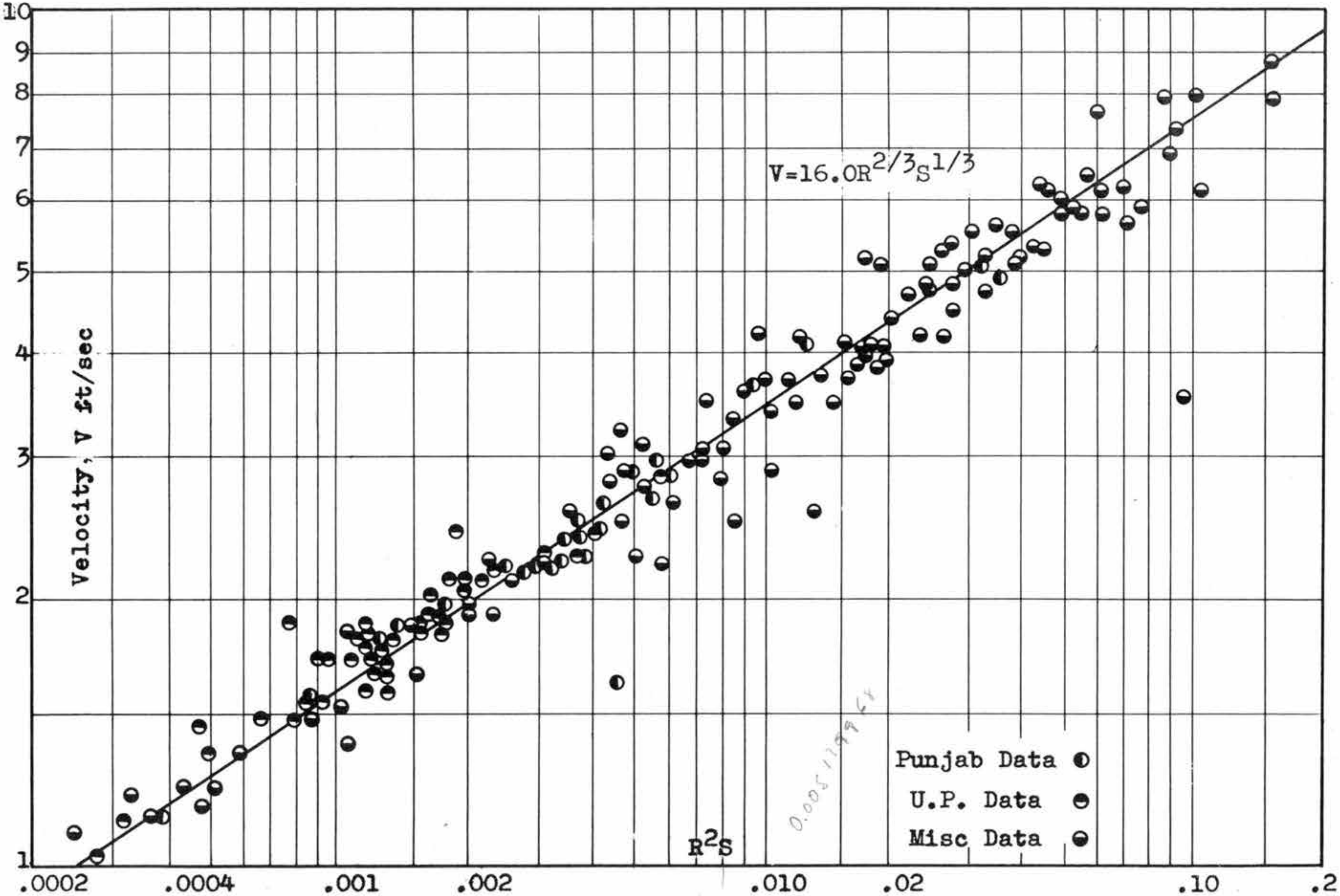


Fig. 73 Variation of average velocity V with R^2S, India data

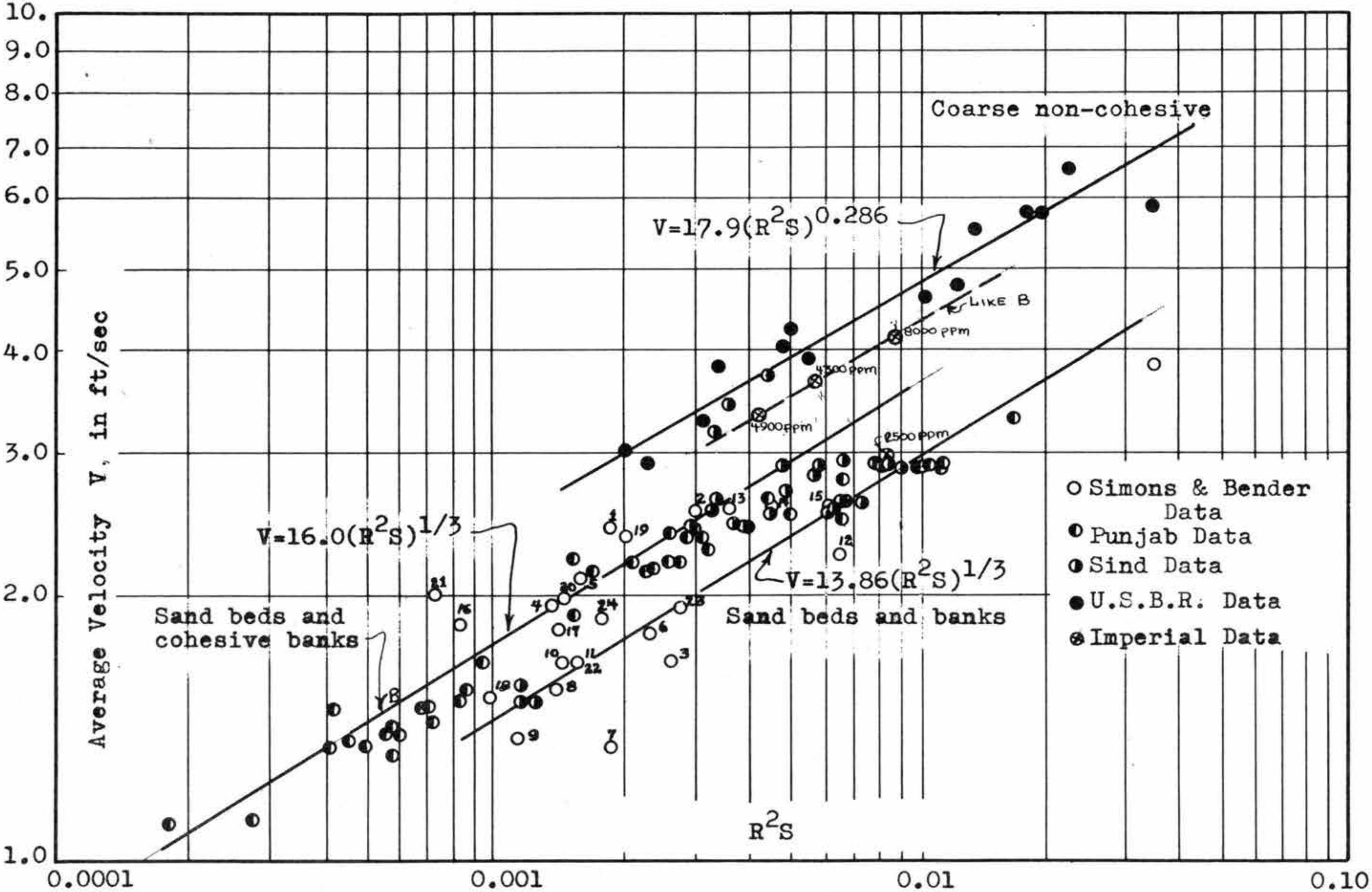


Fig. 74 Variation of average velocity V with R^2S and type of channel, all data

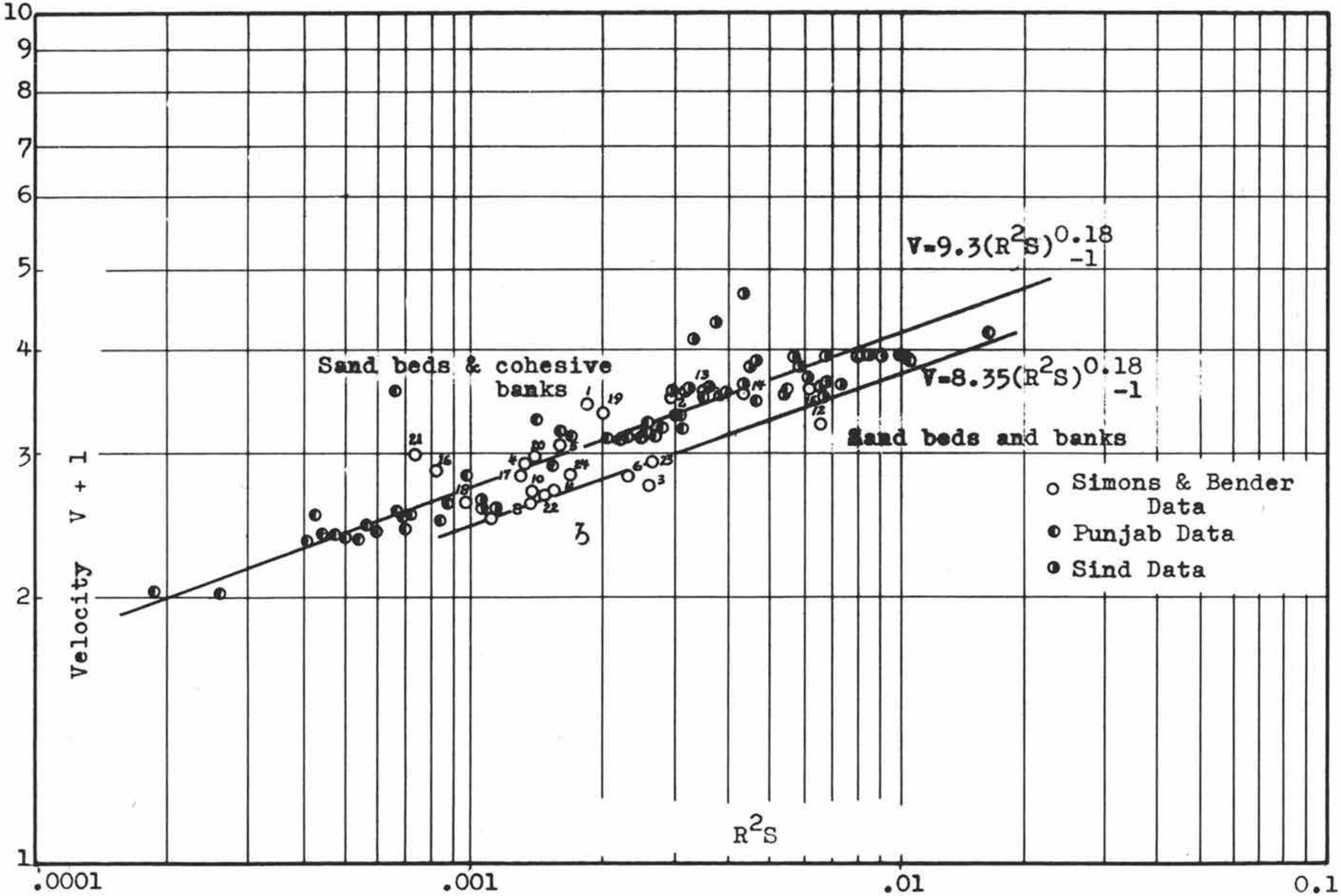


Fig. 75 Variation of average velocity V + 1 with R^2S and type of channel

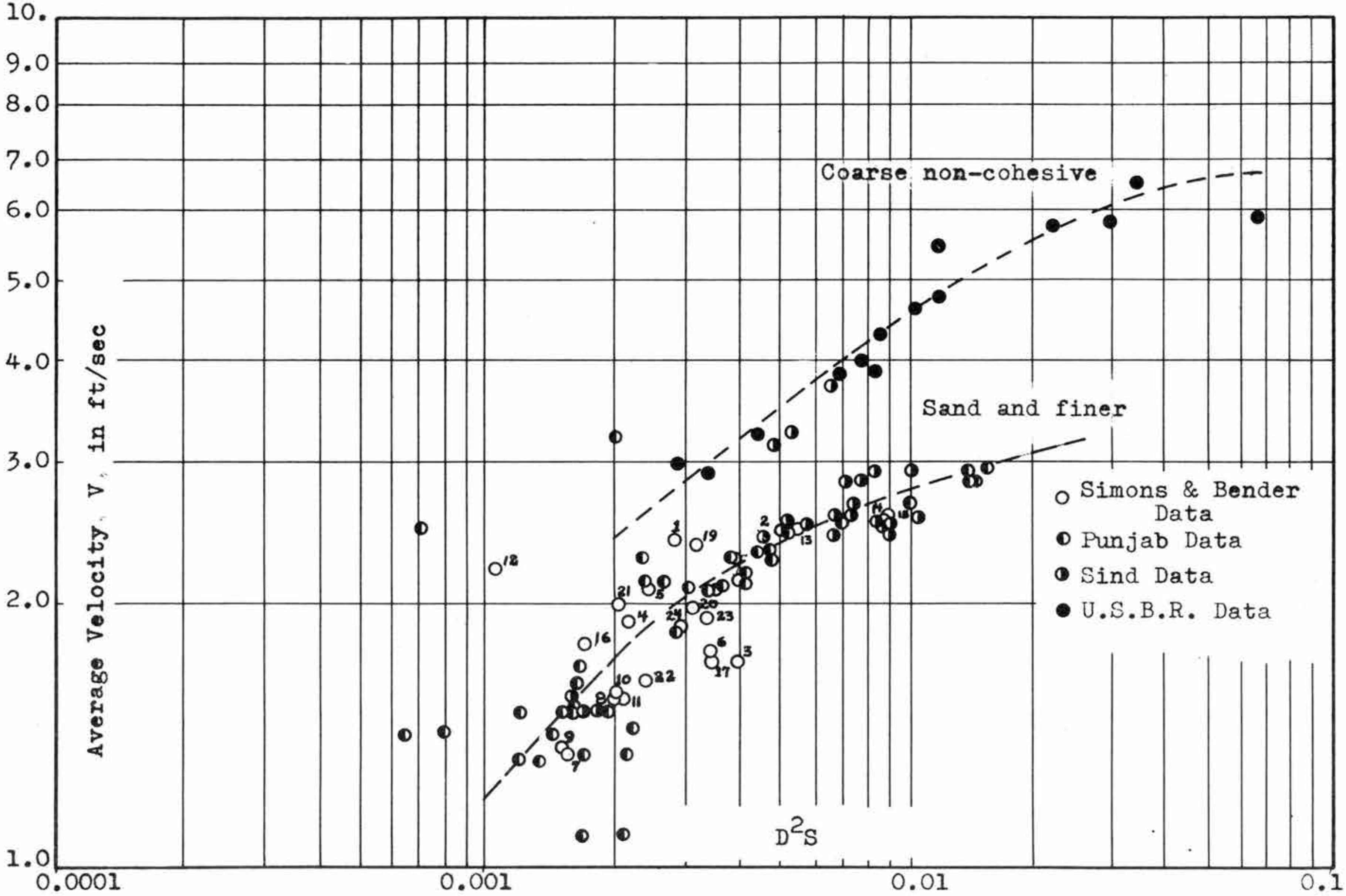


Fig. 76 Variation of average velocity V with D^2S and type of channel

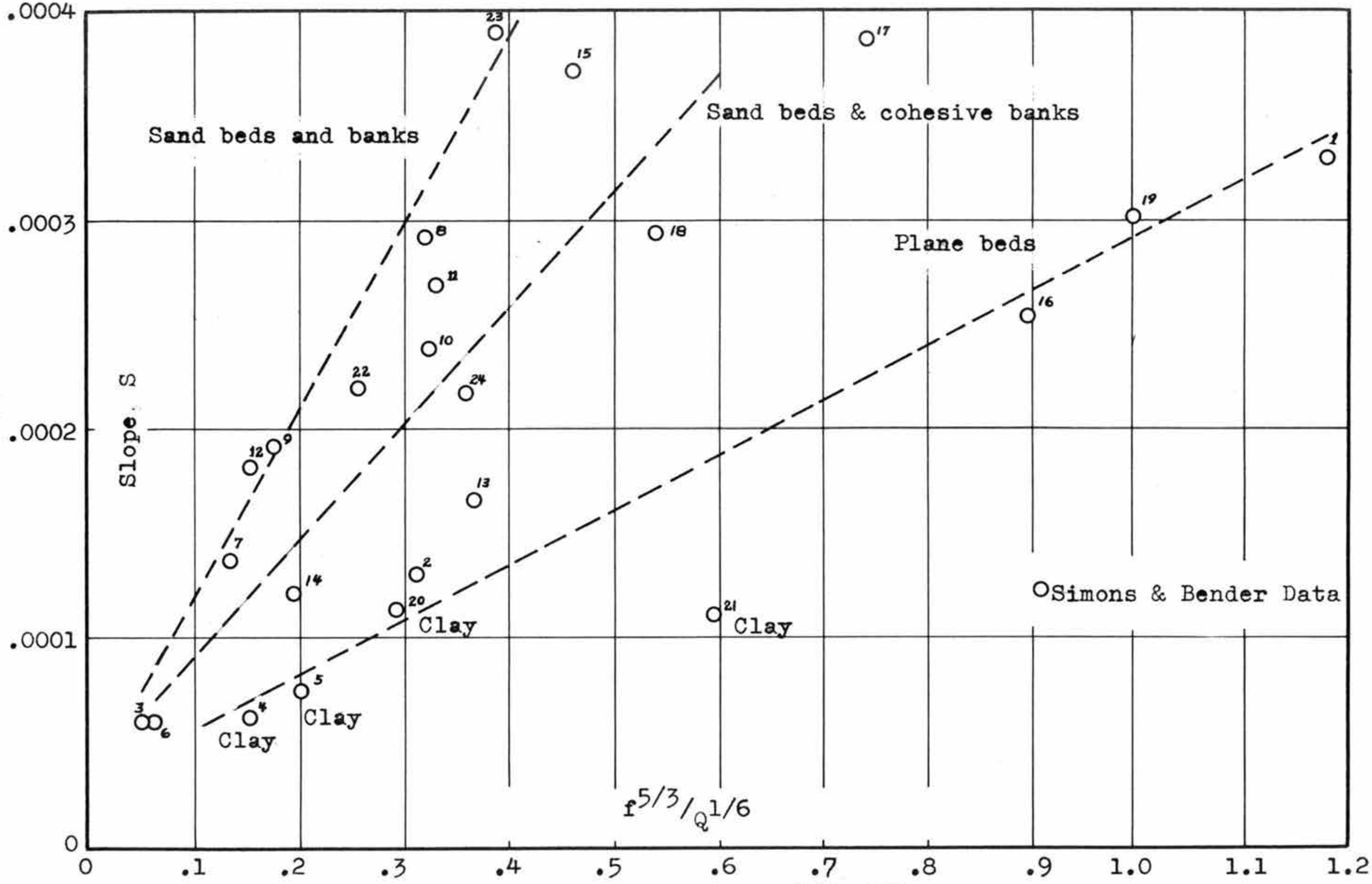


Fig. 77 Variation of slope S with $f^{5/3}/Q^{1/6}$ and type of channel

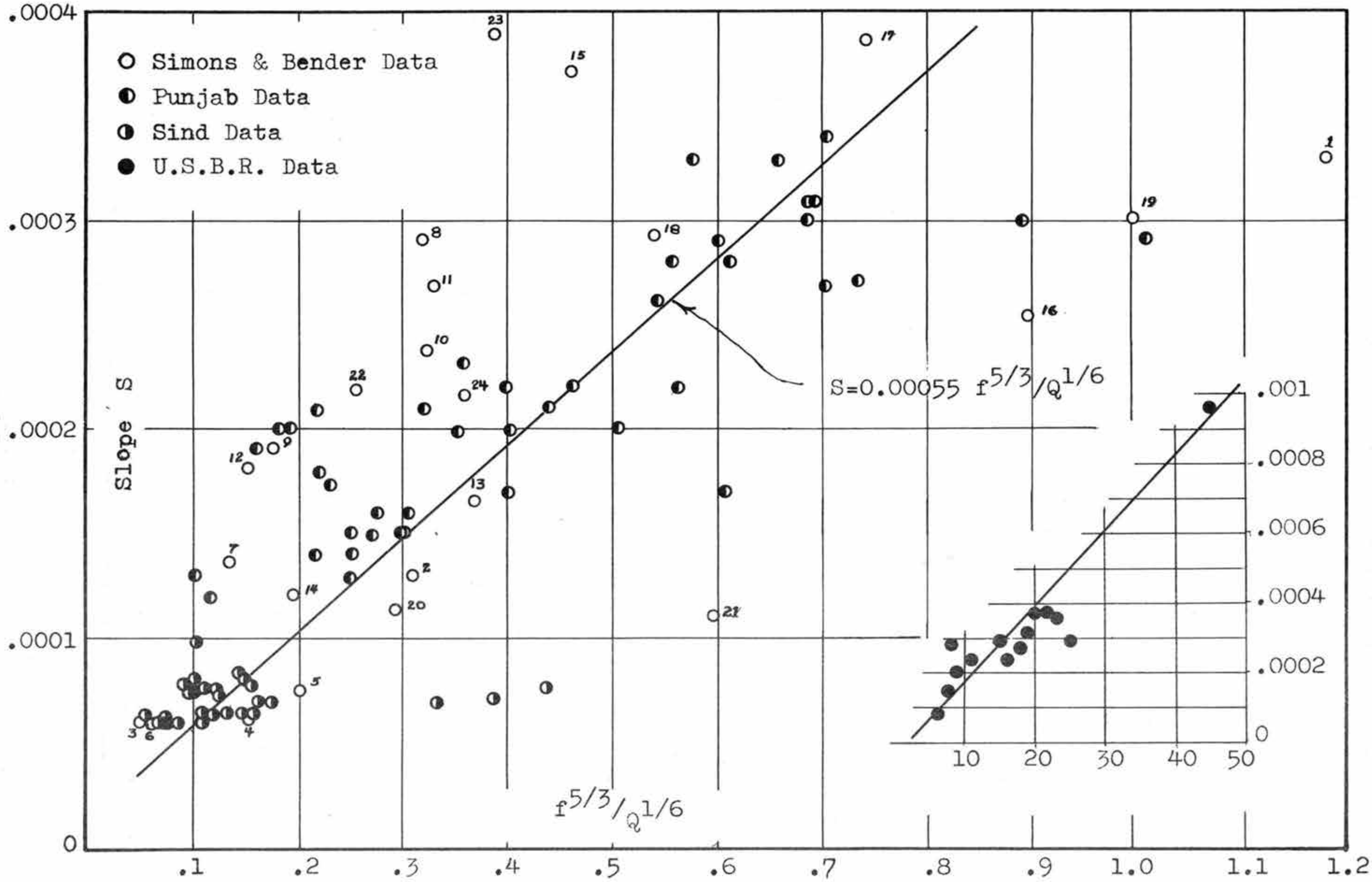


Fig. 78 Variation of slope S with $f^{5/3}/Q^{1/6}$ and type of channel, all data

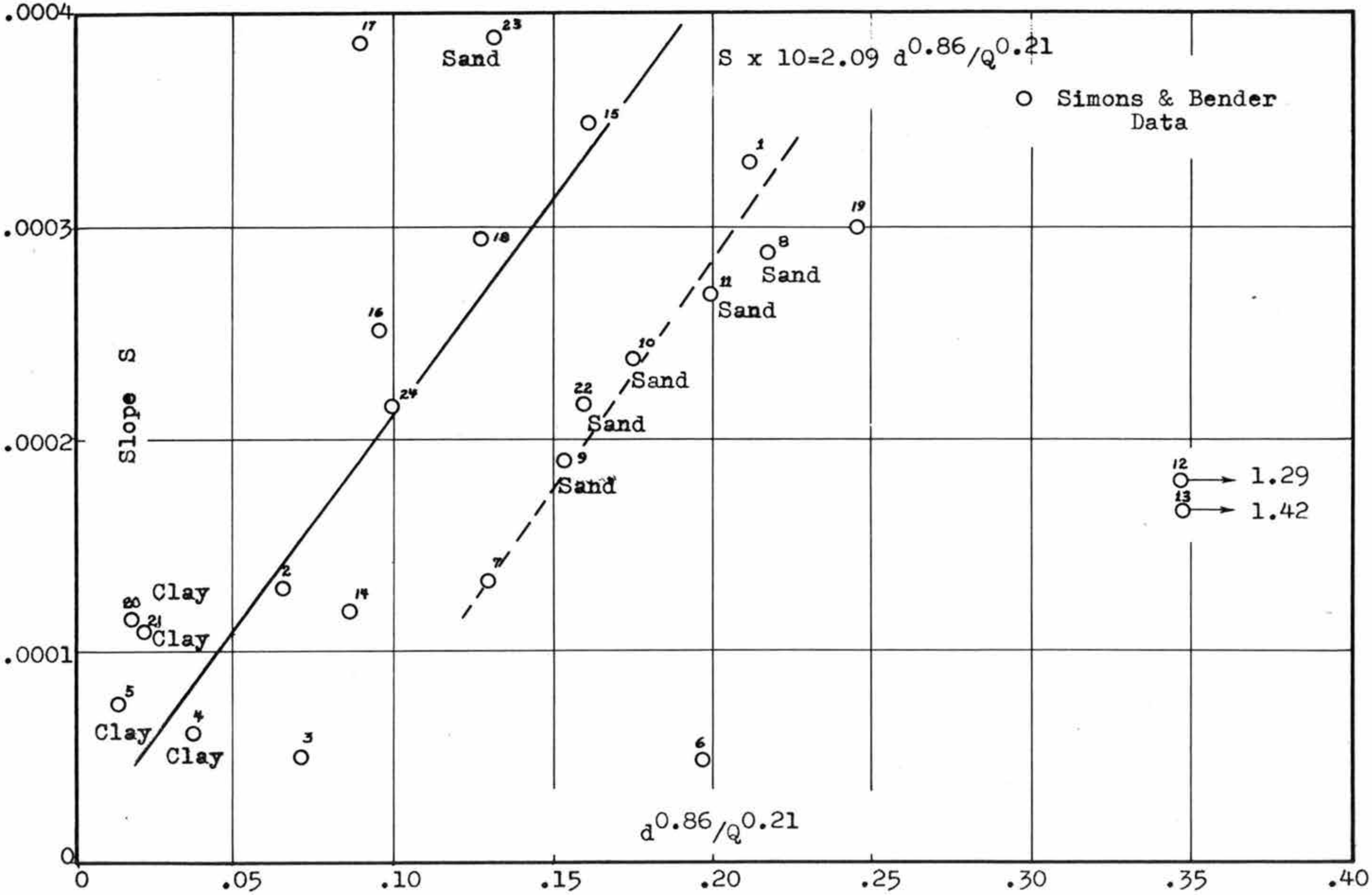


Fig. 79 Variation of slope S with $d^{0.86}/Q^{0.21}$

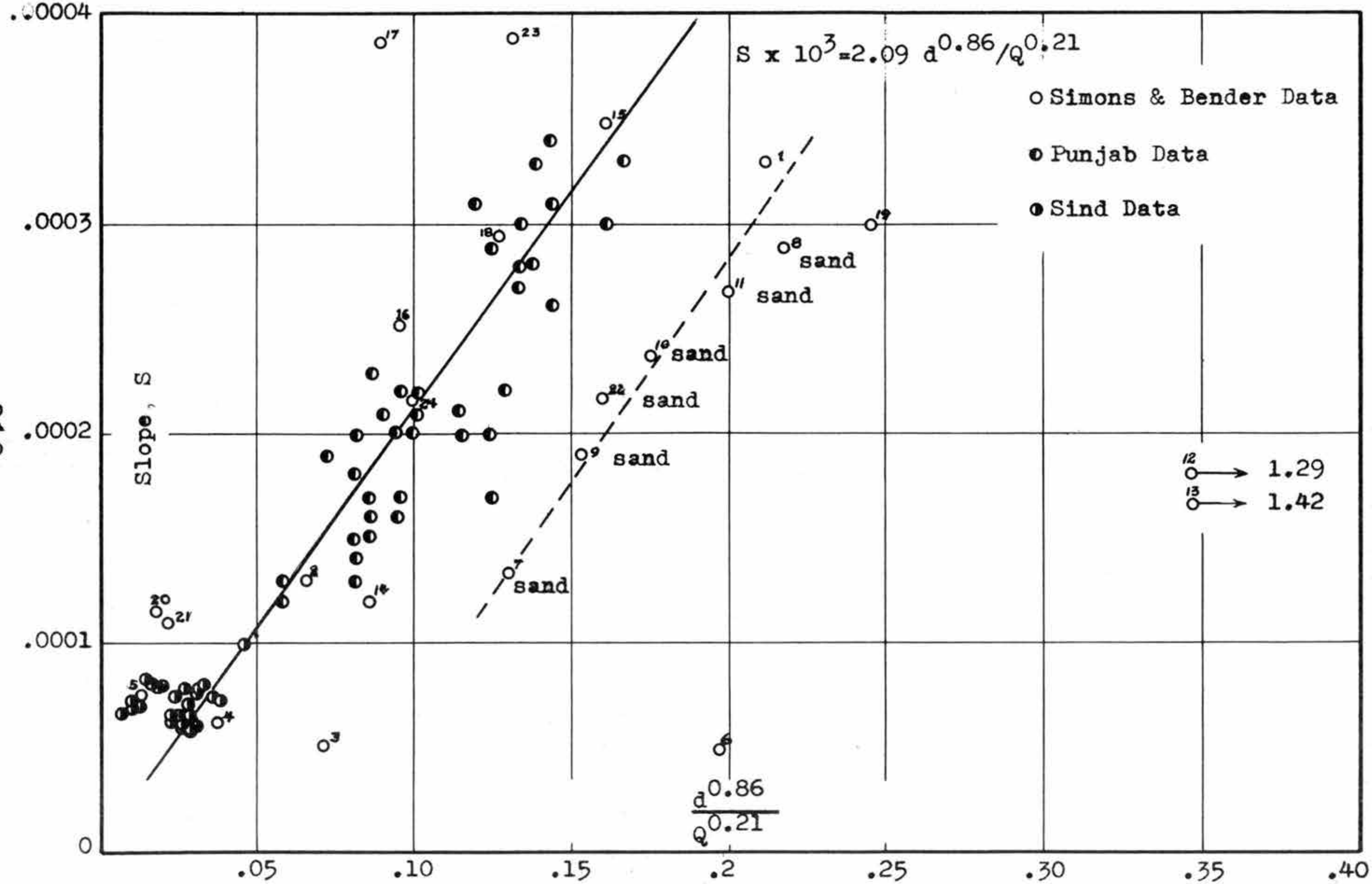


Fig. 80 Variation of slope S with $d^{0.86}/Q^{0.21}$ three groups of data

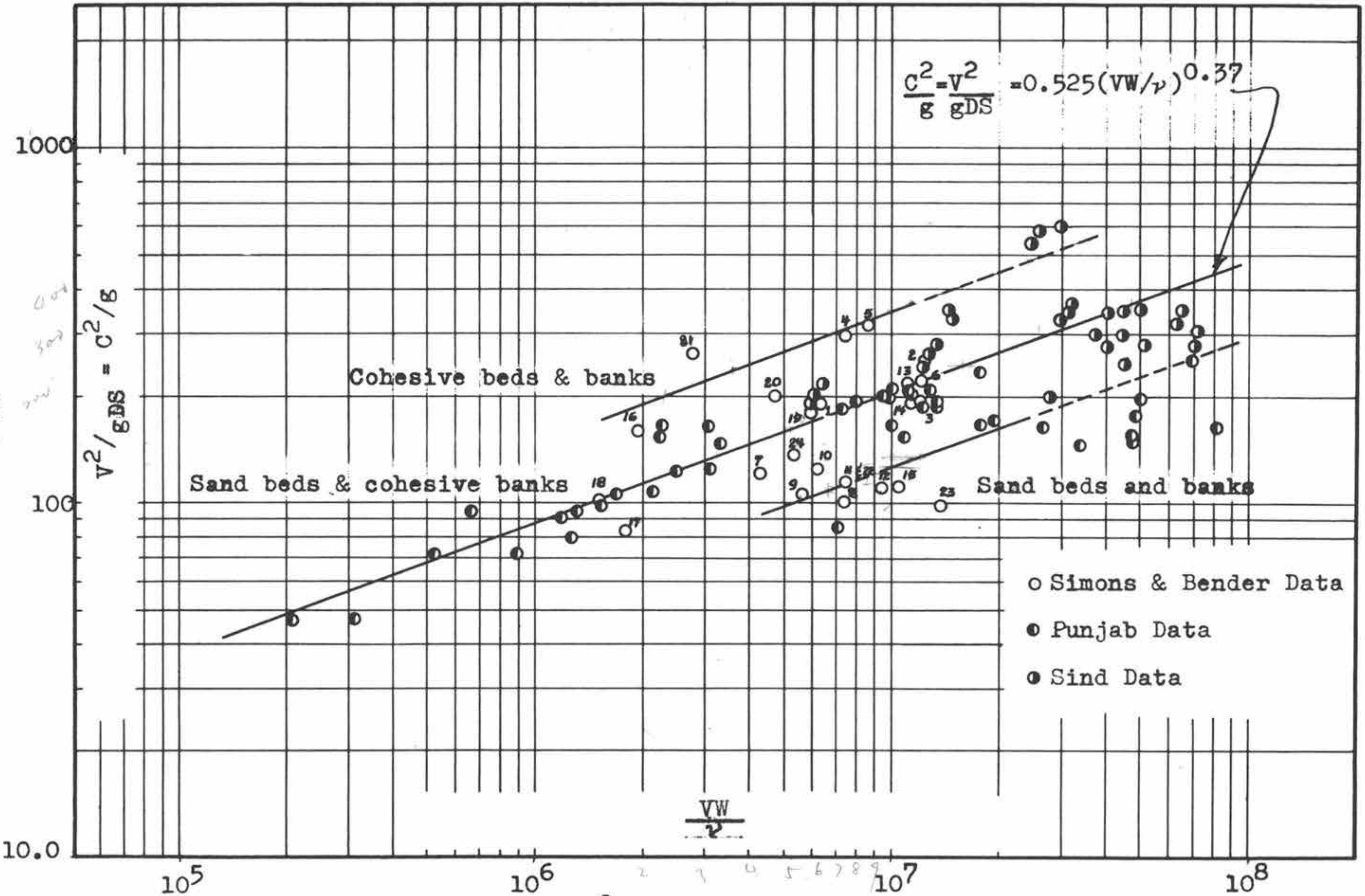


Fig. 81 Variation of V^2/gDS with VW/ν and type of channel

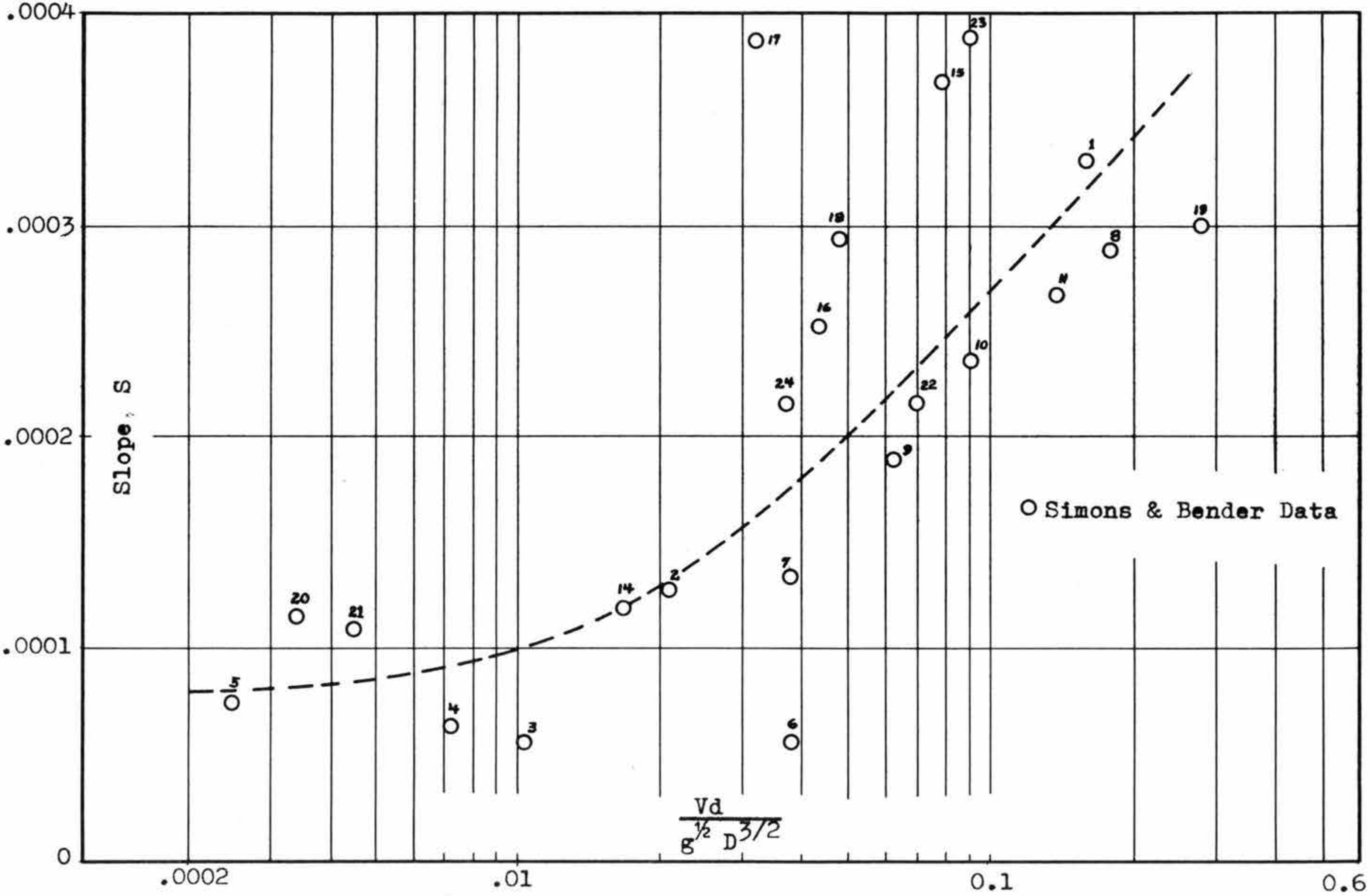


Fig. 82 Variation of slope S with $Vd/g^{1/2}D^{3/2}$

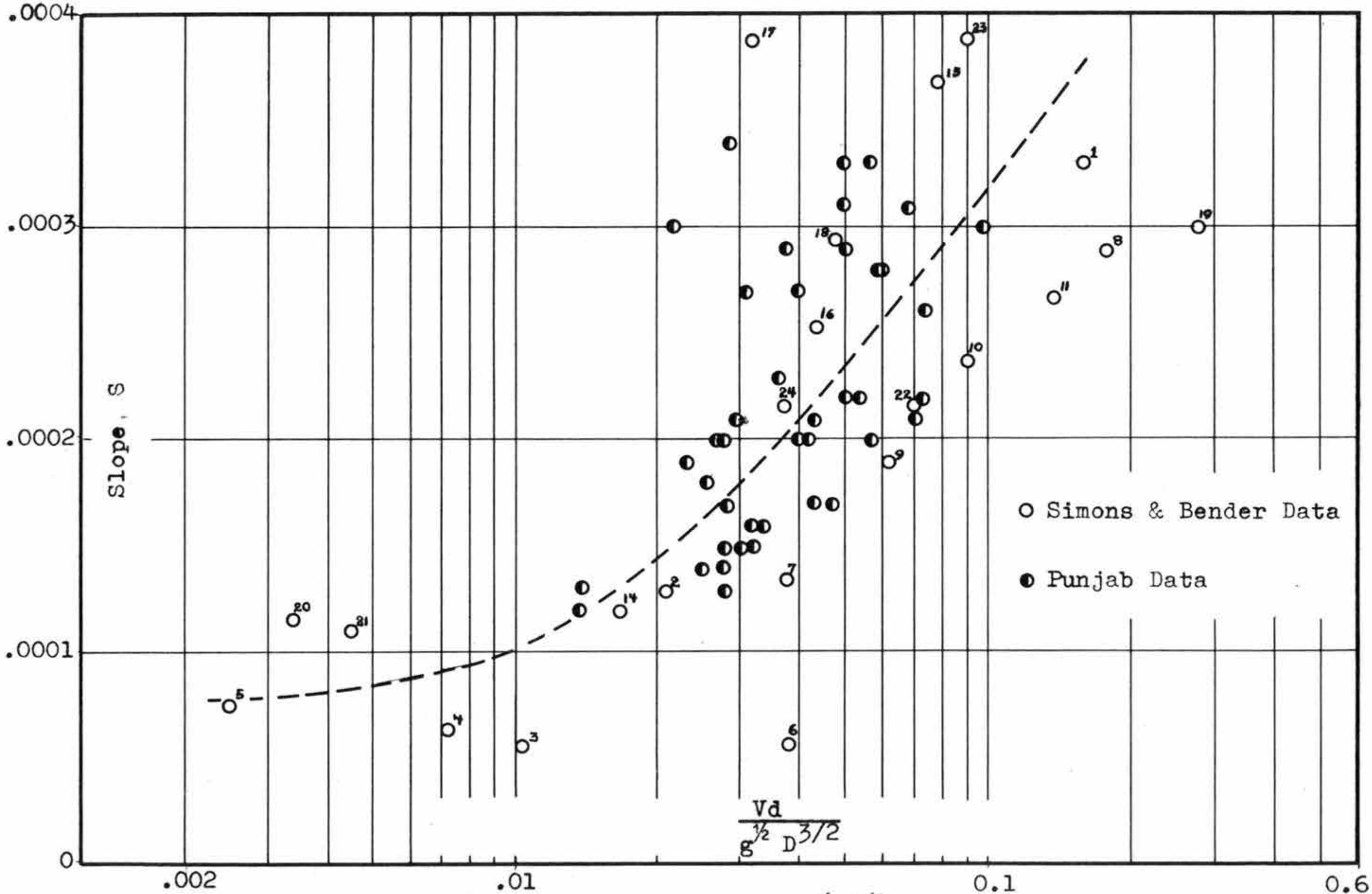


Fig. 83 Variation of slope S with $Vd/g^{1/2}D^{3/2}$ two groups of data

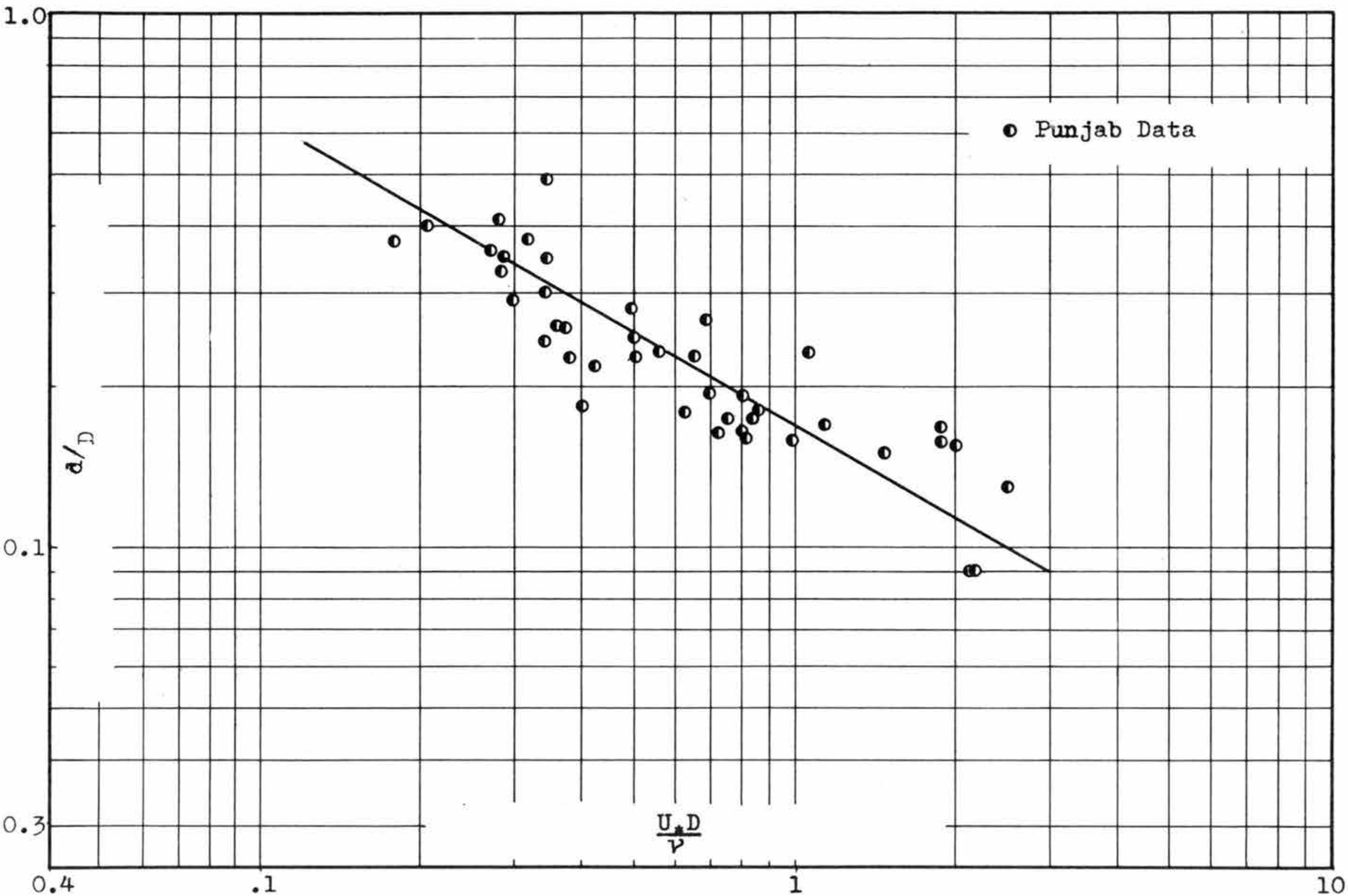


Fig. 84 Variation of median size-bed depth ratio d/D with U*D/

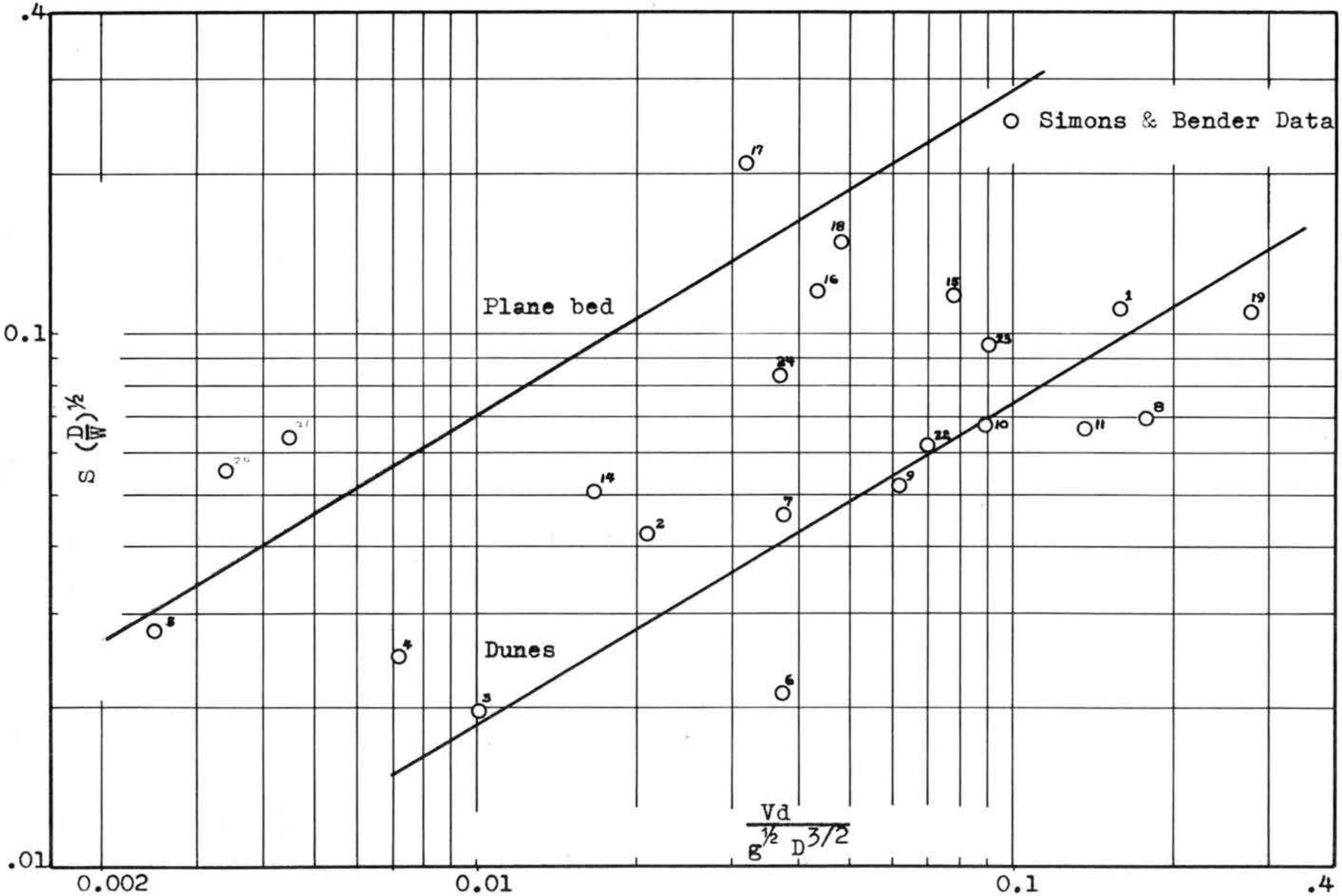


Fig. 85 Variation of $S(D/W)^{1/2}$ with $Vd/g^{1/2}D^{3/2}$ two groups of data

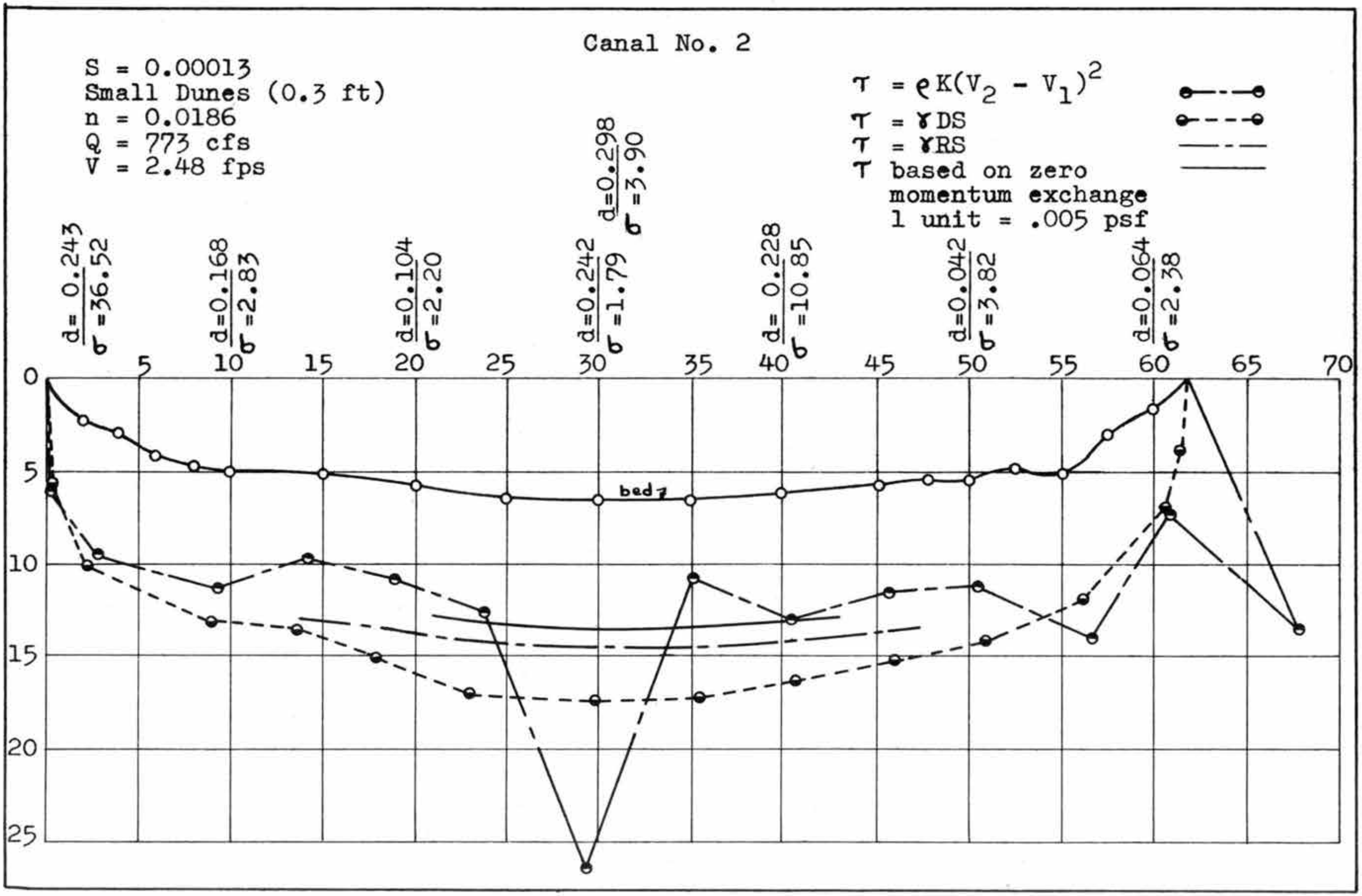


Fig. 86 Tractive force distribution, Canal No. 2

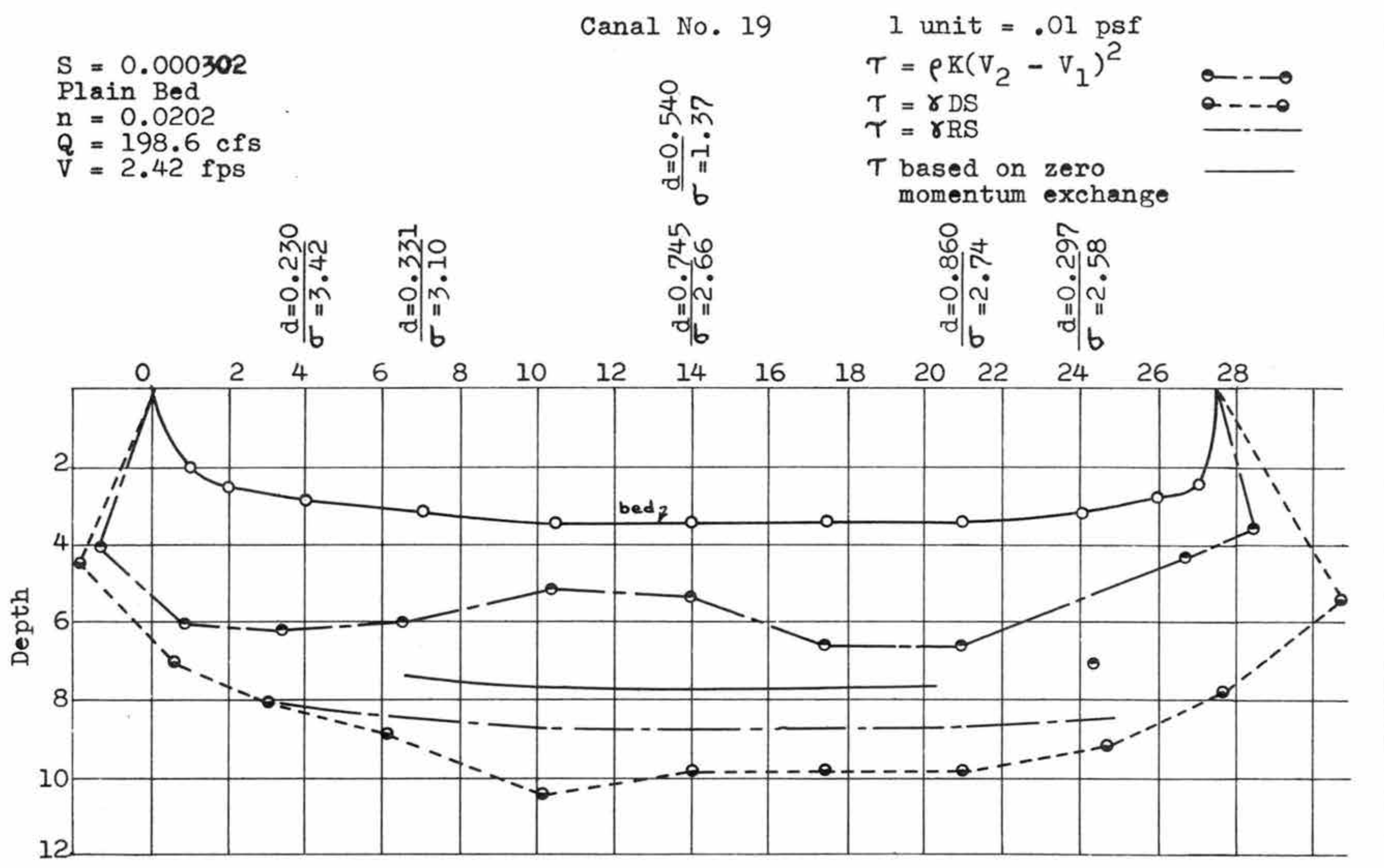


Fig. 87 Tractive force distribution, Canal No. 19

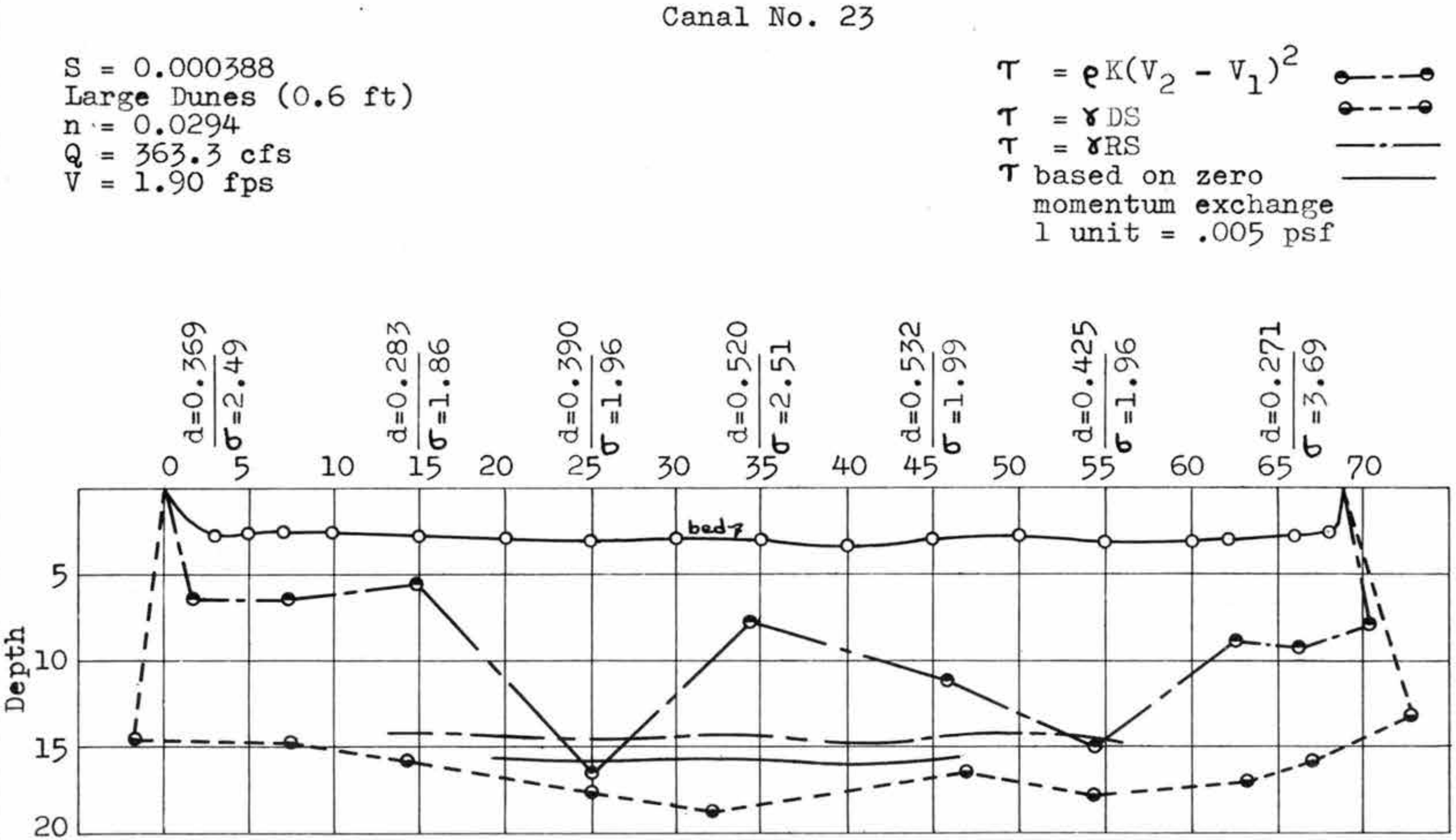


Fig. 88 Tractive force distribution, Canal No. 23

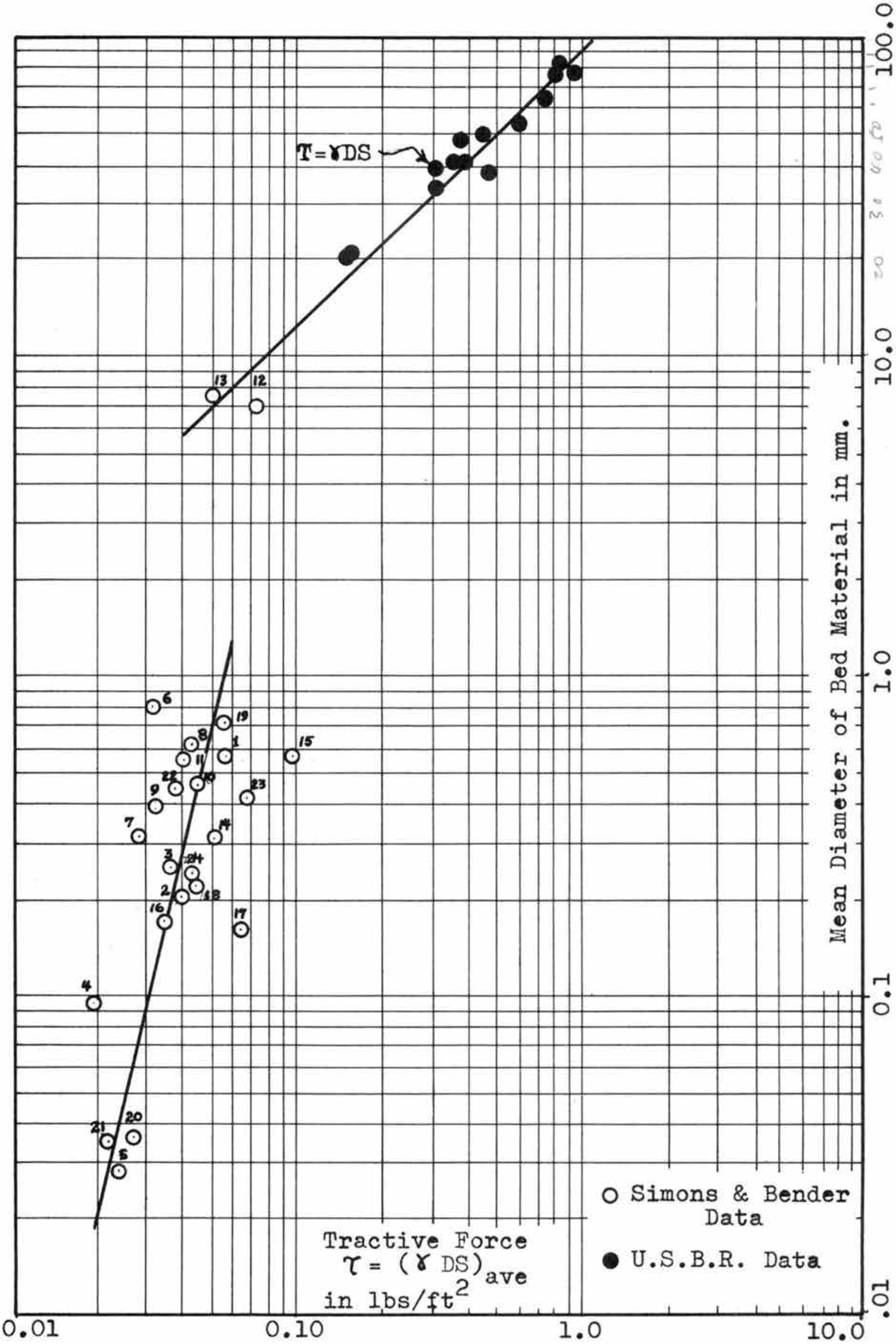


Fig. 89 Variation of tractive force $\tau = (\gamma DS)_{ave}$ with bed material d

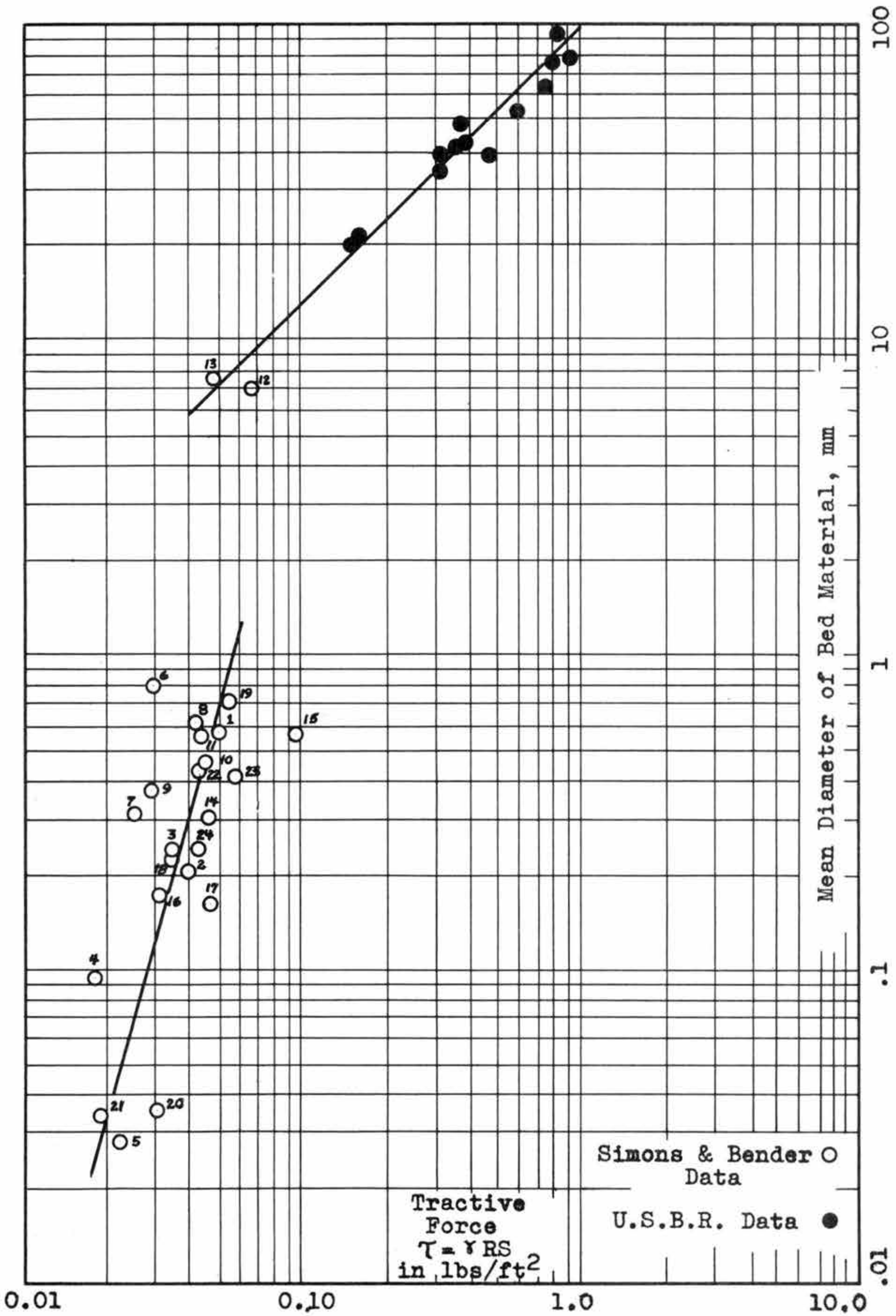


Fig. 90 Variation of tractive force τ = γRS with bed material d

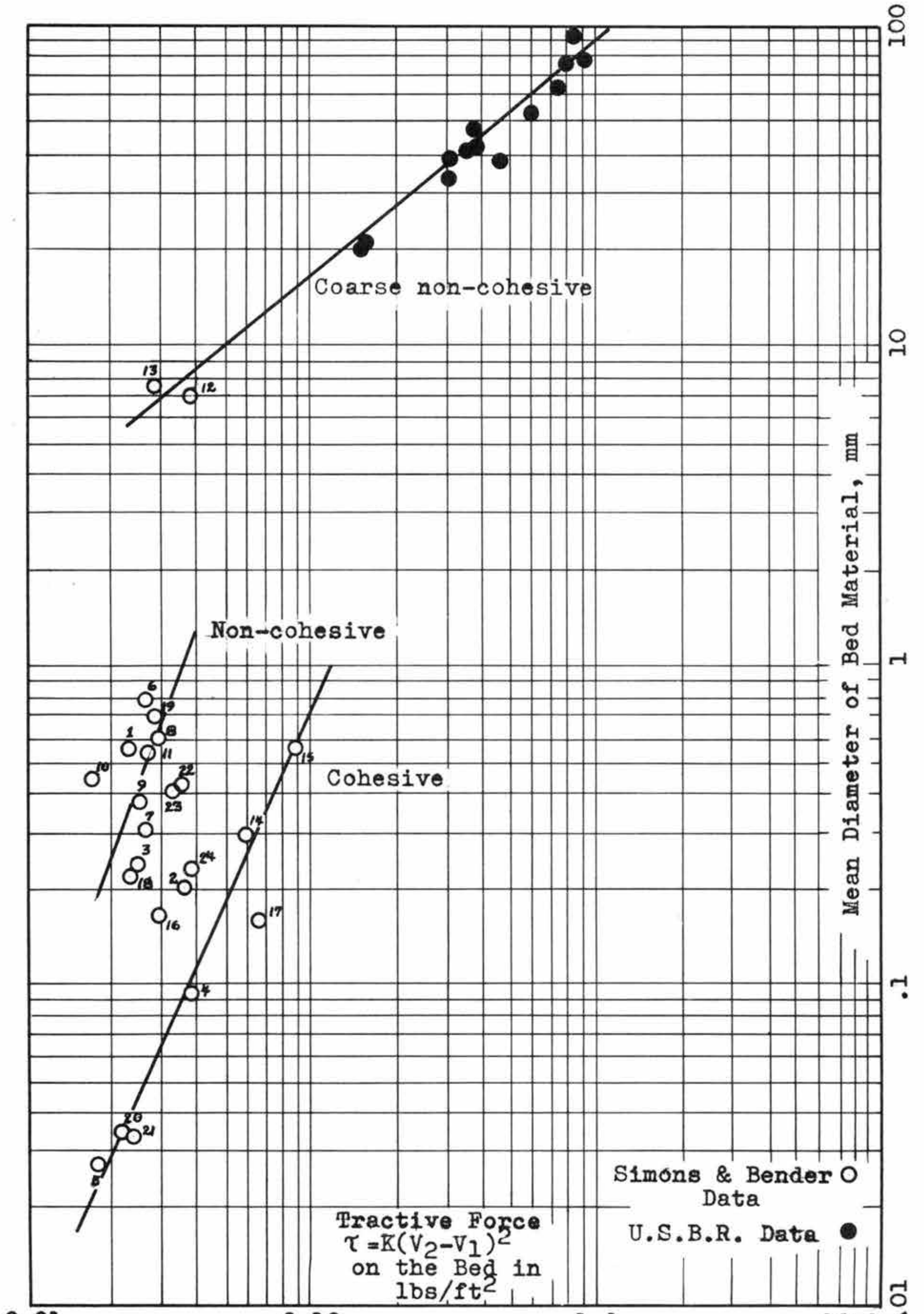


Fig. 91 Variation of tractive force $\tau = K(V_1 - V_2)^2$ with bed material d and type of channel

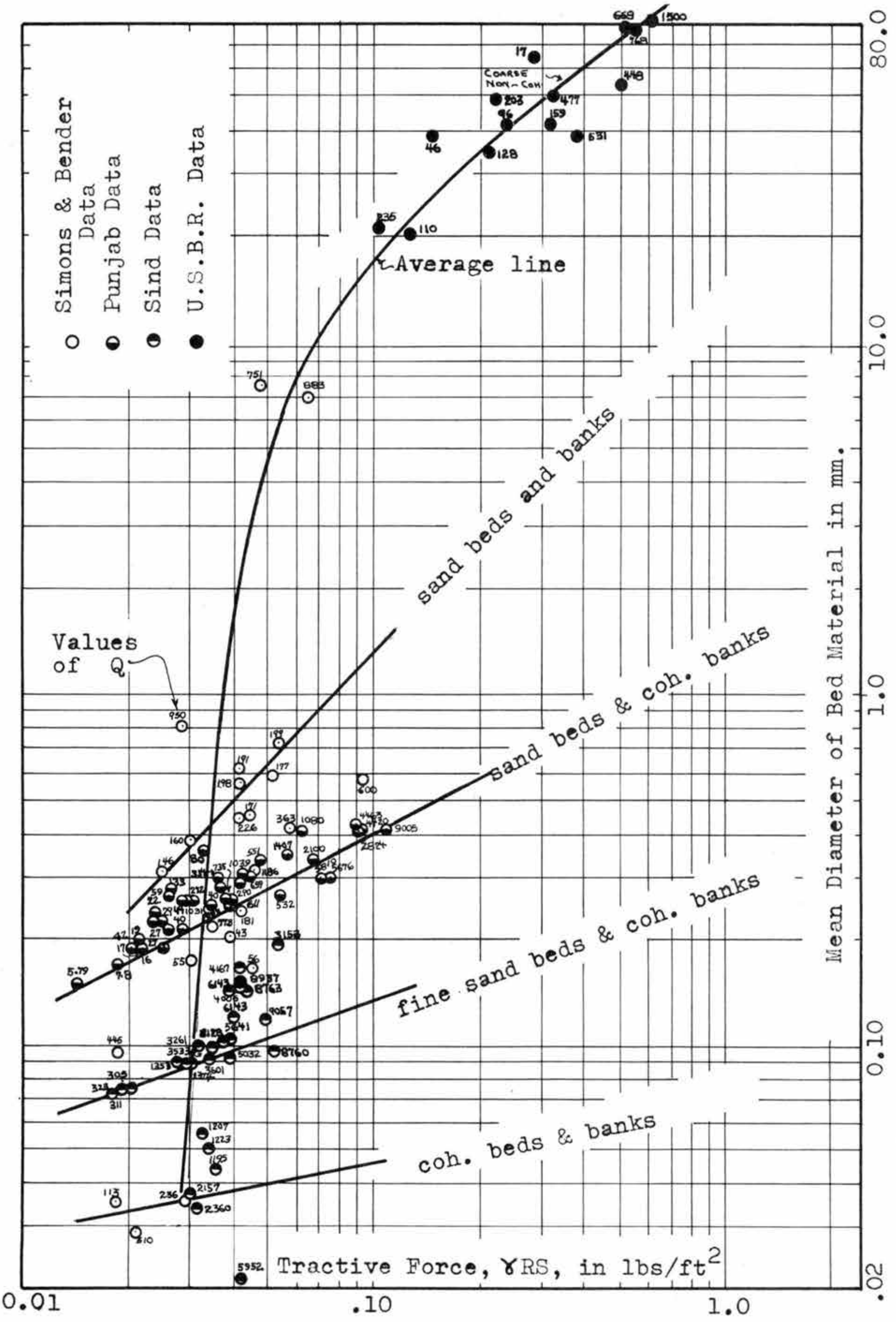


Fig. 92 Variation of tractive force with bed material d type of channel and discharge Q

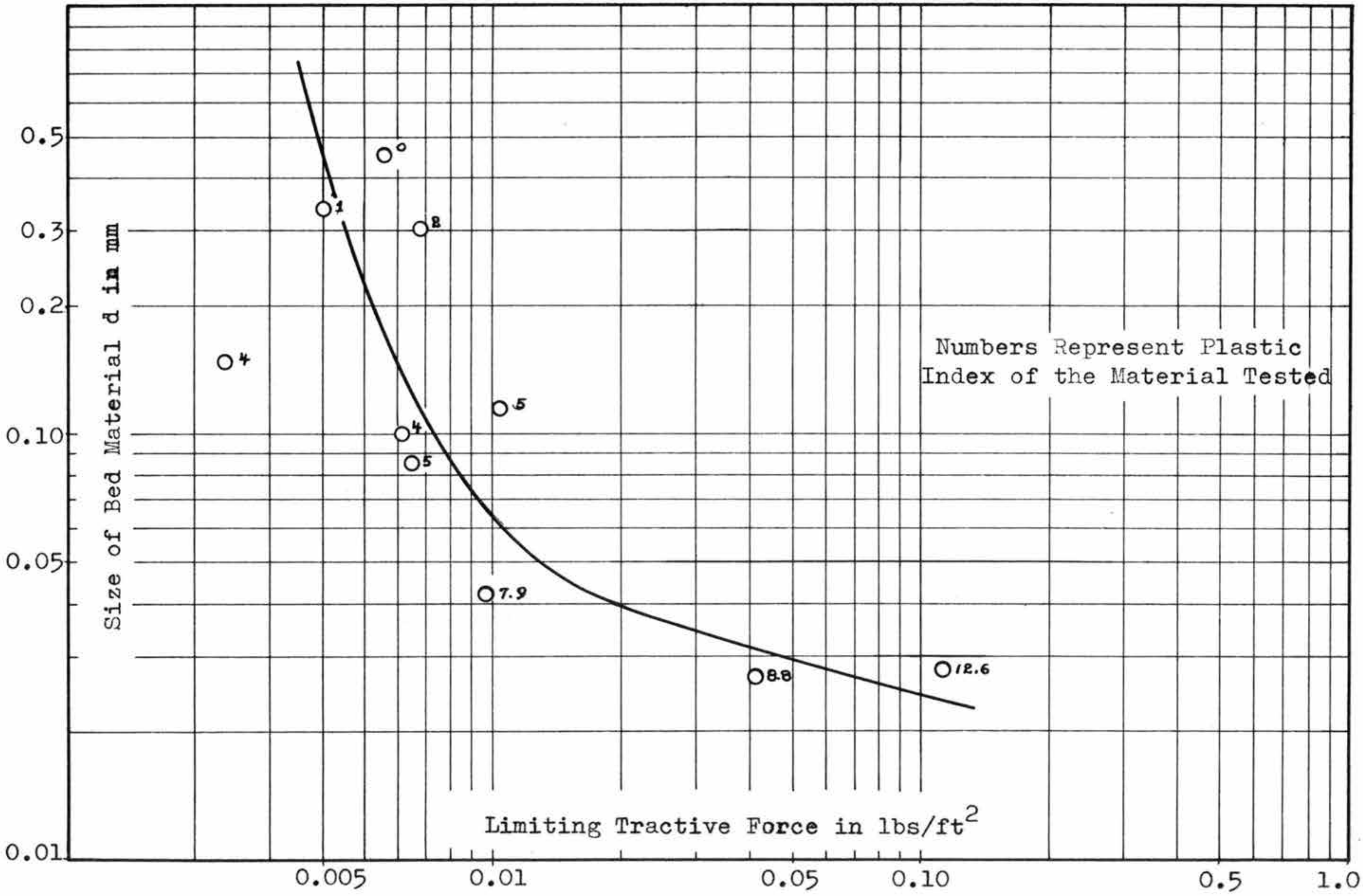


Fig. 93 Variation of bed material d with tractive force and plastic index, Wyoming flume data

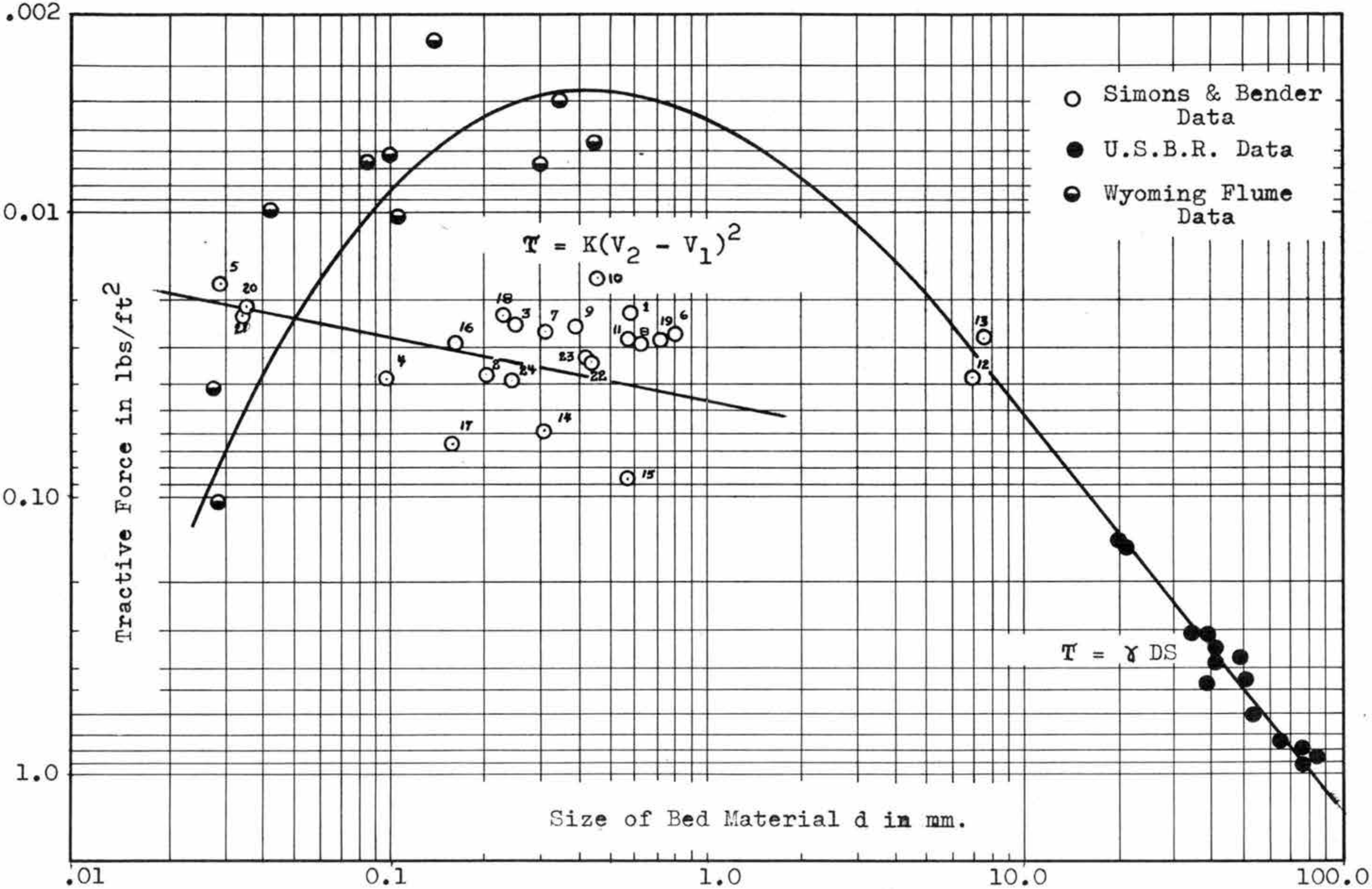


Fig. 94 Variation of tractive force with bed material d, Wyoming flume data included

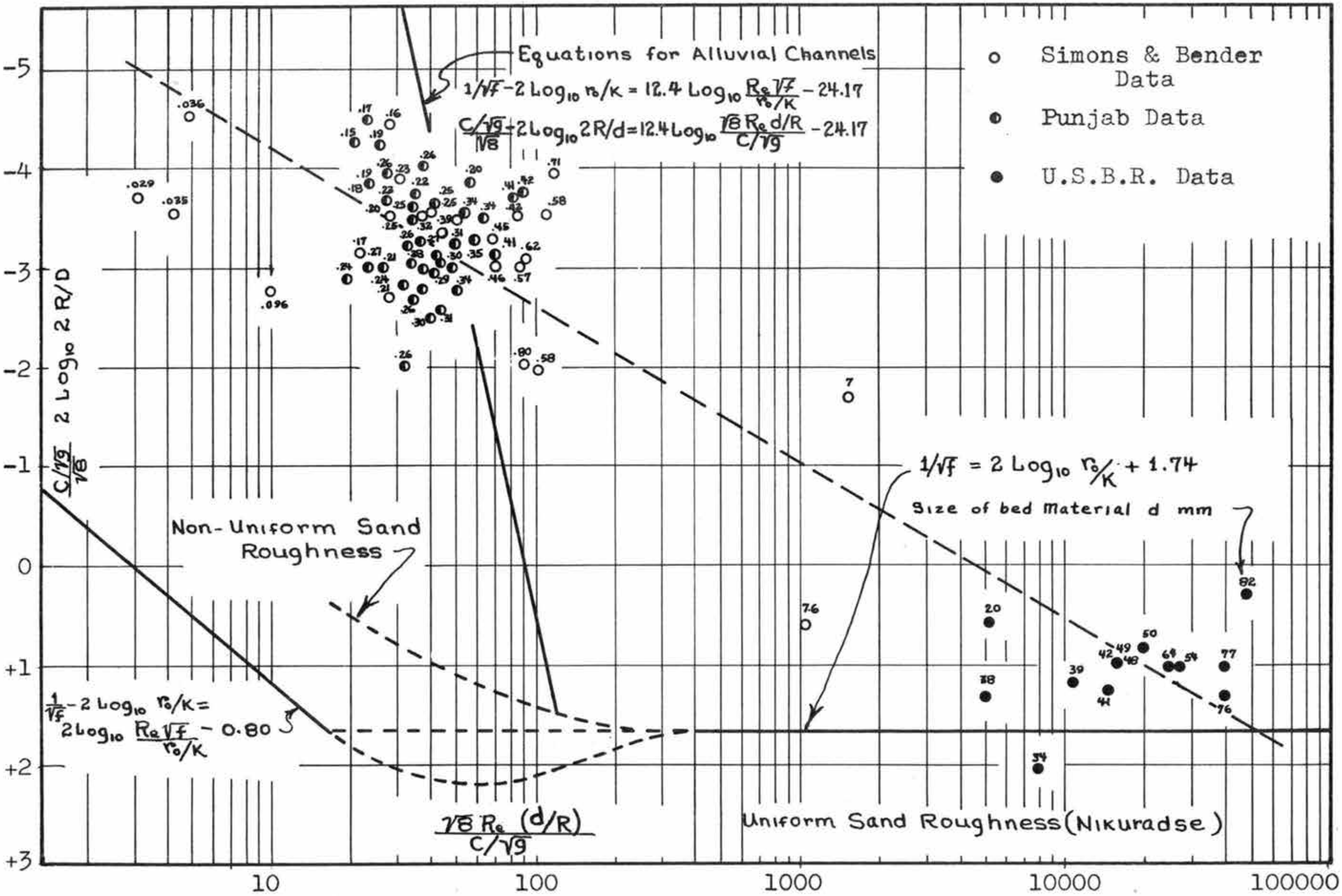


Fig. 95 Transition function for channel roughness

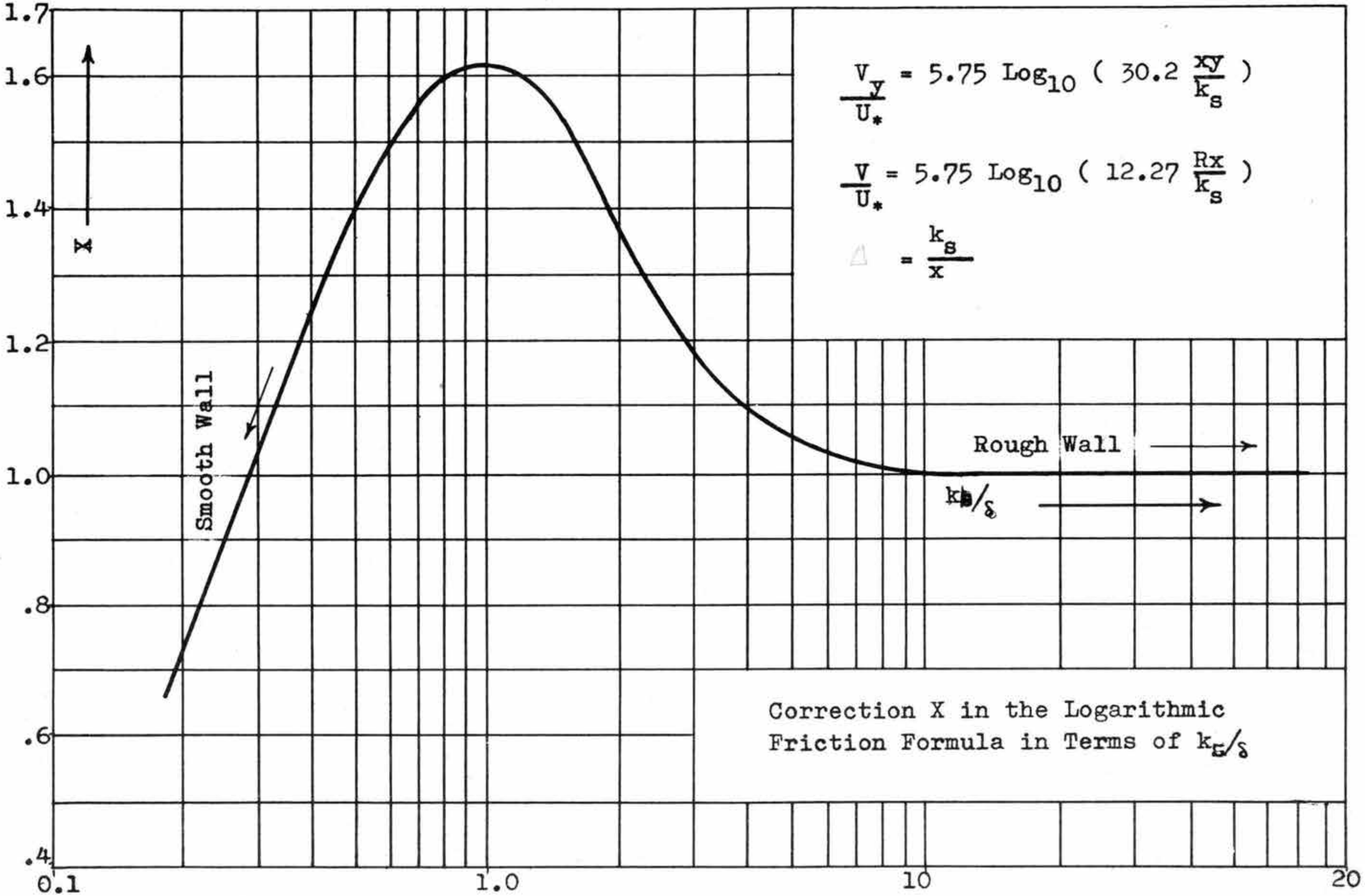


Fig. 96 Einstein corrective parameter

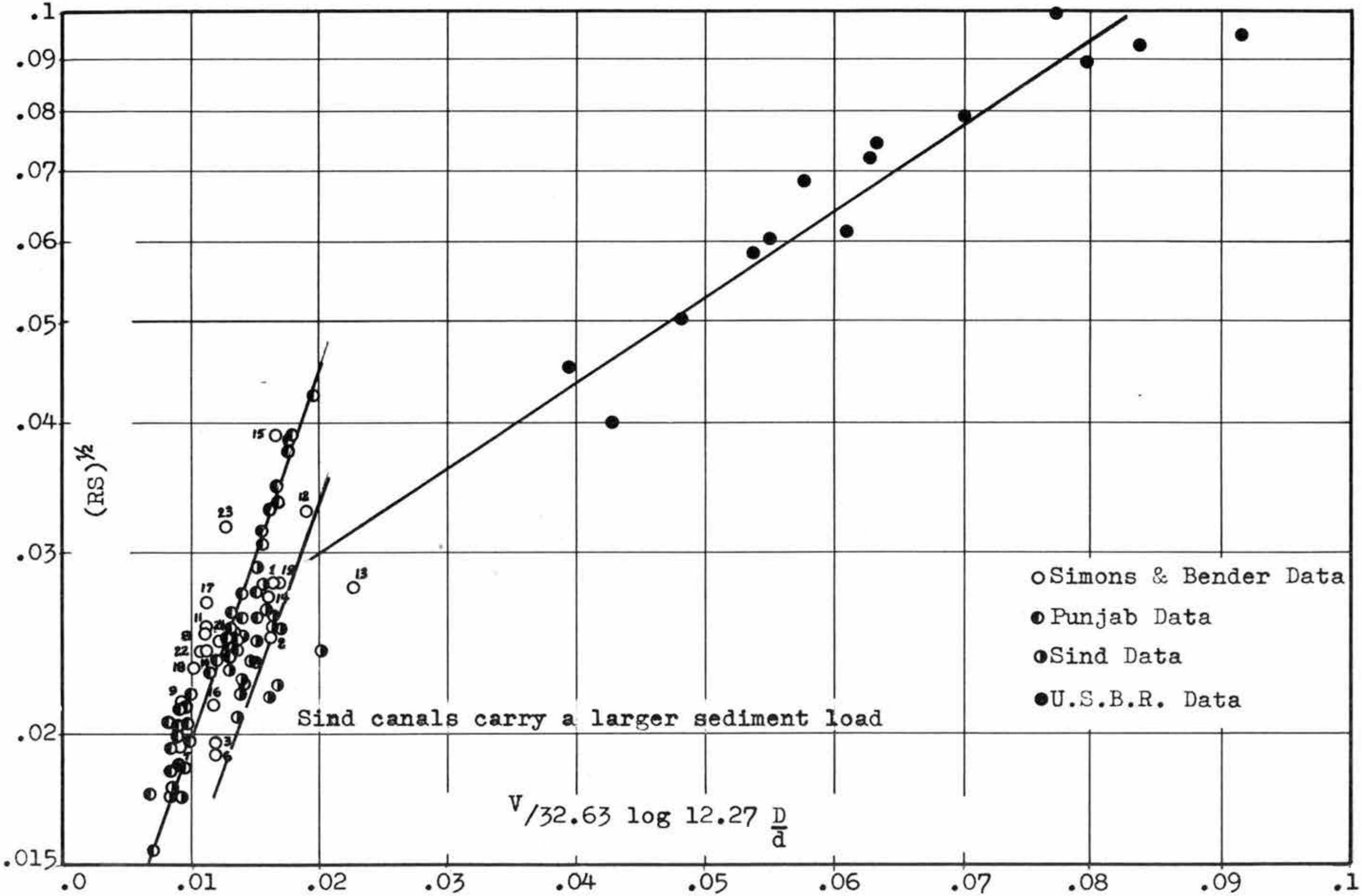


Fig. 97 Variation based on the modified Einstein equation

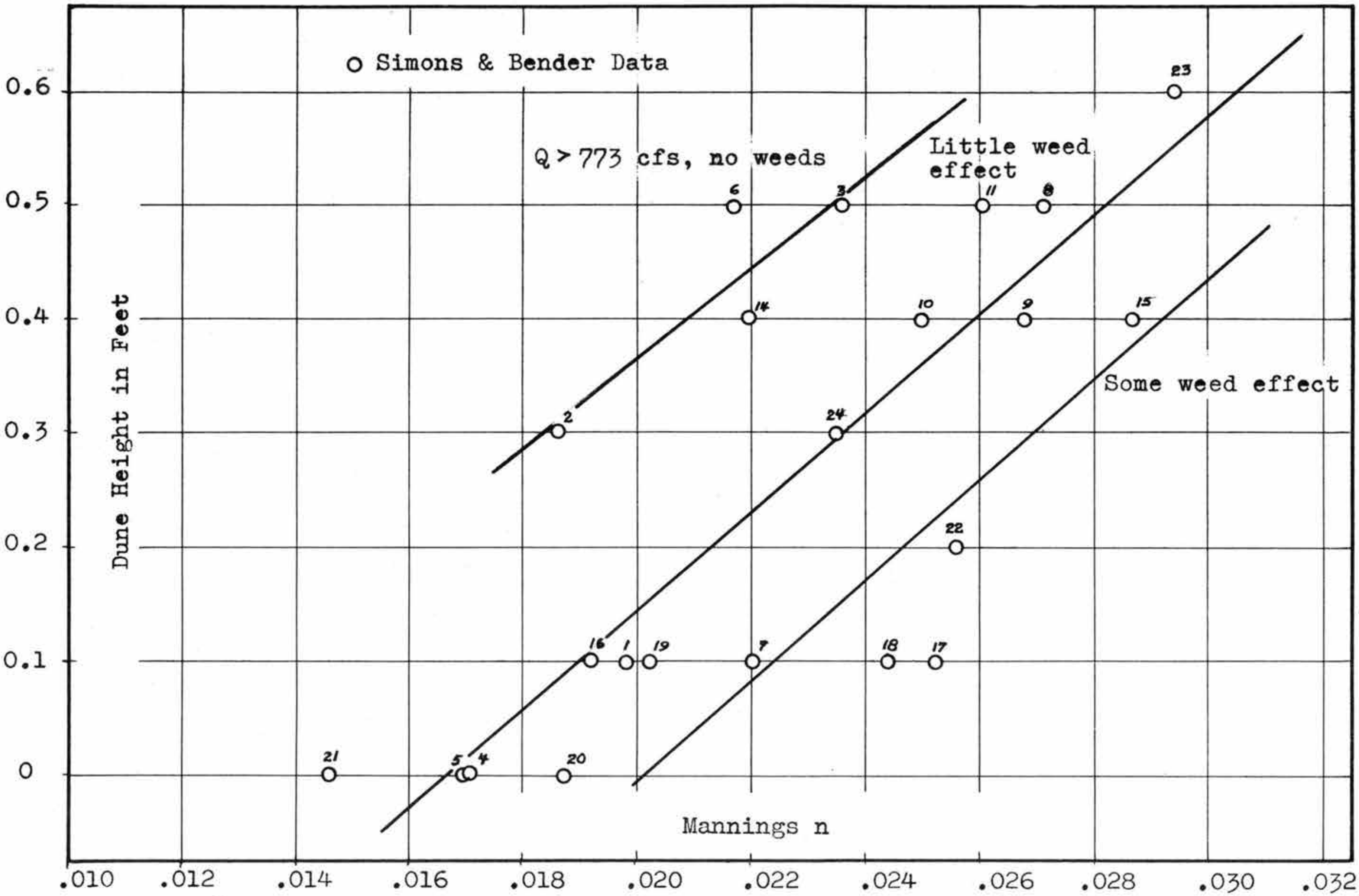


Fig. 98 Variation of dune height with Mannings n and extent of bank vegetation

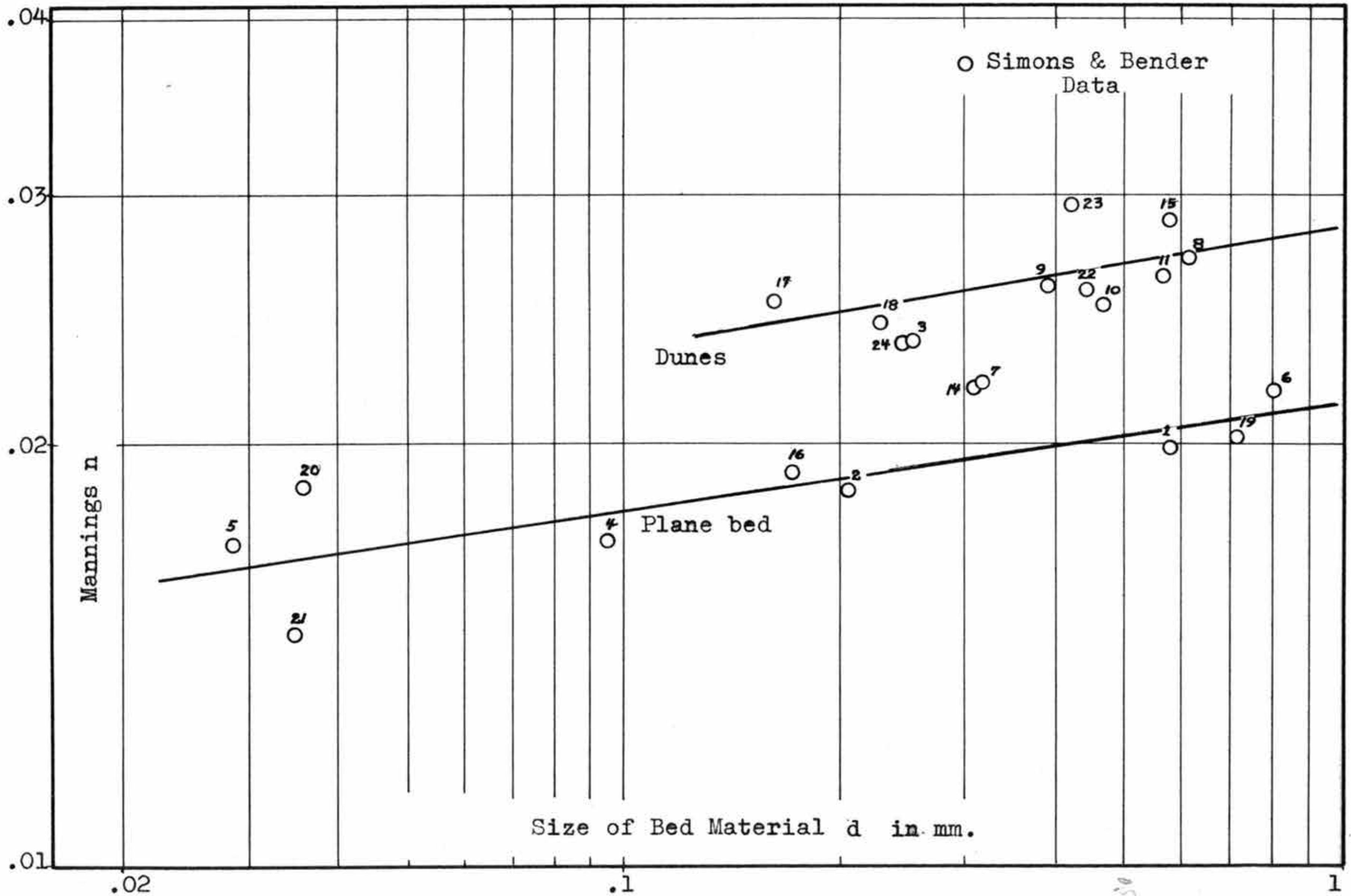


Fig. 99 Variation of Mannings n with bed material d and bed conditions

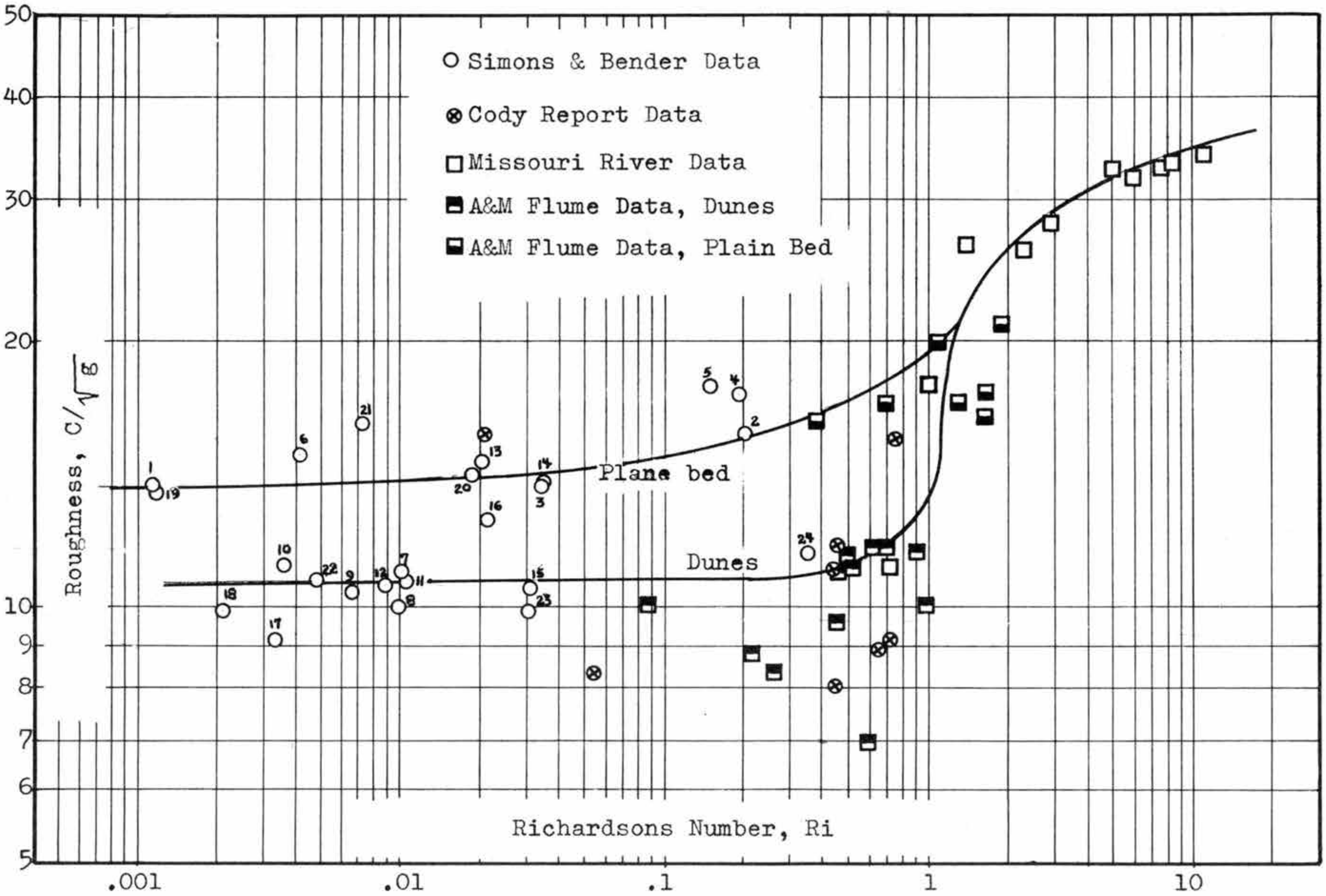


Fig. 100 Variation of $C/\sqrt{g}$ with Richardsons No. Ri and bed conditions

APPENDIX B

TABULATED DATA & COMPUTED PARAMETERS

cont.
Table 13, General Information on Canals Investigated by Simons & Bender

No.	Name	Location	Maximum Sustained Discharge	Discharge
1	Bijou, 53	West of Ft. Morgan, Colo. T3N, R59W, S10	190.	177.
2	Farmers	5 miles east of Mitchel, Neb. T23N, R	950.	773
3	Ft. Laramie I	West of Torrington, Wyo. Mile 31.65	1125.	1031
4	Ft. Laramie II	South of Lyman, Neb. Below mile 91.2	475.	445
5	Ft. Laramie III	South of Lyman, Neb. at mile 87.18	530.	510
6	Ft. Laramie IV	Southwest of Torrington, Wyo. at mile 38.5	1030.	950
7	Ft. Morgan I	West of Ft. Morgan, Colo. T3N, R58W, S1	137.	137.
8	Ft. Morgan II	7 miles west of Ft. Morgan, Colo. T4N, R58W, S18 & 19	190.	191.
9	Ft. Morgan III	1 mile west of Ft. Morgan, Colo. T4N, R58W, S36, R55W, S30	160.	160.
10	Ft. Morgan IV	West of Ft. Morgan T4N, R58W, NW¼ sec 28	170.	171
11	Ft. Morgan V	West of Ft. Morgan T4N, R59W, NE¼ S13	200.	198
12	Garland I	10 miles west of Powell, Wyo. S of H.W.14, T54N, R100W, S17	880.	883
13	Garland II	4.5 miles W of Powell, Wyo. Parallel to H.W14, T55N, R99W	750	751

Table 13, General Information on Canals Investigated by Simons & Bender

No.	Name	Location	Maximum Sustained Discharge	Discharge
14	Interstate	North of Morril, Neb. at mile 64.7	1200.	1039.
15	Larimer Weld	Immediately west of intersection of the Canal & H.W.87 west of Ft. Collins, Colo.	600.	600.
16	Lucerne I	16 miles west of Torrington, Wyo. Barnes Siding, T26N, R63W, S32	55.0	55.0
17	Lucerne II	1 mile west of Barnes Siding Parallel to H.W.26, T26N, R63W, S30	60.0	56.0
18	North Platte Ditch	4.5 miles west of Torrington, Wyo. Parallel to H.W.26, T25N, R62W, S36	45.0	43.0
19	Bijou, 54	West of Ft. Morgan, Colo. T3N, R59W, S10	190.0	199.0
20	CNPP&ID	0.7 miles N of Funk, Neb. below mile 33.8	240.	236.
21	Lat A29.1	0.5 miles NE of Holdrege, Neb. at mile 0	110.	113.
22	Cozad	South of Gothenburg, Neb. T11N, R25W, S17	240.	227.
23	Dawson	South of Cozad, Neb. T10N, R23W, S7	360.	363.
24	Taylor Ord	West of Taylor, Neb. at mile 3.4	180.	181.

cont.

Table 13, General Information on Canals Investigated by Simons & Bender

No.	Extent of Bank Vegetation*	Bank Material**	Stability	Maintainance Required	Berm Formation	Method of Operation During Season
1	M	MC	stable	none	W. bank	intermittent
2	L	MC	stable	none	none	continuous
3	L	C	stable	none	very little	continuous
4	L	C	stable	none	very little	continuous
5	L	C	stable	none	very little	continuous
6	L	C	stable	none	none	continuous
7	M	C	stable	none	very little	slightly intermittent
8	L	NC	stable	none	none	s. intermittent
9	L	NC	stable	none	very little	s. intermittent
10	L	NC	stable	none	none	s. intermittent
11	L	NC	stable	none	none	s. intermittent
12	L	gravel	stable	none	none	continuous
13	L	gravel	stable	none	none	continuous
14	L	MC	stable	none	none	continuous
15	L	MC	marginal	none	none	intermittent
16	M	MC	stable	none	very little	continuous
17	M	MC	stable	none	very little	continuous
18	H	MC	stable	none	very little	continuous
19	M	MC	stable	none	W. bank	intermittent
20	H	C	stable	none	very little	continuous
21	H	C	stable	none	very little	continuous
22	M	NC	stable	none	none	continuous
23	L	NC	marginal	none	none	continuous
24	H	NC	stable	none	very little	continuous

* H = heavy, M = Moderate, L = Light.

** NC = Non-Cohesive, MC = Moderately Cohesive, C = Cohesive

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 1 Sta 7+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0		
2.0	2.05	0.5	1.50
		0.8	1.66
		1.2	1.68
		1.8	1.20
4.0	2.6	0.3	1.82
		0.3	1.85
		0.5	2.09
		0.5	2.01
		1.0	2.32
		1.0	2.36
		1.6	2.24
		1.6	2.21
		2.1	1.76
		2.35	1.73
7.0	2.8	0.3	2.62
		0.6	2.65
		1.1	2.72
		1.7	2.59
		2.3	2.35
		2.55	2.12
		0.3	2.62
		0.6	2.88
		1.2	2.88
		1.8	2.85
		2.4	2.62
		2.6	2.45
		2.75	2.35
13.0	3.04	0.3	2.82
		0.6	3.11
		1.2	3.08
		1.8	2.95
		2.4	2.79
		2.6	2.62
		2.79	2.55
16.0	3.0	0.3	2.95
		0.6	3.11
		1.2	3.08
		1.8	3.02
		2.4	2.72
		2.6	2.69
		2.75	2.39
19.0	3.0	0.3	2.62
		0.6	2.92
		1.2	2.92
		1.8	2.88
		2.4	2.79
		2.6	2.69
		2.75	2.25
22.0	2.9	0.3	2.42
		0.6	2.52
		1.2	2.69
		1.8	2.59
		2.3	2.42
		2.5	2.32
		2.65	2.22
25.0	2.6	0.3	1.99
		0.5	2.12
		1.0	2.25
		1.6	2.15
		2.1	1.93
		2.35	1.73
26.0	2.4	0.5	1.83
		1.0	2.06
		1.5	1.99
		1.8	1.79
		2.15	1.56

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 2 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---			6.1	1.99
2.0	2.35	0.5	1.39	35.0	6.5	0.7	2.85
		0.9	1.66			1.3	2.85
		1.4	1.33			2.6	2.85
		1.9	1.39			3.9	2.72
4.0	3.0	---	---			5.2	2.55
6.0	4.2	0.4	2.09			5.7	2.19
		0.8	2.22			6.1	2.25
		1.7	2.39	40.0	6.2	0.6	2.75
		2.5	2.32			1.2	2.78
		3.4	1.99			2.5	2.65
		3.8	1.90			3.7	2.62
8.0	4.8	---	---			5.0	2.32
10.0	5.0	0.5	2.52			5.4	2.09
		1.0	2.62			5.8	1.96
		2.0	2.72	45.0	5.7	0.6	2.75
		3.0	2.65			1.1	2.78
		4.0	2.35			2.3	2.62
		4.3	2.09			3.4	2.55
		4.6	2.09			4.6	2.32
15.0	5.2	0.5	2.82			4.9	2.25
		1.0	2.92			5.3	1.96
		2.1	2.98	48.0	5.5	---	---
		3.1	2.82	50.0	5.3	0.5	2.62
		4.2	2.65			1.1	2.65
		4.5	2.49			2.1	2.68
		4.8	2.42			3.2	2.59
20.0	5.8	0.6	2.95			4.2	2.39
		1.2	2.88			4.6	2.25
		2.3	2.88			4.9	2.22
		3.5	2.82	52.5	4.7	---	---
		4.6	2.65	55.0	4.1	0.4	2.22
		5.0	2.42			0.8	2.25
		5.4	2.25			1.6	2.25
25.0	6.4	0.6	2.92			2.5	1.89
		1.3	2.98			3.3	1.89
		2.6	2.88			3.7	1.76
		3.8	2.62	57.5	3.0	0.6	1.82
		5.1	2.29			2.4	1.49
		5.6	2.22			1.8	1.77
		6.0	2.02	60.0	1.6	0.4	1.05
30.0	6.5	0.7	2.92			0.6	1.08
		1.3	2.88			1.0	0.85
		2.6	2.92			1.2	0.87
		3.9	2.82	62.0	0	---	---
		5.2	2.42				
		5.7	2.35				

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 3 **Sta 5+00**

Distance from Initial point	Depth	Observation Depth	Velocity
0	0		
2.0	4.6	0.5	0.62
		0.92	0.58
		1.8	0.75
		2.8	0.63
		3.7	0.47
		4.2	0.60
4.0	6.4	- - -	- - -
6.0	7.0	0.7	0.90
		1.4	1.08
		2.8	1.24
		4.2	1.33
		5.6	0.93
		6.3	0.98
		6.5	0.80
8.0	7.1	- - -	- - -
10.0	7.7	0.8	1.36
		1.5	1.44
		3.01	1.66
		4.6	1.49
		6.2	1.31
		6.9	1.16
		7.3	1.11
13.0	8.0	- - -	- - -
16.0	8.3	0.8	1.89
		1.7	1.82
		3.3	2.08
		5.0	2.05
		6.6	1.89
		7.5	1.63
		7.8	1.59
		8.0	1.46
22.0	8.7	0.9	2.22
		1.7	2.22
		3.5	2.09
		5.2	1.92
		7.0	1.73
		7.8	1.49
		8.3	1.46
28.0	8.5	0.9	2.19
		1.9	2.25
		3.4	2.25
		5.1	2.19
		6.8	1.69
		7.7	1.56
		8.1	1.49

Distance from Initial point	Depth	Observation Depth	Velocity
34.0	8.5	0.8	2.06
		0.9	2.25
		0.8	2.09
		1.7	2.15
		3.4	2.19
		5.1	1.99
		6.8	1.60
		7.7	1.37
		8.1	1.32
		8.1	1.12
40.0	8.4	0.8	2.22
		0.9	2.32
		1.7	1.12
		3.4	2.22
		5.0	2.09
		6.7	1.73
		7.6	1.41
		7.9	1.39
		7.9	1.46
46.0	8.3	0.8	2.19
		1.7	2.22
		3.3	2.16
		5.0	2.02
		6.6	1.86
		7.5	1.61
		7.9	1.50
52.0	8.4	0.8	2.32
		1.7	2.17
		3.4	2.15
		5.0	2.09
		6.7	1.82
		7.6	1.59
		8.0	1.31
58.0	8.4	0.8	2.06
		1.7	2.06
		3.4	1.99
		5.0	1.96
		6.7	1.79
		7.6	1.53
		8.0	1.39
64.0	8.3	0.8	1.68
		1.7	1.83
		3.3	1.94
		5.0	1.81
		6.6	1.74
		7.5	1.48
		7.9	1.29

TABLE 14 VELOCITY DISTRIBUTION DATA

Canal No. 3 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity
67.0	8.3	- - -	- - -
70.0	7.9	0.8	1.36
		1.6	1.57
		3.2	1.76
		4.7	1.59
		6.3	1.22
		7.1	1.11
		7.5	0.95
72.0	7.4	- - -	- - -
74.0	6.5	0.7	1.20
		1.3	1.26
		2.6	1.36
		3.9	1.33
		5.2	1.13
		5.7	1.06
		6.1	0.98
76.0	5.3	- - -	- - -
78.0	4.1	0.4	0.83
		0.8	0.92
		1.6	1.00
		3.2	0.92
		3.7	0.82
		2.5	0.95
80.0	0	- - -	- - -

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 4 **Sta 5+00**

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
2.0	2.4	0.5	1.10
		1.0	1.24
		1.4	1.20
		1.9	1.16
4.0	3.7	---	---
6.0	4.5	0.5	1.51
		0.9	1.66
		1.8	1.89
		2.7	1.89
		3.6	1.59
		4.1	1.43
8.0	5.1	---	---
10.0	5.5	0.6	1.83
		1.1	2.02
		2.2	2.22
		3.3	2.22
		4.4	2.06
		4.8	1.76
		5.1	1.57
12.0	5.8	---	---
14.0	5.9	0.6	2.15
		1.2	2.25
		2.4	2.35
		3.5	2.29
		4.7	1.99
		5.1	1.92
		5.5	1.86
16.0	6.0	---	---
18.0	6.2	0.6	2.35
		1.2	2.42
		2.5	2.52
		3.7	2.42
		5.0	2.15
		5.4	1.99
		5.8	1.73
20.0	6.2	---	---
22.0	6.2	0.6	2.45
		1.2	2.52
		2.5	2.58
		3.7	2.39
		5.0	2.06
		5.4	1.92
		5.8	1.63
		---	---

Distance from Initial point	Depth	Observation Depth	Velocity
26.0	6.2	0.6	2.35
		1.2	2.39
		2.5	2.52
		3.7	2.29
		5.0	2.06
		5.4	1.86
		5.8	1.80
28.0	6.2	---	---
30.0	6.1	0.6	2.09
		1.2	2.22
		2.4	2.29
		3.7	2.09
		4.9	1.82
		5.3	1.69
		5.7	1.59
32.0	6.0	---	---
34.0	6.0	0.6	1.82
		1.2	1.96
		2.4	2.15
		3.6	2.06
		4.8	1.76
		5.2	1.53
		5.6	1.34
36.0	5.8	---	---
38.0	5.5	0.6	1.52
		1.1	1.63
		2.2	1.86
		3.3	1.73
		4.4	1.56
		4.8	1.49
		5.1	1.46
40.0	4.7	---	---
42.0	4.0	0.4	1.23
		0.8	1.27
		1.6	1.46
		2.4	1.36
		3.2	1.18
		3.6	1.05
43.0	3.1	---	---
44.0	2.2	---	---
44.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 5 **Sta 6+00**

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
0	0.9	---	---
2.0	3.7	0.4	1.23
		0.7	1.36
		1.5	1.36
		2.2	1.16
		3.0	0.95
		3.3	0.92
4.0	4.3	---	---
6.0	5.2	0.5	1.66
		1.0	1.82
		2.1	1.96
		3.1	1.89
		3.6	1.56
		3.9	1.16
10.0	5.7	0.6	2.09
		1.1	2.12
		2.3	2.32
		3.4	2.19
		4.6	1.82
		5.1	1.59
		5.3	1.47
12.0	5.9	---	---
14.0	6.0	0.6	2.32
		1.2	2.39
		2.4	2.55
		3.6	2.55
		4.8	2.22
		5.4	1.99
		5.6	1.92
16.0	6.1	---	---
18.0	6.0	0.6	2.49
		1.2	2.55
		2.4	2.68
		3.6	2.65
		4.8	2.45
		5.4	2.25
		5.6	2.22
22.0	6.0	0.6	2.65
		1.2	2.65
		2.4	2.58
		3.6	2.58
		4.8	2.35
		5.4	2.19
26.0	6.0	0.6	2.65
		1.2	2.65
		2.4	2.65

Distance from Initial point	Depth	Observation Depth	Velocity
		3.6	2.62
		4.8	2.49
		5.4	2.35
		5.6	2.12
30.0	6.0	0.6	2.49
		1.2	2.58
		2.4	2.65
		3.6	2.52
		4.8	2.35
		5.4	2.25
		5.6	2.02
34.0	6.0	0.6	2.29
		1.2	2.39
		2.4	2.39
		3.6	2.35
		4.8	2.16
		5.4	2.06
		5.6	2.02
36.0	5.7	---	---
38.0	5.4	0.5	2.02
		1.1	2.15
		2.2	2.25
		3.2	2.19
		4.3	2.09
		5.0	1.86
40.0	4.7	---	---
42.0	4.3	0.4	1.56
		0.9	1.73
		1.7	1.86
		2.6	1.86
		3.4	1.63
		3.9	1.59
44.0	3.3	---	---
45.0	2.9	0.6	1.06
		1.2	1.33
		2.3	1.29
		2.5	1.23
47.0	1.3	---	---
47.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 6 **Sta 7+00**

Distance from Initial point	Depth	Observation Depth	Velocity
0	0		
4.0	1.2	0.4	1.08
		0.8	0.85
8.0	2.9	0.4	1.73
		2.3	1.10
		2.5	1.06
12.0	4.8	1.0	1.82
		3.8	1.43
		4.4	1.06
16.0	6.4	1.3	1.90
		5.1	1.76
		6.0	1.13
20.0	7.7	1.5	2.25
		6.2	1.89
		7.3	1.49
25.0	7.8	---	---
30.0	7.4	1.5	2.15
		4.4	2.12
		5.9	1.84
		6.5	1.66
		7.0	1.51
35.0	8.3	1.7	2.12
		6.8	1.66
		7.9	1.26
40.0	8.3	1.7	2.19
		6.8	1.64
		7.3	1.47
		7.9	1.24
45.0	8.1	7.7	2.19
50.0	7.9	1.6	2.06
		6.3	1.53
		7.5	1.03
55.0	7.5	1.5	2.12
		6.0	1.79
		7.1	1.39
60.0	7.7	1.5	1.96
		6.2	1.66
		7.3	1.33
65.0	7.9	1.7	1.99
		6.3	1.66
		7.5	1.39
70.0	7.5	1.5	1.76
		6.0	1.59
		7.1	1.19
75.0	5.7	1.2	1.46
		4.6	1.31
		5.3	1.08
80.0	3.3	0.7	1.03
		2.6	1.08
		2.9	0.87
86.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 7 **Sta** 6+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0					2.8	1.29
1.0	1.5					3.0	1.23
4.0	2.9	0.3	0.76	20.0	3.5	0.4	1.76
		0.6	0.36			0.7	1.76
		1.2	1.23			1.4	1.66
		1.7	1.29			2.1	1.66
		2.3	1.19			2.8	1.39
		2.5	1.03			3.0	1.36
6.0	3.4	0.3	1.13	22.0	3.5	0.4	1.76
		0.7	1.33			0.7	1.69
		1.4	1.36			1.4	1.66
		2.0	1.33			2.1	1.49
		2.7	1.16			2.8	1.42
		3.0	1.00			3.0	1.29
8.0	3.5	0.4	1.36	24.0	3.5	0.4	1.69
		0.7	1.42			0.7	1.73
		1.4	1.43			1.4	1.66
		2.1	1.43			2.1	1.63
		2.8	1.19			2.8	1.36
		3.0	1.19			3.0	1.29
10.0	3.55	0.4	1.56	26.0	3.55	0.4	1.56
		0.7	1.59			0.7	1.59
		1.4	1.62			1.4	1.59
		2.1	1.56			2.1	1.56
		2.8	1.19			2.8	1.33
		3.0	1.19			3.0	1.26
12.0	3.55	0.4	1.66	28.0	3.5	0.4	1.43
		0.7	1.66			0.7	1.46
		1.4	1.62			1.4	1.49
		2.1	1.56			2.1	1.42
		2.8	1.33			2.8	1.29
		3.0	1.29			3.0	1.13
14.0	3.5	0.4	1.76	30.0	3.35	0.3	1.19
		0.7	1.76			0.7	1.36
		1.4	1.69			1.3	1.36
		2.1	1.66			2.0	1.29
		2.8	1.49			2.7	1.16
		3.0	1.36			2.9	1.09
16.0	3.55	0.4	1.82	32.0	2.8		
		0.7	1.73	33.0	2.3		
		1.4	1.73	34.0	0		
		2.1	1.56				
		2.8	1.42				
		3.0	1.26				
18.0	3.5	0.4	1.76				
		0.7	1.76				
		1.4	1.69				
		2.1	1.59				

TABLE 14 VELOCITY DISTRUBITION AREA

Canal No. 8 **Sta 6+00**

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	- - -	- - -
2.0	2.0	0.25	1.29
		0.4	1.52
		0.8	1.56
		1.2	1.49
		1.6	1.39
4.0	2.7	0.3	1.66
		0.5	1.69
		1.1	1.86
		1.6	1.86
		2.2	1.54
		2.45	1.52
8.0	2.6	0.3	1.83
		0.5	1.89
		1.0	1.86
		1.6	1.89
		2.1	2.73
		2.35	1.52
12.0	2.5	0.3	1.89
		0.5	1.89
		1.0	1.92
		1.5	1.82
		2.0	1.76
		2.25	1.49
16.0	2.5	0.3	1.80
		0.5	1.76
		1.0	1.76
		1.5	1.73
		2.0	1.53
		2.25	1.52
20.0	2.2	0.2	1.73
		0.4	1.96
		0.9	1.86
		1.3	1.59
		1.8	1.09
		1.95	1.46
24.0	2.4	0.3	1.76
		0.5	1.70
		1.0	1.69
		1.4	1.63
		1.9	1.63
		1.15	1.33
28.0	2.45	0.3	1.99
		0.5	1.86
		1.0	1.86
		1.5	1.70
		2.0	1.66
		2.2	1.49
32.0	2.3	0.3	1.96
		0.5	1.96
		0.9	1.33
		1.4	1.76
		1.8	1.69
		2.05	1.66
36.0	2.5	0.3	1.86
		0.5	1.93
		1.0	1.86
		1.5	1.76
		2.0	1.59
		2.25	1.49
40.0	2.6	0.3	1.83
		0.5	1.80
		1.0	1.76
		1.6	1.60
		2.1	1.43
		2.35	1.52
44.0	2.8	0.3	1.83
		0.6	1.80
		1.1	1.63
		1.7	1.63
		2.2	1.36
		2.55	0.84
48.0	1.8	0.3	1.36
		0.4	1.36
		0.7	1.46
		1.1	1.40
		1.4	1.21
		1.5	1.26
50.0	1.5	- - -	- - -
53.0	0	- - -	- - -

TABLE 14 VELOCITY DISTRIBUTION **AREA**

Canal No. 9 **Sta** 6+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
4.0	2.85	0.3	1.16	40.0	2.45	0.3	1.22
		0.3	1.16			0.5	1.34
		0.6	1.21			1.0	1.38
		1.1	1.20			1.5	1.35
		1.7	1.08			2.0	1.20
		2.3	0.52			2.2	1.12
8.0	3.0	0.3	1.50	42.0	1.5	1.25	0.81
		0.6	1.53			1.0	0.90
		1.2	1.37			0.6	1.01
		1.8	1.49			0.3	1.00
		2.4	1.30	43.0	0.9	- - -	- - -
		2.6	1.22	44.0	0	- - -	- - -
16.0	3.1	0.3	1.72				
		0.6	1.72				
		1.2	1.58				
		1.9	1.60				
		2.3	1.42				
		2.6	1.26				
20.0	3.0	0.3	1.80				
		0.6	1.78				
		1.2	1.69				
		1.8	1.55				
		2.4	1.43				
		2.6	1.28				
24.0	2.9	0.3	1.81				
		0.6	1.79				
		1.2	1.68				
		1.7	1.56				
		2.3	1.38				
28.0	2.85	0.3	1.84				
		0.6	1.80				
		1.1	1.70				
		1.7	1.49				
		2.3	1.30				
32.0	2.75	0.3	1.82				
		5.5	1.82				
		1.1	1.80				
		1.7	1.65				
		2.2	1.45				
36.0	2.8	0.3	1.80				
		0.6	1.76				
		1.1	1.74				
		1.7	1.58				
		2.2	1.34				
		2.55	1.16				

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 10 Sta 5+45

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
2.0	2.2	0.4	1.33
		0.9	1.76
		1.3	1.72
		1.8	1.43
		1.95	1.30
5.0	2.8	0.6	2.06
		1.1	1.98
		1.2	1.95
		2.2	1.91
		2.4	1.70
		2.55	1.57
10.0	3.0	0.6	2.18
		1.2	2.20
		1.8	2.08
		2.4	1.90
		2.6	1.82
		2.75	1.53
15.0	2.9	0.6	2.11
		1.2	2.05
		1.7	1.98
		2.3	1.90
		2.5	1.79
		2.65	1.39
20.0	2.9	0.6	2.01
		1.2	1.87
		1.7	1.78
		2.3	1.68
		2.5	1.55
		2.65	1.53
25.0	3.0	0.6	2.11
		1.2	2.10
		1.8	1.88
		2.4	1.70
		2.6	1.39
		2.75	1.07
30.0	2.5	0.5	1.95
		1.0	1.85
		1.5	1.55
		2.0	0.96
		2.25	0.92
35.0	2.6	0.5	1.92
		1.0	1.82
		1.6	1.62
		2.1	1.53
		2.35	1.55
40.0	2.4	0.5	2.00
		1.0	2.00
		1.4	1.78
		1.9	1.58
		2.15	1.51
44.0	1.9	0.4	1.04
		0.8	0.86
		1.1	0.75
		1.5	0.67
		1.65	0.63
45.0	0.8	---	---
46.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 11 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---	35.0	2.6	0.5	1.92
2.0	2.2	0.4	1.33			1.0	1.82
		0.9	1.76			1.6	1.62
		1.3	1.72			2.1	1.53
		1.8	1.43			2.35	1.55
		1.95	1.30	40.0	2.4	0.5	2.00
5.0	2.8	0.6	2.06			1.0	2.00
		1.1	1.98			1.4	1.78
		1.2	1.95			1.9	1.58
		2.2	1.91			2.15	1.51
		2.4	1.70	44.0	1.9	0.4	1.04
		2.55	1.57			0.8	0.86
10.0	3.0	0.6	2.18			1.1	0.75
		1.2	2.20			1.5	0.67
		1.8	2.08			1.65	0.63
		2.4	1.90	45.0	0.8	---	---
		2.6	1.82	46.0	0	---	---
		2.75	1.53				
15.0	2.9	0.6	2.11				
		1.2	2.05				
		1.7	1.98				
		2.3	1.90				
		2.5	1.79				
		2.65	1.39				
20.0	2.9	0.6	2.01				
		1.2	1.87				
		1.7	1.78				
		2.3	1.68				
		2.5	1.55				
		2.65	1.53				
25.0	3.0	0.6	2.11				
		1.2	2.10				
		1.8	1.88				
		2.4	1.70				
		2.6	1.39				
		2.75	1.07				
30.0	2.5	0.5	1.95				
		1.0	1.85				
		1.5	1.55				
		2.0	0.96				
		2.25	0.92				

TABLE 14 VELOCITY DISTRIBUTION **AREA**

Canal **No. 12 Sta** 5+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0		
2.0	2	0.3	0.70
		0.5	0.70
		0.9	0.77
		1.4	0.63
		1.7	0.67
4.0	3.3	- - -	- - -
5.0	4.0	0.4	1.08
		0.9	1.03
		1.7	1.08
		2.6	1.18
		3.4	1.33
		3.7	1.46
7.5	6.8	- - -	- - -
10.0	5.9	0.6	1.76
		1.2	2.02
		2.4	2.29
		3.7	1.92
		4.9	1.73
		5.6	1.56
12.5	6.8	- - -	- - -
15.0	7.1	0.7	2.42
		1.4	2.49
		2.8	2.52
		4.3	2.45
		5.7	1.92
		6.4	1.89
		6.7	1.86
20.0	7.6	0.8	2.42
		1.5	2.61
		3.0	2.75
		4.6	2.58
		6.0	2.35
		6.7	1.92
		7.2	2.02
25.0	8.3	0.8	2.78
		1.7	2.75
		3.3	2.82
		5.0	2.55
		6.6	2.22
		7.5	1.96
		7.9	2.02
30.0	8.5	0.9	2.98
		1.7	2.98
		3.4	3.01
		5.1	2.72
		6.8	2.35
		7.7	2.09
		8.1	2.02

Distance from Initial point	Depth	Observation Depth	Velocity
35.0	8.3	0.8	2.88
		1.7	3.05
		3.3	3.01
		5.0	2.82
		6.6	2.55
		7.5	2.29
		7.8	1.99
40.0	8.1	0.8	2.68
		1.6	2.68
		3.2	2.91
		4.9	2.78
		6.5	2.39
		7.3	2.29
		7.7	1.86
45.0	7.8	0.8	2.35
		1.6	2.62
		3.1	2.78
		4.7	2.72
		6.2	2.29
		7.0	1.91
		7.5	1.73
47.5	7.6	- - -	- - -
50.0	7.2	0.7	2.02
		1.4	2.29
		2.9	2.58
		4.3	2.48
		5.8	2.06
		6.5	1.69
		6.9	1.43
52.5	6.2	- - -	- - -
55.0	5.1	0.5	1.20
		1.0	1.33
		2.1	1.82
		3.1	1.64
		4.2	1.39
		4.7	1.05
58.0	3.0	0.3	0.87
		0.6	0.72
		1.2	0.50
		1.8	0.29
		2.4	Moss
		2.7	Moss
60.0	0	- - -	- - -

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 13 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
2.0	2.2	---	---
3.0	2.8	0.3	1.44
		0.6	1.66
		1.1	1.79
		1.7	1.69
		2.2	1.37
		2.4	1.36
		2.55	1.36
6.0	4.0	0.4	2.06
		0.8	2.12
		1.6	2.29
		2.5	2.12
		3.3	1.84
		3.6	1.79
		3.75	1.59
9.0	4.7	---	---
12.0	5.5	0.6	2.72
		1.1	2.78
		2.2	2.72
		3.3	2.706
		3.3	2.63
		3.3	2.68
		4.4	2.30
		5.0	2.09
		5.25	2.12
18.0	5.7	0.6	2.98
		1.1	2.98
		2.3	3.08
		3.4	2.88
		4.6	2.65
		5.1	2.55
		5.3	2.39
		5.45	2.25
21.0	5.8	---	---
24.0	5.8	0.6	3.01
		1.2	2.92
		2.3	2.92
		3.4	2.92
		4.6	2.62
		5.4	2.29
		5.0	2.62
		5.55	2.22
27.0	5.8	---	---
30.0	5.9	0.6	3.05
		1.2	3.05
		2.3	3.05
		3.5	2.82

Distance from Initial point	Depth	Observation Depth	Velocity
		4.7	2.55
		5.3	2.42
		5.5	2.35
		5.65	2.19
33.0	5.9	---	---
36.0	5.9	0.6	3.05
		1.2	3.05
		2.3	3.05
		3.5	2.85
		4.7	2.72
		5.3	2.42
		5.5	2.09
		5.65	2.29
39.0	5.8	---	---
42.0	5.8	0.6	3.02
		1.2	3.02
		2.3	3.02
		3.4	2.85
		4.6	2.59
		5.0	2.42
		5.4	2.35
		5.55	1.99
45.0	5.7	---	---
48.0	5.5	0.6	2.75
		1.1	2.85
		2.2	2.85
		3.3	2.72
		4.4	2.72
		4.7	2.49
		5.0	2.22
		5.25	1.92
49.0	5.35	---	---
51.0	4.9	--	---
54.0	3.9	0.4	1.98
		0.8	2.09
		1.6	2.19
		2.3	2.12
		3.1	1.80
		3.5	1.44
		3.65	1.62
57.0	2.6	0.3	1.36
		0.5	1.54
		1.0	1.53
		1.6	1.53
		2.2	1.20
		2.35	1.00
58.0	2.1	---	---
60.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 14 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0		
2.5	3.5	0.4	1.10
		0.7	1.20
		1.4	1.30
		2.1	1.30
		2.8	1.27
		3.1	1.29
4.0	4.8	- - -	- - -
6.0	5.8	0.6	2.09
		1.2	2.22
		2.3	2.22
		3.5	2.06
		4.6	1.86
		5.2	1.56
		5.4	1.46
8.0	7.0	- - -	- - -
10.0	7.7	0.8	2.42
		1.5	2.58
		3.1	2.62
		4.6	2.55
		6.2	2.15
		6.9	1.96
		7.3	1.92
15.0	8.6	0.9	2.75
		1.7	2.85
		3.4	2.98
		5.2	2.75
		6.9	2.39
		7.7	2.15
		8.2	1.89
20.0	8.6	0.9	3.01
		1.7	3.01
		3.4	2.92
		5.2	2.75
		6.9	2.42
		7.7	2.32
		8.2	1.79
25.0	8.8	0.9	3.08
		1.8	3.21
		3.5	3.21
		5.0	2.85
		7.0	2.32
		7.9	2.06
		8.4	1.94
30.0	9.0	0.9	3.01
		1.8	3.11
		3.6	3.05
		5.4	2.82
		7.2	2.42
		8.1	2.15
		8.4	1.73
		8.6	1.73
35.0	8.6	0.9	2.88
		1.7	2.98
		3.4	2.88
		5.2	2.72
		6.9	2.62
		7.7	2.29
		8.2	1.92
40.0	8.5	0.9	2.88
		1.7	2.98
		3.4	3.01
		5.2	2.85
		6.9	2.42
		7.7	2.19
		8.1	1.96
45.0	8.2	0.8	2.68
		1.6	2.92
		3.3	2.78
		4.9	2.58
		6.6	2.49
		7.4	2.42
		7.8	1.96
47.5	7.5	- - -	- - -
50.0	5.8	0.6	2.19
		1.2	2.32
		2.3	2.29
		3.5	2.09
		4.6	1.96
		5.2	1.46
		5.4	1.43
52.5	4.2	- - -	- - -
55.0	2.9	0.6	2.09
		1.2	1.99
		1.7	1.82
		2.3	1.73
		2.5	1.63
57.5	1.8	- - -	- - -
59.0	1.1	0.3	0.44
		0.5	0.46
		0.7	0.60
61.0	0	- - -	- - -

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 15 Sta 7+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0			22.0	5.0	0.5	3.21
2.0	3.25	0.65	1.30			1.0	3.17
		2.00	1.79			2.0	3.17
		2.60	1.79			3.0	2.98
		2.75	1.08			4.0	2.47
		2.75	1.20			4.5	2.16
		2.95	0.97			4.6	2.36
		2.95	0.93			4.7	2.11
4.0	4.0	0.4	1.99	26.0	5.4	0.4	2.74
		0.8	2.15			1.08	3.28
		1.2	2.40			2.16	3.13
		1.7	2.43			3.24	2.98
		2.2	2.26			4.32	2.39
		3.2	1.87			4.32	2.02
		3.4	1.82			4.90	2.01
		3.6	1.45			5.05	1.62
		3.75	1.39			5.20	1.15
6.0	4.30	0.3	2.24	30.0	5.2	0.4	3.28
		0.86	2.36			1.14	3.20
		2.8	2.39			1.72	3.32
		3.44	2.14			2.88	2.86
		3.80	1.85			4.04	2.70
		3.95	1.73			4.45	2.55
		4.05	1.75			4.70	2.16
10.0	4.6	0.4	2.70			4.80	1.24
		0.92	2.84	34.0	4.9	0.4	3.05
		2.30	2.97			0.98	3.20
		3.68	2.47			1.96	3.20
		4.10	2.39			2.84	3.13
		4.25	1.97			3.92	2.51
		4.35	1.97			4.40	2.36
14.0	4.9	0.4	2.94			4.65	2.16
		1.0	3.13	38.0	5.0	0.5	2.90
		1.96	2.97			1.0	2.94
		2.94	3.01			2.0	3.13
		3.92	2.43			3.0	3.01
		4.2	2.47			4.0	2.59
		4.4	2.15			4.25	2.67
		4.6	2.09			4.50	2.24
		4.7	1.71			4.75	1.78
18.0	4.85	0.35	2.98	42.0	4.9	0.4	2.54
		1.05	3.17			0.98	2.70
		1.94	3.13			1.96	2.70
		2.91	2.78			2.94	2.55
		3.88	2.70			3.92	2.40
		4.35	2.28			4.15	2.16
		4.50	1.40			4.4	1.89
		4.65	1.58			4.65	1.20

TABLE 14 VELOCITY DISTRIBUTION DATA

Canal No. 15 Sta 7+00

Distance from Initial point	Depth	Observation Depth	Velocity
46.0	4.25	0.35	2.01
		0.85	2.36
		1.70	2.54
		2.55	2.28
		3.40	2.16
		3.50	2.05
		3.75	1.93
		4.00	1.62
49.0	3.4	0.4	1.74
		0.68	1.89
		1.36	2.09
		2.04	1.97
		2.77	1.43
		2.90	1.32
		3.1	1.08
50.0	2.4	0.48	0.85
		1.1	0.89
		1.92	0.97
54.0	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 16 Sta 2+00

Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0	- - -	- - -	12.0	1.5	0.3	1.36
1.0	1.85	.38	1.46			0.6	1.46
		.75	1.66			0.9	1.36
		1.48	1.73			1.25	1.16
		1.60	1.56	13.0	0.9	0.18	1.11
2.0	2.5	0.3	1.51			0.54	1.03
		0.5	1.63			0.65	0.92
		1.0	1.86	14.0	0	- - -	- - -
		1.5	2.06				
		2.0	1.76				
		2.25	1.59				
3.0	2.65	.30	1.64				
		.53	1.79				
		1.06	2.09				
		1.59	2.15				
		2.12	1.92				
		2.40	1.65				
4.0	2.62	.30	1.82				
		.53	1.96				
		1.05	2.19				
		1.57	2.12				
		2.10	1.96				
		2.37	1.66				
6.0	2.65	.30	2.15				
		.53	2.25				
		1.06	2.35				
		1.59	2.32				
		2.12	2.09				
		2.40	1.92				
8.0	2.65	.30	2.12				
		.53	2.25				
		1.06	2.35				
		1.59	2.22				
		2.12	2.06				
		2.40	1.69				
10.0	2.5	0.30	1.56				
		0.50	1.82				
		2.00	1.63				
		2.25	1.44				
11.0	2.2	0.44	1.69				
		0.88	1.82				
		1.32	1.63				
		1.76	1.46				
		1.95	1.36				

TABLE 14 VELOCITY DISTRIBUTION DATA

Canal No. 17 Sta 3+50

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
0	1.2	---	---
1.0	2.9	---	---
2.0	2.5	0.5	1.49
		1.0	1.63
		1.5	1.53
		2.0	1.24
		2.25	1.10
4.0	3.0	0.6	2.19
		1.2	2.25
		1.8	2.12
		2.4	1.69
		2.75	1.36
6.0	3.2	0.6	2.68
		1.3	2.55
		1.9	2.25
		2.6	1.92
		2.95	1.46
8.0	3.05	0.55	2.35
		1.25	2.35
		1.85	2.25
		2.45	1.88
		2.80	1.66
10.0	2.8	0.6	1.77
		1.1	1.86
		1.7	1.73
		2.2	1.69
		2.55	1.56
11.0	2.3	---	---
12.0	1.6	0.4	1.43
		0.8	1.41
		1.2	1.20
		1.35	1.12
13.0	0	---	---

Canal No. 18 Sta 3+50

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	0.3	1.20
1.0	1.5	0.6	1.36
		1.0	1.05
		1.25	0.98
2.0	2.2	0.4	1.70
		0.9	1.73
		1.3	1.64
		1.8	1.39
		1.95	1.05
3.0	2.5	0.5	1.79
		1.0	1.86
		1.5	1.73
		2.0	1.54
		2.25	1.10
4.0	2.7	0.3	1.79
		0.5	1.89
		1.1	1.96
		1.6	1.83
		2.2	1.53
		2.45	1.37
6.0	2.8	0.3	1.79
		0.6	1.92
		1.1	1.96
		1.7	2.02
		2.2	1.89
		2.55	1.63
8.0	2.7	0.5	1.82
		1.1	1.96
		1.6	1.96
		2.2	1.70
		2.45	1.51
9.0	2.55	0.55	1.67
		1.05	1.79
		1.55	1.76
		2.05	1.56
		2.30	1.46
10.0	2.4	0.4	1.49
		0.9	1.47
		1.4	1.34
		1.9	1.23
		2.15	1.10
11.0	2.25	0.45	1.33
		0.85	1.39
		1.05	1.29
		1.75	0.93
		1.90	0.59
12.0	1.8	---	---
12.5	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 19 Sta 7+00

Distance from Initial Point	Depth	Observation Depth	Velocity	Distance from Initial Point	Depth	Observation Depth	Velocity
2.0	2.5	0.5	1.26			1.9	2.65
		1.0	1.06			2.6	2.35
		1.5	0.63			2.8	2.16
		2.0	0.49			2.95	2.20
		2.25	0.41	26.0	2.8	0.6	2.02
4.0	2.8	0.6	1.89			1.1	2.25
		1.1	2.08			1.7	2.15
		1.7	1.79			2.2	1.9.
		2.2	1.62			2.4	1.84
		2.3	1.50			2.55	1.82
		2.25	1.41	27.0	2.5	---	---
7.0	3.1	0.6	2.25	27.5	2.1	---	---
		1.3	2.55				
		1.9	2.34				
		2.6	2.06				
		2.7	2.02				
		2.85	1.89				
10.5	3.4	0.7	2.98				
		1.4	2.98				
		2.0	2.95				
		2.7	2.69				
		3.0	2.61				
		3.15	2.52				
14.0	3.4	0.7	3.28				
		1.4	3.25				
		2.0	3.05				
		2.7	2.95				
		3.0	2.67				
		3.15	2.75				
17.5	3.4	0.7	3.22				
		1.4	3.18				
		2.0	3.05				
		2.7	2.80				
		3.0	2.65				
		3.15	2.48				
21.0	3.4	0.7	2.88				
		1.4	3.02				
		2.0	2.95				
		2.7	2.67				
		3.0	2.63				
		3.15	2.38				
24.0	3.2	0.6	2.45				
		1.3	2.75				

TABLE 14 VELOCITY DISTRIBUTION DATA

Canal No. 20 Sta 4+00				Canal No. 21 Sta 4+18			
Distance from Initial point	Depth	Observation Depth	Velocity	Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---	1.0	1.1	---	---
1.0	1.5	---	---	2.0	1.7	0.4	1.52
2.0	2.0	0.4	1.28			0.7	1.75
		0.8	1.46			1.0	1.74
		1.2	1.31			1.3	1.60
		1.6	1.22			1.45	1.44
5.0	4.0	0.4	1.95	4.0	2.7	0.5	1.91
		0.8	2.05			1.1	2.12
		1.6	2.11			1.6	2.07
		2.4	1.98			2.3	1.88
		3.2	1.78			2.45	1.72
		3.6	1.70	6.0	3.8	---	---
7.0	4.8	---	---	8.0	4.2	0.5	2.28
10.0	5.3	0.5	2.28			0.8	2.35
		1.1	2.35			1.7	2.48
		2.1	2.35			2.5	2.38
		3.2	2.28			3.4	2.19
		4.2	2.13			3.8	2.01
		4.9	1.93			3.95	2.09
13.0	5.3	---	---	10.0	4.4	0.5	2.36
15.0	5.3	0.5	2.38			0.9	2.41
		1.1	2.38			1.8	2.52
		2.1	2.38			2.6	2.56
		3.2	2.28			3.5	2.34
		4.2	2.09			4.0	2.17
		4.9	1.88			4.15	1.97
17.0	5.3	---	---	12.0	4.0	0.5	2.28
20.0	5.15	0.5	2.18			0.8	2.31
		1.0	2.21			1.6	2.42
		2.1	2.31			2.4	2.55
		3.1	2.15			3.2	2.40
		4.1	1.93			3.6	2.24
		4.7	1.66			3.75	2.03
23.0	4.2	---	---	15.0	2.8	0.6	1.92
25.0	3.6	0.7	1.88			1.1	1.93
		1.4	1.86			1.7	1.98
		2.2	1.82			2.2	1.72
		2.9	1.68			2.55	1.57
		3.2	1.56	18.0	1.5	0.5	1.35
27.0	2.5	---	---			0.9	1.21
28.0	2	0.4	1.05			1.1	1.11
		0.8	1.33			1.25	1.13
		1.2	1.40	20.0	0	---	---
		1.6	1.27				
29.0	1.5	---	---				
30.0	0	---	---				

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 22 Sta 5+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	---	---
1.0	0.4	---	---
2.0	0.8	---	---
3.0	1.6	0.3	0.89
		0.6	0.67
		1.2	0.39
4.0	2.15	---	---
5.0	2.6	0.5	1.39
		1.0	1.33
		1.6	1.22
		2.2	0.99
		2.35	0.89
10.0	3.2	0.6	1.95
		1.3	1.82
		1.9	1.82
		2.6	1.39
		2.8	1.41
		2.95	1.28
15.0	3.4	0.68	2.25
		1.4	2.08
		2.0	1.86
		2.7	1.48
		3.0	1.41
20.0	3.2	0.6	2.35
		1.3	2.07
		1.9	2.05
		2.6	1.81
		2.8	1.46
25.0	3.2	0.6	2.12
		1.3	1.98
		1.9	1.82
		2.6	1.68
		2.8	1.48
30.0	2.8	0.6	2.32
		1.1	2.19
		1.7	2.05
		2.2	1.85
		2.4	1.63
35.0	3.3	0.7	2.22
		1.3	2.00
		2.0	1.86
		2.6	1.74
		2.9	1.55
40.0	3.2	0.6	1.97
		1.3	1.90
		1.9	1.76
		2.6	1.50
		2.8	1.51
45.0	2.5	0.6	1.24
		1.0	1.13
		1.5	0.99
		2.0	0.98
46.0	2.4	---	---
47.0	1.8	0.4	1.16
		0.7	0.88
		1.1	0.76
		1.4	0.49
48.0	1.0	---	---
49.1	0	---	---

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 23 Sta 3+60

Distance from Initial point	Depth	Observation Depth	Velocity
0	1.5	- - -	- - -
2.0	1.5	- - -	- - -
3.0	2.6	0.5	1.38
		1.0	1.45
		1.6	1.56
		2.0	1.41
		2.2	1.32
4.0	2.6	- - -	- - -
5.0	2.6	- - -	- - -
7.0	2.5	0.5	2.14
		1.0	2.22
		1.5	2.18
		1.9	2.05
		2.1	1.93
10.0	2.5	- - -	- - -
12.0	2.8	- —	- - -
14.0	2.7	- - -	- - -
15.0	2.7	0.5	2.15
		1.1	1.91
		1.6	1.88
		2.1	1.70
		2.3	1.66
18.0	2.9	- - -	- - -
20.0	2.8	- - -	- - -
22.0	2.9	- - -	- - -
24.0	3.0	- -	- - -
25.0	3.0	0.6	2.18
		1.2	2.15
		1.8	1.98
		2.4	1.57
		2.6	1.47
28.0	2.8	- - -	- - -
30.0	2.8	- - -	- - -
32.0	2.95	- - -	- - -
35.0	3.3	0.7	2.12
		1.3	2.08
		2.0	1.88
		2.6	1.78
		2.9	1.78
38.0	2.9	- - -	- - -
40.0	3.2	- - -	- - -
42.0	2.9	- - -	- - -
45.0	2.8	0.6	2.25
		1.1	2.10
		1.7	1.91
		2.2	1.72
		2.4	1.70

Distance from Initial point	Depth	Observation Depth	Velocity
48.0	2.6	- - -	- - -
50.0	2.6	- - -	- - -
52.0	3.1	- - -	- - -
55.0	3.0	0.6	2.35
		1.2	2.26
		1.8	2.08
		2.4	1.73
		2.6	1.21
57.5	3.1	- - -	- - -
60.0	3.1	- - -	- - -
62.0	2.9	0.6	2.28
		1.2	2.22
		1.7	2.32
		2.3	2.17
		2.5	1.99
64.0	2.9	- - -	- - -
66.0	2.7	0.5	1.58
		1.1	1.86
		1.6	1.68
		2.1	1.45
		2.3	1.39
67.0	2.6	0.5	1.38
		1.0	1.45
		1.6	1.56
		2.0	1.41
		2.2	1.32
68.0	2.35	- - -	- - -
69.0	0	- - -	- - -

TABLE 14 VELOCITY DISTRIBUTION AREA

Canal No. 24 Sta 4+00

Distance from Initial point	Depth	Observation Depth	Velocity
0	0	- - -	- - -
.5	1.4	- - -	- - -
1.0	1.9	- - -	- - -
2.0	2.4	0.5	1.28
		1.0	1.16
		1.4	1.02
		1.9	0.81
		2.0	0.79
3.5	3.4	- - -	- - -
5.0	3.6	0.7	1.78
		1.4	1.90
		2.2	1.77
		2.9	1.52
		3.2	1.36
8.0	3.6	0.7	2.12
		1.4	2.25
		2.2	2.18
		2.9	1.98
		3.2	1.93
10.0	3.7	0.7	2.25
		1.5	2.32
		2.2	2.20
		3.0	1.82
		3.3	1.57
12.5	3.7	0.7	2.38
		3.0	1.82
15.0	3.8	0.8	2.45
		1.5	2.32
		2.2	2.02
		3.0	1.93
		3.4	1.87
17.5	3.6	0.7	2.38
		2.9	1.72
20.0	3.8	0.8	2.30
		1.5	2.35
		2.2	2.18
		3.0	1.92
		3.4	1.51
22.5	3.5	0.7	2.15
		1.4	2.25
		2.1	2.25
		2.8	1.88
		3.1	1.67
25.0	3.7	0.7	1.99
		1.5	2.05
		2.2	2.05
		3.0	1.77
		3.3	1.65
27.5	3.4	0.7	1.58
		1.4	1.74
		2.0	1.72
		5.7	1.56
		3.0	1.40
28.5	2.7	- - -	- - -
29.5	2.3	- - -	- - -
29.5	0	- - -	- - -

Table 15, Cross-Section Data

Canal 1						Canal 2					
Sta 4+00		Sta 6+00		Sta 7+00		Sta 3+00		Sta 5+00		Sta 7+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
0	0.20	1	1.15	2	2.05	1	2.0	2	2.35	1	1.1
1	1.60	2	1.60	4	2.60	2	2.6	4	3.00	2	2.0
2	2.20	3	2.05	7	2.80	3	3.3	6	4.20	3	3.3
3	2.58	4	2.50	10	3.00	4	3.7	8	4.80	4	3.9
4	2.65	5	2.90	13	3.04	5	3.8	10	5.00	5	4.0
6	2.84	6	3.15	16	3.00	6	4.0	15	5.20	6	4.9
8	3.19	7	3.20	19	3.00	8	4.3	20	5.80	8	5.0
10	3.32	8	3.30	22	2.90	10	4.7	25	6.40	10	5.1
12	3.41	9	3.30	25	2.60	12	5.0	30	6.50	12	5.2
14	3.41	10	3.35	26	2.40	14	5.2	35	6.50	14	5.3
16	3.46	11	3.45	27	0	16	5.3	40	6.20	16	5.3
18	3.50	12	3.45			18	5.2	45	5.70	18	5.4
20	3.50	13	3.45			22	5.6	48	5.50	20	5.8
21	3.38	14	3.40			24	6.0	50	5.30	24	5.9
22	3.20	15	3.40			28	6.3	52.5	4.70	28	6.1
23	2.84	16	3.30			30	6.6	55	4.10	30	6.2
24	2.45	17	3.25			32	6.9	57.5	3.00	34	6.1
25	2.20	18	3.25			36	6.5	60	1.60	38	6.0
26	1.34	19	3.15			40	6.7	62	0	40	5.8
26.5	0	20	3.10			42	6.3			44	5.6
		21	3.05			46	5.9			48	5.9
		22	3.05			50	5.8			50	5.8
		23	3.00			52	5.3			52	5.7
		24	2.90			54	5.0			54	5.1
		25	2.90			56	4.1			56	4.8
		26	2.55			57	3.8			58	4.0
		27	2.00			58	3.2			60	3.1
		27	0			59	2.6			62	1.9
						60	2.0			63	1.0
						60	0			63	0

Table 15 cont., Cress-Section Data

Canal 3						Canal 4					
Sta 2+00		Sta 5+00		Sta 5+70		Sta 4+00		Sta 5+00		Sta 6+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
2	3.80	2	4.60	2	1.70	1	2.40	2	2.40	1	1.75
4	5.40	4	6.40	4	3.10	2	3.20	4	3.70	2	2.50
6	6.45	6	7.00	6	5.10	4	4.20	6	4.50	4	3.75
8	6.90	8	7.10	8	6.20	6	5.10	8	5.10	6	4.50
10	7.55	10	7.70	10	7.20	8	5.30	10	5.50	8	5.20
12	8.05	13	8.00	12	7.80	10	5.65	12	5.80	10	5.70
14	8.30	16	8.30	14	8.10	12	5.80	14	5.90	12	5.85
16	8.30	22	8.70	16	8.10	14	6.10	16	6.00	14	6.00
18	8.35	28	8.50	18	8.30	16	6.10	18	6.20	16	6.15
20	8.35	34	8.50	22	8.55	18	6.10	20	6.20	18	6.20
24	8.50	40	8.40	24	8.60	20	6.00	22	6.20	20	6.20
28	8.60	46	8.30	26	8.40	22	6.00	24	6.20	22	6.25
32	8.80	52	8.40	28	8.50	24	6.00	26	6.20	24	6.20
36	8.80	58	8.40	36	8.30	28	6.00	28	6.20	26	6.00
40	8.75	64	8.30	40	8.55	30	6.00	30	6.10	28	6.00
44	8.70	67	8.30	48	8.55	32	6.00	32	6.00	30	5.80
48	8.65	70	7.60	52	8.60	34	6.00	34	6.00	32	5.60
52	8.60	72	7.40	56	8.70	36	5.50	36	5.80	34	5.25
56	8.50	74	6.50	60	8.50	38	4.90	38	5.50	36	4.90
60	8.45	76	5.30	64	8.40	39	4.60	40	4.70	38	4.60
62	8.45	78	4.10	68	8.30	40	4.00	42	4.00	40	3.90
64	8.30	80	0	72	8.35	41	3.10	43	3.10	41	3.20
66	7.90			76	8.20	42	2.75	44	2.00	42	2.50
68	7.55			80	8.00	42	0	44	0	42.5	0
70	6.70			82	7.55						
72	6.20			84	7.20						
74	4.75			86	6.00						
76	1.80			88	4.50						
77	0			90	2.70						
				91	0						

Table 15 cont., Cross-Section Data

Canal 5						Canal 6					
Sta 5+00		Sta 6+00		Sta 7+00		Sta 2+00		Sta 5+00		Sta 7+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
0	0.85	0	0.90	0	2.7	3	1.20	4	1.50	4	1.20
1	1.60	2	3.70	1	3.2	6	2.60	8	2.41	8	2.90
2	2.35	4	4.30	2	3.75	9	4.20	12	4.39	12	4.80
3	3.70	6	5.20	3	4.40	12	5.12	16	5.82	16	6.40
4	4.60	8	5.50	4	5.00	16	6.19	20	7.20	20	7.70
5	4.85	10	5.70	5	5.30	20	7.22	25	8.00	25	7.80
6	5.20	12	5.90	6	5.60	25	7.80	30	8.10	30	7.40
7	5.30	14	6.00	7	6.00	30	7.91	35	8.03	35	8.30
8	5.70	16	6.10	8	6.00	35	7.50	40	7.60	40	8.30
10	5.80	18	6.00	9	6.05	40	8.30	45	7.80	45	8.10
12	6.00	22	6.00	10	6.10	45	8.42	50	8.18	50	7.90
14	6.15	26	6.00	14	6.00	50	8.24	55	8.34	55	7.50
16	6.10	30	6.00	16	6.15	55	8.11	60	8.30	60	7.70
20	6.15	34	6.00	20	6.15	60	8.00	65	8.00	65	7.90
22	6.10	36	5.70	24	6.25	65	7.80	70	7.94	70	7.50
26	6.10	38	5.40	26	6.20	70	7.97	75	7.02	75	5.70
30	6.00	40	4.70	28	6.10	74	7.02	80	4.37	80	3.30
32	5.75	42	4.30	30	6.05	78	4.00	84	2.20	86	0
34	5.60	44	3.30	32	5.95	82	2.23	88	0		
36	5.50	45	2.90	34	5.75	87	0				
38	5.90	47	1.30	36	5.50						
40	5.00	47	0	38	5.10						
41	4.60			39	4.85						
42	4.35			40	4.60						
43	3.30			41	4.00						
44	3.50			42	3.60						
45	3.05			43	3.15						
46	2.4			44	1.30						
47.5	0			46	0						

Table 15 cont., Cross-Section Data

Canal 7						Canal 8					
Sta 4+00		Sta 6+00		Sta 8+00		Sta 4+00		Sta 5+00		Sta 6+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
1	1.85	0	0	0	0	0	0	0	0	0	0
2	2.25	1	1.5	1	1.8	2	2.65	2	1.45	2	2.00
4	3.05	2	2.6	2	2.5	4	2.95	4	1.75	4	2.70
6	3.30	4	2.9	4	3.35	6	3.00	6	2.05	8	2.60
8	3.57	6	3.4	6	3.50	8	2.85	8	2.05	12	2.50
10	3.63	8	3.5	8	3.65	10	3.25	10	2.20	16	2.50
12	3.70	10	3.55	10	3.70	12	2.95	12	2.15	20	2.20
14	3.60	12	3.55	12	3.70	14	2.90	14	2.25	24	2.40
16	3.60	14	3.50	14	3.70	16	2.80	16	2.30	28	2.45
18	3.60	16	3.55	16	3.70	18	2.95	18	2.40	32	2.30
20	3.50	18	3.50	18	3.70	20	2.80	20	2.45	36	2.50
22	3.60	20	3.50	20	3.70	22	2.80	22	2.50	40	2.60
24	3.50	22	3.50	22	3.60	24	2.70	24	2.60	44	2.80
26	3.50	24	3.50	24	3.70	26	2.65	26	2.80	48	1.80
28	3.35	26	3.55	26	3.50	28	2.50	28	2.70	50	1.50
30	3.20	28	3.50	28	3.40	30	2.80	30	2.75	53	0
32	2.40	30	3.35	30	2.70	32	2.35	32	2.75		
33	1.70	32	2.8	31	2.25	34	2.10	34	2.85		
33.5	0	33	2.3	32	0	36	1.90	36	2.85		
		34	0			38	2.15	38	2.85		
						40	2.15	40	2.70		
						42	2.45	42	2.65		
						44	2.45	44	2.35		
						46	2.60	46	2.30		
						48	2.55	48	2.20		
						50	2.0	50	2.30		
						52	0	52	1.95		
								54	0		

Table 15 cont., Cross-Section Data

Canal 9						Canal 10					
Sta 5+00		Sta 6+00		Sta 7+00		Sta 3+00		Sta 4+00		Sta 5+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	1.5	2	1.9	1	1.30	1	1.7	1	1.40	1	0.90
2	1.90	4	2.85	2	1.80	2	2.0	2	2.00	2	1.50
3	2.30	8	3.00	3	2.40	3	2.6	3	2.50	3	1.80
4	2.80	12	3.00	4	2.75	4	2.9	4	2.75	4	2.15
6	2.90	16	3.10	6	2.70	5	2.95	5	2.80	5	2.90
8	2.90	20	3.00	8	2.70	6	2.95	6	2.80	6	2.90
10	2.90	24	2.90	10	2.70	8	2.90	7	2.80	7	3.00
12	2.90	28	2.85	12	2.73	10	2.90	8	2.80	8	2.90
14	2.95	32	2.75	14	2.73	12	3.05	10	2.90	10	2.80
16	2.90	36	2.80	16	2.70	14	2.95	12	2.60	12	2.80
18	3.00	40	2.45	18	2.80	16	2.95	14	2.70	14	2.90
20	2.90	42	1.50	20	2.86	18	2.80	16	2.70	16	3.00
22	2.90	43	0.90	22	2.82	20	2.85	18	2.90	18	3.00
24	2.90	44	0	24	2.70	22	2.90	20	2.80	20	3.05
26	2.80			26	2.80	24	3.85	22	2.90	22	3.00
28	2.80			28	2.70	26	2.95	24	3.10	24	2.95
30	2.82			30	2.72	28	2.75	26	3.00	26	3.20
32	2.74			32	2.62	30	2.65	28	2.95	28	3.00
34	2.70			34	2.70	32	2.75	30	2.90	30	3.00
36	2.70			36	2.65	34	2.65	32	2.90	32	2.95
38	2.70			38	2.70	36	2.65	34	2.90	34	2.75
40	2.75			40	2.76	38	2.65	36	2.80	36	2.00
42	2.50			42	2.60	39	2.35	38	2.30	37	1.90
43	2.25			44	2.00	40	1.90	39	2.15	38	1.80
44	1.90			46	0	40.75	0	40	2.15	39	1.60
45	1.50							41	2.15	40	1.40
46	0							42	2.20	41	1.00
								43	2.00	42	0
								43.5	0		

Table 15 cont., CrosseSection Data

Canal 10 cont.						Canal 11					
Sta 5+45		Sta 6+00		Sta 7+00		Sta 3+00		Sta 4+00		Sta 5+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	1.1	1	1.10	1	0.9	1	1.75	1	1.45	2	2.20
2	1.95	2	1.80	2	1.80	2	2.05	2	1.75	5	2.80
4	2.55	3	2.30	3	2.30	3	2.20	3	2.20	10	3.0
6	2.80	4	2.75	4	2.70	4	2.35	4	2.45	15	2.90
8	2.90	6	2.85	6	2.85	5	2.50	5	2.40	20	2.90
10	3.10	8	2.85	8	2.85	6	2.60	6	2.55	25	3.00
12	2.90	10	2.90	10	2.95	7	2.65	7	2.65	30	2.50
14	3.00	12	2.90	12	3.00	8	2.75	8	2.70	35	2.60
16	3.00	14	3.00	14	2.85	10	2.70	10	2.85	40	2.40
18	3.20	16	2.95	16	2.90	12	2.60	12	2.75	44	1.90
20	3.20	18	2.90	18	2.90	14	2.75	14	2.70	45	0.80
22	3.05	20	2.85	20	3.00	16	2.90	16	3.10	46	0
24	3.00	22	2.90	22	3.10	18	2.95	18	3.60		
26	2.95	24	2.90	24	3.20	20	3.00	20	3.35		
28	2.95	26	2.80	26	3.90	22	3.17	22	3.35		
30	3.00	28	3.00	28	2.90	24	3.45	24	3.36		
32	3.10	30	2.95	30	2.95	26	3.20	26	3.10		
34	2.85	32	2.80	32	2.65	28	3.00	28	2.85		
36	2.40	34	2.40	33	2.60	30	2.80	30	2.80		
37	2.05	35	2.30	34	2.20	32	2.85	32	2.55		
38	1.70	36	2.00	35	1.90	34	2.75	34	2.55		
39	0.60	37	1.65	38	1.80	36	2.80	36	2.55		
39.5	0	37.75	0	37	0	38	2.80	38	2.55		
						40	2.95	40	2.55		
						42	3.15	42	2.55		
						44	3.10	44	2.50		
						45	2.35	45	2.20		
						46	1.90	46	1.55		
						47	1.40	47	0.90		
						48	0	47.5	0		

Table 15 cont., Cross-Section Data

Canal 11 cont.				Canal 12						Canal 13	
Sta 6+00		Sta 8+00		Sta 4+00		Sta 5+00		Sta 6+00		Sta 4+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	1.55	1	1.65	2	2.50	2	2.00	2	2.40	2	2.00
2	2.15	2	2.00	4	3.10	4	3.30	4	3.40	4	3.00
3	2.60	3	2.40	6	4.40	5	4.00	6	4.10	6	3.75
4	2.90	4	2.55	8	5.10	7.5	5.60	8	4.40	8	4.40
5	3.10	5	2.65	10	5.50	10	5.90	10	4.90	10	5.05
6	3.25	6	2.55	12	5.50	12.5	6.80	12	5.30	12	5.50
7	3.20	7	2.70	14	6.50	15	7.10	14	5.50	14	5.60
8	3.55	8	2.65	16	6.90	20	7.60	16	5.80	16	5.65
9	3.50	10	2.40	18	7.20	25	8.30	18	6.40	18	5.65
10	3.30	12	2.40	20	7.40	30	8.50	20	6.80	20	5.70
12	3.05	14	2.75	22	7.60	35	8.30	22	7.10	24	5.70
14	2.85	16	2.80	24	7.70	40	8.10	24	7.50	28	5.70
16	2.75	18	2.70	26	7.80	45	7.80	28	7.80	32	5.70
18	2.65	20	2.85	28	7.70	47.5	7.60	32	8.00	36	5.65
22	2.55	22	2.75	32	7.60	50	7.20	34	7.80	40	5.60
24	3.05	24	2.65	36	7.60	52.5	6.20	38	7.70	42	5.60
26	3.30	28	2.65	38	7.80	55	5.10	42	7.40	44	5.60
28	3.25	30	2.60	40	7.90	58	3.00	44	7.30	46	5.50
30	3.15	34	2.90	44	7.90	60	0	46	6.90	48	5.05
32	2.90	36	2.85	46	7.70			48	6.60	50	5.05
34	2.80	38	2.80	48	8.00			50	6.30	52	4.50
36	2.90	40	2.75	50	7.70			52	5.90	54	3.70
38	2.90	41	2.40	52	7.40			54	5.40	56	3.00
40	2.75	42	2.35	54	7.00			55	5.10	58	2.05
42	2.45	43	2.25	55	6.00			56	4.40	60	0
44	2.25	44	2.05	56	5.50			58	4.00		
45	2.05	45	1.85	58	4.80			59	3.40		
46	1.60	46	1.55	60	3.70			60	2.60		
47	1.30	47	1.10	61	2.40			61	1.90		
47.5	0	47.5	0	62	0			62	0		

Table 15 cont., Cross-Section Data

Canal 13 Cont.				Canal 14						Canal 15	
Sta 5+00		Sta 6+00		Sta 4+00		Sta 5+00		Sta 6+00		Sta 5+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
2	2.20	2	2.50	1	1.10	2.5	3.5	1	2.30	1	2.1
3	2.80	4	3.30	2	1.60	4	4.8	2	3.00	2	3.5
6	4.00	6	4.00			6	5.8	3	3.50	4	4.0
9	4.70	8	4.75	4	3.75	8	7.0	4	4.40	6	4.2
12	5.50	10	5.30	6	4.75	10	7.7	6	5.40	8	4.4
18	5.70	12	5.70	8	5.50	12.5	8.5	8	6.00	10	4.6
21	5.80	14	5.80	10	6.25	15	8.6	10	7.00	12	4.7
24	5.80	16	5.90	12	7.10	20	8.6	12	7.10	14	4.7
27	5.80	18	5.95	14	7.80	25	8.8	14	7.60	16	4.9
30	5.90	24	5.95	16	8.50	30	9.0	16	7.90	18	5.2
33	5.90	28	5.95	18	8.50	35	8.6	18	8.15	22	4.8
36	5.90	32	5.90	20	8.75	40	8.5	20	8.50	26	5.0
39	5.80	36	5.90	22	8.75	45	8.2	24	8.75	30	5.2
42	5.80	40	5.90	24	9.10	47.5	7.5	26	9.00	34	4.8
45	5.70	42	5.75	26	9.00	50.0	5.8	28	9.20	38	4.9
48	5.50	44	5.65	28	8.90	52.5	4.2	30	9.10	42	5.1
49	5.35	46	5.35	30	8.80	55	2.9	32	9.20	44	4.9
51	4.90	48	4.95	32	9.00	57.5	1.2	34	9.05	46	4.3
54	3.90	50	4.35	34	8.80	59	1.1	40	8.90	48	3.9
57	2.60	52	3.60	36	8.65	61	0	42	8.75	50	3.3
58	2.10	54	2.80	42	8.50			44	8.90	52	2.2
60	0	56	2.10	44	8.30			46	8.75	54	1.2
		57	1.75	46	8.00			48	7.90	55.6	0
		59	0	48	7.50			50	6.90		
				50	5.50			52	5.10		
				52	5.00			54	4.00		
				54	4.25			56	2.50		
				56	2.70			58	1.40		
				58	1.50			60	0.75		
				60	1.0			61	0		
				62	0						

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Table 15 cont., Cross-Section Data

Canal 15 cont.				Canal 16						Canal 17	
Sta 7+00		Sta 9+00		Sta 0+70		Sta 2+00		Sta 4+00		Sta 3+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
2	3.25	1	1.2	1	1.16	1	1.85	1	1.6	0.5	0.60
4	4.00	2	2.4	2	1.80	2	2.50	2	2.2	1	1.20
6	4.30	4	4.0	3	2.35	3	2.65	3	2.5	2	1.90
10	4.60	6	4.5	4	2.80	4	2.62	4	2.9	3	2.00
14	4.90	8	4.6	5	2.85	6	2.65	5	3.0	4	2.60
18	4.85	10	4.7	6	2.90	8	2.65	6	3.0	5	2.90
22	5.00	12	4.5	7	2.90	10	2.50	7	3.05	6	3.00
26	5.40	14	4.4	8	3.00	11	2.20	8	3.05	7	3.00
30	5.20	16	4.7	9	3.00	12	1.50	9	3.05	8	3.00
34	4.90	18	4.8	10	3.00	13	0.90	10	3.10	9	2.95
38	5.00	20	5.0	11	2.50	14	0	11	2.90	10	2.50
42	4.90	22	5.2	12	2.10			12	2.00	11	2.15
46	4.25	24	5.1	13	1.50			13	1.1	12	1.55
49	3.40	26	4.8	14	0			14	0	13	0.7
50	2.40	28	4.7							13.5	0
54	0	30	4.7								
		32	4.8								
		34	4.9								
		36	5.1								
		38	5.1								
		40	5.2								
		42	4.6								
		44	4.3								
		46	3.4								
		48	2.6								
		50	1.1								
		51.6	0								

Table 15 cont., Cross-Section Data

Canal 17 cont.				Canal 18						Canal 19	
Sta 3+50		Sta 4+00		Sta 2+00		Sta 3+00		Sta 4+00		Sta 5+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0.90	0	0	0	0	0	0	0	0
0	1.2	1	1.50	0	0.70	1	1.50	0	2.25	0	0.26
1	2.9	2	2.20	1	1.75	2	2.20	1	2.45	1	1.78
2	2,5	3	2.55	2	2.37	3	2.50	2	2.55	2	2.50
4	3.0	4	2.80	3	2.80	4	2.70	3	2.70	3	2.81
6	3.2	5	2.95	4	2.90	6	2.80	4	2.90	4	2.88
8	3.05	6	3.00	5	2.90	8	2.70	5	2.85	6	3.10
10	2.80	7	2.90	6	2.95	9	2.55	6	2.70	8	3.42
11	2.3	8	3.20	7	2.98	10	2.40	7	2.75	10	3.53
12	1.6	9	3.00	8	2.95	11	2.15	8	2.65	12	3.59
13	0	10	2.90	9	2.75	12	1.80	9	2.45	14	3.63
		11	2.50	10	2.50	12.5	0	9.5	2.35	16	3.70
		12	2.10	11	1.50			10	2.00	18	3.73
		13	1.40	12	0.3			10.5	1.50	20	3.68
		13.5	0	12	0			11	0.60	21	3.58
								11.5	0	22	3.43
										23	3.07
										24	2.73
										25	2.44
										26	1.43
										26.5	0

Table 15 cont., Cross-Section Data

Canal 19 cont.								Canal 20			
Sta 6+00		Sta 7+00		Sta 9+00		Sta 10+00		Sta 1+00		Sta 2+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
0	0.28	2	2.5	0	0.25	0	0.20	0	1.00	0	0.2
1	1.34	4	2.8	1	1.60	1	1.64	1	1.65	1	1.40
2	1.83	7	3.1	2	2.17	2	2.41	2	2.00	2	2.10
3	2.43	10.5	3.4	3	2.52	3	2.64	3	2.65	3	2.80
4	2.86	14	3.4	4	2.68	4	2.85	4	3.10	4	3.20
5	2.96	17.5	3.4	6	2.97	6	3.06	5	4.00	5	3.70
6	3.10	21	3.4	8	3.16	8	3.31	6	4.40	6	4.10
8	3.40	24	3.2	10	3.39	10	3.43	8	5.05	7	4.50
10	3.54	26	2.8	12	3.50	12	3.53	10	5.30	8	4.70
12	3.51	27	2.5	14	3.58	14	3.55	12	5.50	10	5.10
14	3.62	27.5	2.1	16	3.64	16	3.53	14	5.60	12	5.65
16	3.52	27.5	0	18	3.69	18	3.53	16	5.80	14	5.70
18	3.50			20	3.60	20	3.52	18	5.90	16	5.45
20	3.45			22	3.45	22	3.43	20	5.80	18	5.25
22	3.41			23	3.20	23	3.34	22	5.00	20	5.50
23	3.61			24	2.90	24	3.11	23	4.60	22	5.20
24	3.23			25	2.50	25	2.92	24	4.15	23	5.00
25	2.97			26	1.74	26	2.47	25	3.60	24	4.60
26	2.65			27	0	27	1.82	26	3.00	25	4.10
27	2.00					27.5	0	27	2.50	26	3.60
28	1.22							28	1.70	27	3.05
28.5	0							29	1.30	28	2.60
								30	1.0	29	2.10
								30	0	30	1.50
										30.2	0

Table 15 cont., Cross-Section Data

Canal 20 cont.						Canal 21					
Sta 4+00		Sta 5+00		Sta 7+00		Sta 1+00		Sta 3+00		Sta 4+18	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	1.50	1	1.80	1	1.40	1	1.20	1	1.10	1	1.10
2	2.00	2	2.20	2	2.20	2	1.95	2	1.60	2	1.70
5	4.00	3	2.70	3	2.90	3	2.55	3	2.30	4	2.70
7	4.80	4	3.35	4	3.45	4	3.00	4	2.85	6	3.80
10	5.30	5	3.90	5	3.95	5	3.50	5	3.50	8	4.20
13	5.30	6	4.40	6	4.35	6	4.10	6	3.95	10	4.40
15	5.30	7	4.70	7	4.70	7	4.50	7	4.15	12	4.00
17	5.30	8	5.05	8	5.20	8	4.65	8	4.35	16	2.80
20	5.15	10	5.45	10	5.60	9	4.70	9	4.70	18	1.50
23	4.20	12	5.70	12	5.85	10	4.70	10	4.65	20	0
25	3.60	14	6.00	14	5.60	11	4.65	11	4.50		
27	2.50	16	6.00	16	5.70	12	4.60	12	4.35		
28	2.00	18	5.90	18	5.60	13	4.20	13	4.20		
29	1.50	20	5.40	20	5.20	14	3.95	14	3.90		
30	0	22	4.50	21	4.80	15	3.45	15	3.35		
		23	4.15	22	4.40	16	2.75	16	2.90		
		24	3.50	23	3.90	17	2.30	17	2.45		
		25	3.00	24	3.20	18	1.70	18	1.60		
		26	2.30	25	2.90	19	1.05	19	1.00		
		27	1.80	26	1.85	20	0	20	0		
		28	1.00	27	1.60						
		29	0	28	1.1						
				28.5	0						

Table 15 cont., Cross-Section Data

Canal 21 cont.				Canal 22							
Sta 5+00		Sta 7+00		Sta 1+00		Sta 3+00		Sta 5+00		Sta 6+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	1.00	1	1.10	1	0.80	1	0.60	1	0.4	1	0.60
2	1.65	2	1.60	2	1.05	2	1.10	2	0.8	2	1.20
3	2.25	3	2.60	3	1.45	3	1.55	3	1.6	3	1.50
4	2.80	4	2.95	4	1.60	4	1.65	4	2.15	4	2.00
5	3.50	5	3.50	5	1.90	5	2.30	5	2.60	5	2.45
6	3.90	6	3.75	6	2.15	6	2.50	10	3.20	6	2.80
7	4.25	7	4.00	7	2.40	7	2.75	15	3.40	7	3.00
8	4.45	8	4.10	8	2.65	8	3.00	20	3.20	8	3.15
9	4.65	9	4.30	10	2.95	9	3.20	25	3.20	9	3.15
10	4.65	10	4.40	11	3.05	10	3.45	30	2.80	10	3.20
11	4.50	11	4.35	12	3.25	12	3.75	35	3.30	12	3.00
12	4.20	12	4.30	14	3.40	14	3.80	40	3.20	14	3.00
13	3.90	13	4.15	16	3.70	16	3.90	45	2.50	16	3.10
14	3.60	14	3.80	18	3.65	18	3.90	46	2.40	18	3.10
15	3.25	15	3.40	20	3.60	20	4.00	47	1.80	20	3.30
16	2.80	16	2.90	24	3.90	26	3.90	48	1.00	24	3.40
17	2.15	17	2.20	26	3.85	30	4.10	49.1	0	28	3.65
18	1.65	18	1.50	32	3.75	32	4.00			30	3.60
19	0.95	19	1.10	34	3.60	34	3.80			32	3.55
20	0	20	0	36	3.05	36	3.50			36	3.60
				40	2.90	40	2.75			40	3.40
				42	2.70	41	2.85			41	3.30
				44	2.70	42	2.70			42	3.15
				45	2.65	45	2.50			43	2.90
				46	2.45	46	2.25			44	2.65
				47	1.90	47	2.00			45	2.35
				48	1.20	50	1.00			46	2.00
				49	0.80	51	0			47	1.20
				50	0.55					48	0.40
				51	0					48.25	0

Table 15 cont., Cross-Section Data

Canal 22 cont.						Canal 23					
Sta 8+00		Sta 1+00		Sta 3+00		Sta 3+60		Sta 4+00		Sta 5+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0	0	0
1	0.15	1	1.40	1	0.90	0	1.50	1	1	1	2.60
2	0.80	2	1.80	2	1.90	2	1.50	2	1.85	2	2.05
3	1.10	3	2.10	3	2.00	3	2.60	3	2.25	3	2.15
4	1.20	4	2.30	4	2.20	4	2.60	4	2.35	4	2.60
5	1.40	5	2.50	6	2.00	5	2.60	6	2.50	6	2.60
6	1.50	8	2.60	10	2.10	7	2.50	8	2.40	8	2.65
7	1.60	10	2.80	12	2.15	10	2.50	10	2.30	10	2.55
8	1.70	12	2.50	14	2.25	12	2.80	12	3.00	12	2.45
10	1.70	16	2.70	16	2.15	14	2.70	14	2.80	14	2.50
11	2.20	20	2.50	20	2.20	15	2.70	16	2.60	16	2.65
12	2.75	24	2.60	22	2.25	20	2.80	18	2.55	18	2.55
14	3.00	28	2.55	26	2.05	22	2.90	20	2.90	20	2.60
18	3.30	30	2.60	28	2.10	24	3.00	22	2.85	24	2.40
20	3.65	32	2.30	30	2.50	25	3.00	24	3.00	28	2.30
24	3.70	36	2.75	32	2.70	30	2.80	26	2.85	32	2.40
26	3.90	40	2.40	36	2.60	32	2.95	28	3.10	34	2.50
28	3.80	42	2.70	42	2.50	35	3.20	32	3.00	36	2.60
32	3.75	46	2.30	48	2.45	38	2.80	34	2.90	40	2.50
36	3.60	48	2.80	50	2.40	40	3.10	36	2.80	44	2.40
40	3.75	50	2.20	52	2.45	45	2.80	38	2.60	48	2.45
43	3.60	54	2.40	56	2.60	50	2.60	40	2.65	50	2.60
44	3.70	58	2.15	58	2.90	52	3.10	42	2.95	52	2.30
45	3.45	60	2.30	62	2.85	55	3.00	44	2.75	54	2.20
46	3.20	64	2.25	64	2.60	60	3.10	46	2.75	56	2.35
47	2.80	66	2.55	66	2.50	64	2.90	48	2.80	58	2.30
48	2.70	68	2.20	68	1.90	66	2.70	52	2.75	60	2.35
49	2.35	69	1.90	69	1.80	67	2.60	54	2.70	62	2.30
50	1.85	70	1.30	69.5	2.00	68	2.35	58	2.80	64	1.90
51	1.10	71	0	69.5	0	69	2.0	59	2.50	64.8	1.40
52	0					69	0	60	0	65	0

Table 15 cont., Cross-Section Data
Canal 24

Sta 0+00		Sta 2+00		Sta 4+00		Sta 6+00		Sta 8+00	
Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth	Dist.	Depth
0	0	0	0	0	0	0	0	0	0
1	2.6	1	2.6	0.5	1.40	1	1.6	1	1.40
2	2.3	2	3.1	1	1.90	2	2.4	2	2.40
3	3.5	3	3.3	2	2.40	3	2.7	3	3.20
4	3.7	4	3.4	3.5	3.40	4	3.25	4	3.60
5	3.75	5	3.5	5	3.60	5	3.60	5	3.70
6	3.70	6	3.5	8	3.60	6	3.65	6	3.75
8	3.65	8	3.7	10	3.70	8	3.85	8	3.80
10	3.90	10	3.6	12.5	3.70	10	3.80	10	3.60
12	3.85	12	3.8	15	3.80	12	3.95	12	3.70
14	3.55	14	3.8	17.5	3.60	14	4.05	14	3.65
16	3.50	16	3.75	20	3.80	16	4.00	16	4.10
18	3.60	18	3.80	22.5	3.50	18	4.00	18	4.20
20	3.80	20	3.70	25	3.70	20	3.90	20	4.30
22	3.80	22	3.70	27.5	3.40	22	4.05	22	4.10
24	3.70	24	3.70	28.5	2.70	24	3.70	24	3.90
25	3.45	25	3.55	29.5	2.30	25	3.50	25	3.85
26	3.10	26	3.30	29.5	0	26	3.30	26	3.70
27	2.45	27	2.75			27	2.80	27	3.40
28	0.90	28	2.20			28	2.25	28	2.90
29	0	29	1.75			29	0.70	29	2.15
		29.5	0			29.5	0	29.5	1.40
								30	0

Table 16. Water Surface Elevations

Canal No.	Water Surface Elevation at Stations 0+00	1+00	2+00	3+00	4+00	5+00	6+00	7+00	8+00	9+00	10+00
1	5.735	5.682	5.638	5.602	5.590	5.565	5.555	5.500	5.476	5.422	5.392
2	7.661	7.656	7.633	7.616	7.620	7.597	7.576	7.564	7.584	7.542	7.523
3	6.198	6.189	6.186	6.170	6.185	6.160	6.166	6.157	6.150	6.150	6.135
4	6.577	6.567	6.575	6.561	6.569	6.569	6.544	6.535	6.518		
5	8.200	8.197	8.197	8.172	8.157	8.161	8.155	8.137	8.161	8.127	
6	Assumed slope was equal to that of Ft. Laramie I										
7	9.575	9.566	9.545	9.519	9.516	9.516	9.514	9.485	9.465	9.446	9.417
8	9.046	9.042	9.044	8.982	8.947	8.933	8.909	8.862	8.835	8.797	
9	8.800	8.779	8.772	8.765	8.735	8.725	8.694	8.694	8.671	8.622	8.582
10	8.315	8.280	8.244	8.235	8.200	8.179	8.49	8.110	8.093	8.061	
11	9.885	9.847	9.822	9.819	9.783	9.752	9.721	9.694	9.666	9.652	
12	8.165	8.169	8.152	8.136	8.103	8.098	8.077	8.055			
13	6.204	6.180	6.153	6.148	6.144	6.127	6.084	6.069	6.085		
14	8.497	8.466	8.471	8.455	8.441	8.436	8.413	8.412	8.409	8.375	8.367
15	7.358	7.321	7.279	7.268	7.222	7.181	7.131	7.115	7.063	7.019	7.005
16	7.379	7.350	7.300	7.302	7.255	7.249					
17	6.148	6.128	6.100	6.024	6.018	5.982					
18	6.595	6.564	6.522	6.504	6.479	6.437	6.385				
19	1.326	1.272	1.256	1.246	1.204	1.176	1.145	1.108	1.106	1.044	0.990
20	9.873	9.860	9.856	9.846	9.833	9.815	9.818	9.788	9.768	9.777	
21	6.674	-----	6.645	-----	6.634	-----	6.608	-----	6.585		
22	9.860	9.841	9.815	9.810	9.782	9.753	9.733	9.709	9.690		
23	1.132	1.111	1.078	1.037	0.997	0.945	0.900	0.877	9.855		
24	9.895	-----	9.853	-----	9.819	-----	9.767	-----	9.728		

15 (cont.)	11+00	12+00
	6.956	6.911

Table 17, **Suspended Load Data,** Canal 2

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.067	0.088	0.125	0.175	0.250	0.500	Method of analysis
6	4.2	0.8	101	70	85	99	100			VWM
		1.7	127	66	82	98	100			
		2.5	168	50	71	99	100			
		3.4	175	52	71	98	100			
		3.8	228	43	66	94	100			
15	5.2	1.0	104	71	81	99	100			VWM
		2.1	126	58	74	94	100			
		3.1	174	42	68	93	99	100		
		4.2	225	44	63	92	100			
		4.5	334	45	66	92	100			
		4.8	339	29	49	84	98			
25	6.4	1.3	102	66	81	96	100			VWM
		2.6	140	53	68	89	99	100		
		3.8	160	51	70	88	99	100		
		5.1	175	43	56	70	95	100		
		5.6	225	40	54	70	82	99	100	
		6.0	301	30	43	57	77	98	100	
30	6.5	1.3	91	68	79	93	100			VWM
		2.6	122	57	70	87	95	100		
		3.9	138	62	78	90	97	100		
		5.2	181	46	60	71	81	98	100	
		5.7	215	40	55	68	76	99	100	
		6.1	258	31	49	63	71	98	100	
35	6.5	1.3	96	70	85	96	100			VWM
		2.6	123	64	80	94	99	100		
		3.9	157	55	71	82	97	100		
		5.2	189	50	65	77	92	100		
		5.7	203	43	59	70	90	100		
		6.1	246	36	52	67	78	98	100	

Table 17, **Suspended Load Data,** Canal 2 cont.

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m.: 0.067	0.088	0.125	0.175	0.250	0.500	Method of analysis
45	5.7	1.1	118	67	82	97	99	100		VWM
		2.3	150	60	73	93	99	100		
		3.4	165	59	71	92	99	100		
		4.6	217	45	61	86	99	100		
		4.9	220	42	64	87	99	100		
		5.6	330	29	50	76	98	100		
55	4.1	0.8	94	70	89	99	100			VWM
		1.6	102	72	88	97	100			
		2.5	118	64	78	93	99	100		
		3.3	128	64	82	98	100			
		3.7	141	60	79	98	100			

All Farmers samples wet sieved over 53 micron sieve prior to visual tube analysis; 0.088 mm and 0.175 mm reported on Farmers samples since 0.088 appears to be the median sand size for many samples.

Suspended Sediment Data, Canal 3

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m.: 0.016	0.031	0.062	0.125	0.25	0.500	Method of analysis
6	7.0	0.7	31			84				wet sieve
		1.4	34			82				
		2.3	32			82				
		4.2	35			84				
		5.6	37			83				
		6.3	35			80				
		6.5	34			75				

Table 17, **Suspended Load Data,** Canal 3 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.25	0.500	Method of analysis
16	8.3	0.8	29			81				wet sieve
		1.7	35			79				
		3.3	32			80				
		5.0	33			80				
		6.6	32			78				
		7.5	34			75				
		7.9	35			71				
28	8.5	0.9	32			79				wet sieve
		1.7	35			82				
		3.4	38			76				
		5.1	37			70				
		6.8	37			72				
		7.5	41			68				
		8.1	45			59				
40	8.4	0.8	29			78				wet sieve
		1.7	36			77				
		3.4	33			75				
		5.0	38			76				
		6.7	41			70				
		7.4	46			69				
		8.0	62			48				
52	8.4	0.8	34			74				wet sieve
		1.7	32			78				
		3.4	36			79				
		5.0	33			65				
		6.7	48			63				
		7.6	57			62				
		8.0	91			40				
64	8.3	0.8	35			86				

Suspended Sediment Data, Canal 3 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.25	0.500	Method of analysis
		1.7	34			86				
		3.3	38			78				
		5.0	35			75				
		6.6	43			70				
		7.5	52			64				
		7.9	69			50				
74	6.5	0.7	28			77				wet sieve
		1.3	34			81				
		2.6	38			77				
		3.9	40			78				
		5.2	40			74				
		5.7	41			76				
		6.1	45			72				

All Ft. Laramie 1 samples contained insufficient sand for visual tube analysis; % finer than 0.062 values determined by wet sieving with 0.062 mm.

Table 17, **Suspended Load Data,** Canal 4

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
6	4.5	0.9	90		98	100				V
		1.8	116		95	100				
		2.7	116		93	100				
		3.6	117		92	100				
		4.1	136		87	100				
14	5.9	1.2	87		94	100				V

Suspended Sediment Data, Canal 4 cont.

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m.: 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		2.4	103		93	100				
		3.5	117		91	100				
		4.7	130		88	100				
		5.1	127		88	98	100			
		5.9	146		84	98	100			
18	6.2	1.2	81		97	100				V
		2.5	91		96	100				
		3.7	107		90	100				
		5.0	113		86	98	100			
		5.4	137		81	97	100			
		5.8	233		61	78	99	100		
22	6.2	1.2	72		93	98	100			V
		2.5	92		96	100				
		3.7	99		90	100				
		5.0	145		80	99	100			
		5.4	144		82	97	100			
		5.8	258		62	84	99	100		
26	6.2	1.2	100		93	100				V
		2.5	121		89	100				
		3.7	140		84	100				
		5.0	145		82	98	100			
		5.4	151		83	97	100			
		5.8	293		62	94	99	100		
30	6.1	1.2	132		89	100				V
		2.4	134		89	99	100			
		3.7	150		86	100				
		4.9	170		84	99	100			
		5.3	191		80	99	100			
		5.7	301		67	97	100			

Table 17, **Suspended Load Data,** Canal 4 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
38	5.5	1.1	142		90	100				V
		2.2	151		87	100				
		3.3	181		86	100				
		4.4	179		85	100				
		4.8	198		85	100				
		5.1	189		83	100				

Suspended Sediment Data, Canal 5

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment, % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
6	5.2	1.0	86		91	100				VWM
		2.1	90		92	100				
		3.1	95		89	100				
		4.2	99		88	100				
		4.8	92		84	100				
14	6.0	1.2	89		89	100				VWM
		2.4	80		92	100				
		3.6	97		87	100				
		4.8	115		79	99	100			
		5.4	130		75	100				
		5.6	133		71	100				
18	6.0	1.2	75		87	100				VWM
		2.4	86		86	100				
		3.6	111		81	100				
		4.8	128		70	100				
		5.4	139		70	99	100			
		5.6	172		59	90	100			
22	6.0	1.2	85		84	100				VWM
		2.4	98		81	100				
		3.6	125		72	99	100			

Table 17, **Suspended Load Data,** Canal 5 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		4.8	131		70	97	100			
		5.4	135		68	98	100			
		5.6	185		57	93	100			
26	6.0	1.2	81		83	100				VWM
		2.4	85		80	100				
		3.6	120		73	100				
		4.8	132		71	100				
		5.4	139		64	96	100			
		5.6	203		53	94	100			
34	6.0	1.2	88		79	100				VWM
		2.4	105		79	100				
		3.6	131		73	100				
		4.8	153		70	100				
		5.4	181		60	100				
		5.6	201		57	97	100			
42	4.3	0.9	105		78	100				VWM
		1.7	102		78	100				
		2.6	109		74	100				
		3.4	124		78	100				
		3.9	136		71	99	100			

All Ft. Laramie 111 samples wet sieved on 53 micron sieve prior to visual tube analysis.

Table 17, Suspended Load Data, Canal 7

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
4	2.9	0.6	63			96				sieve
		1.2	69			96				
		1.7	60			95				
		2.7	69			94				
		3.0	85			94				
10	3.55	0.4	50			97				sieve
		0.7	63			97				
		1.4	46			95				
		2.1	58			95				
		2.8	56			94				
		3.25	63			88				
14	3.5	0.4	58			94				sieve
		0.7	60			96				
		1.4	48			93				
		2.1	81			96				
		2.8	76			97				
		3.15	61			97				
18	3.5	0.4	47			96				sieve
		0.7	42			94				
		1.4	58			98				
		2.1	48			94				
		2.8	64			94				
		3.1	62			81				
22	3.5	0.4	46			96				sieve
		0.7	66			98				
		1.4	43			96				
		2.1	49			95				
		2.8	55			96				
		3.2	62			80				

Table 17, **Suspended Load Data,** Canal 7 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
26	3.5	0.4	28			92				sieve
		0.7	46			96				
		1.4	49			98				
		2.1	65			94				
		2.8	60			96				
		3.2	59			95				
30	3.55	0.7	33			90				sieve
		1.3	33			96				
		2.0	36			96				
		2.7	35			96				
		3.0	35			94				

Analysis of all Ft. Morgan 1 samples consisted only of separation of sands from fines by wet sieve method using 62.5 micron sieve; insufficient sand for V.A. tube analysis and insufficient fines for pipette analysis.

Suspended Sediment Data, Canal 8

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
4	2.6	0.5	40			92				wet sieve
		1.0	45			93				
		1.6	52			72				
		2.1	54			65				
		2.3	29			87				
12	2.8	0.6	58			77				wet sieve
		1.1	59			74				
		1.7	63			75				
		2.2	51			69				
		2.5	61			73				
20	2.4	0.5	43			79				wet sieve

Table 17, **Suspended Load Data,** Canal 8 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		1.0	49			72				
		1.4	54			78				
		1.9	62			54				
		2.1	49			62				
28	2.6	0.5	58			78				wet sieve
		1.0	57			78				
		1.6	89			*47				
		1.6	52			80				
		2.1	54			41				
		2.3	61			51				
36	2.5	0.5	55			89				wet sieve
		1.0	55			85				
		1.5	50			66				
		2.0	44			82				
		2.2	54			84				
44	2.7	0.5	49			90				wet sieve
		1.1	48			93				
		1.6	50			82				
		2.2	36			85				
		2.4	49			80				
48	1.8	0.4	34			91				wet sieve
		0.7	43			82				
		1.1	47			88				
		2.4	52			88				

All samples in this set sieved thru 62.5 micron wet sieve; therefore only one % finer value secured for each sample; this method gives only approximate value.

* **These values include 1 large quartz partical in the sample**

Table 17, **Suspended Load Data,** Canal 9

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m.: 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
4	2.85	0.6	50			95				sieve
		1.1	52			95				
		1.7	48			92				
		2.3	41			95				
		2.5	45			96				
12	3.0	0.6	117			98				sieve
		1.2	155			99				
		1.8	159			99				
		2.4	152			98				
		2.6	138			98				
16	3.1	0.6	123			98				sieve
		1.2	116			99				
		1.9	134			98				
		2.3	133			99				
		2.6	118			99				
		2.8	116			98				
20	3.0	0.6	97			99				sieve
		1.2	98			99				
		1.8	85			98				
		2.4	93			97				
		2.6	106			97				
24	2.9	0.6	76			97				sieve
		1.2	78			97				
		1.7	64			97				
		2.3	79			97				
		2.6	83			94				
28	2.85	0.6	62			97				sieve
		1.1	65			97				
		1.7	53			96				

Table 17, **Suspended Load Data,** Canal 9 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		2.3	69			95				
		2.5	67			91				
32	2.75	0.6	55			95				
		1.1	68			90				
		1.7	65			92				
		2.2	66			92				
		2.4	76			79				
40	2.45	0.5	48			95				sieve
		1.0	54			93				
		1.5	50			95				
		2.0	63			95				

All samples wet sieved only over 62.5 micron sieve.

Suspended Sediment Data, Canal 10

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
see remarks		20% of total tal depth				96	100			V
		40% of total tal depth				95	100			V
		60% of total tal depth				93	99	100		V

Table 17, **Suspended Load Data,** Canal 10 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended Sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		80%of total tal depth				92	98	100		V
		0.4' from bed				83	92	100		V
4	2.5	0.5	92							
		1.0	108							
		1.5	103							
		2.1	118							
12	2.9	0.6	91							
		1.2	105							
		1.8	93							
		2.3	118							
		2.5	121							
20	2.8	0.6	85							
		1.1	95							
		1.7	105							
		2.2	111							
		2.4	114							
28	2.9	0.6	88							
		1.2	73							
		1.8	85							
		2.3	106							
		2.5	112							
36	2.5	0.5	103							
		1.0	90							

Table 17, **Suspended Load Data,** Canal 10 cont

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m.: 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		1.5	82							
		2.1	75							

Composit of all samples at 20% of total depth at stations 4, 12, 28, and 36.
Composit of all samples at 40% of total depth at stations 4, 12, 28, and 36.
Composit of all samples at 60% of total depth at stations 4, 12, 28, and 36.
Composit of all samples at 80% of total depth at stations 4, 12, 28, and 36.
Composit of all samples 0.4 ft. above bed.
No size analysis on individual points.

Suspended Sediment Data, Canal 11

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m.: 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
5	2.8	0.6	91		*					
		1.1	98		*					
		1.7	90		*					
		2.2	97		*					
		2.2	88		*					
15	2.9	0.6	86		*					
		1.2	97		*					
		1.7	99		*					
		2.3	109		*					
		2.5	94		90	96	99	100		V
20	2.9	0.6	98		*					
		1.2	93		*					
		1.7	98		*					

Table 17, **Suspended Load Data,** Canal 11 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		2.3	116		*					
		2.5	112		85	94	98	100		V
25	3.0	0.6	97		*					
		1.2	114		*					
		1.8	104		*	97	100			
		2.4	108		89	57	86	97	100	V
		2.6	227		45					
30	2.5	0.5	114		*					
		1.0	106		*					
		1.5	109		*					
		2.1	153		68	85	100			V
40	2.4	0.5	94		*					
		1.0	96		*					
		1.4	102		*					
		1.9	116		94	98	100			V
10	3.0	0.6	103		*					
		1.2	95		*					
		1.8	110		*					
		2.4	94		*					
		2.6	115		83	88	97	100		V
35	2.6	0.5	100		*					
		1.0	111		*					
		1.6	121		92	98	100			V
		2.1	145		64	78	98	100		V

*** Insufficient sand for analysis.**

Table 17. **Suspended Load Data,** Canal 12

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
5	4.0	0.8	43			70				wet sieve
		1.6	41			77				
		2.4	46			69				
		3.2	45			72				
		3.6	46			61				
15	7.1	0.7	34			76				wet sieve
		1.4	35			72				
		2.8	37			71				
		4.3	45			65				
		5.7	43			63				
		6.4	50			55				
		6.6	74			37				
25	8.3	0.8	27			90				wet sieve
		1.7	27			78				
		3.3	34			76				
		5.0	33			78				
		6.6	36			68				
		7.5	40			68				
		7.9	45			58				
30	8.5	0.9	25			80				wet sieve
		1.7	41			59				
		3.4	28			80				
		5.1	31			77				
		6.8	32			70				
		7.7	35			74				
		8.1	43			60				
35	8.3	0.8	26			84				wet sieve
		1.7	27			81				
		3.3	28			80				

Table 17, **Suspended Load Data,** Canal 12 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		5.5	28			85				
		6.6	26			76				
		7.5	32			78				
		7.8	34			65				
45	7.8	0.8	23			84				wet sieve
		1.6	26			85				
		3.1	28			83				
		4.7	28			80				
		6.2	31			75				
		7.0	28			74				
		7.5	32			61				
55	5.1	0.5	27			82				wet sieve
		1.0	26			77				
		2.1	27			75				
		3.1	26			74				
		4.2	31			73				
		4.7	30			73				

All Garland 1 samples analyzed by 62.5 micron wet sieve only.

Suspended Sediment Data, Canal 13

Distance from bank to sampling station	Total depth	Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
6	4.0	0.8	47			65*				wet sieve
		1.6	47			70*				
		2.5	52			68*				
		3.3	51			79	100			V
		3.6	57			69	98	100		
18	5.7	0.6	42			76*				wet sieve
		1.1	51			75*				

Table 17, **Suspended Load Data,** Canal 13 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		2.3	52			72*				
		3.4	58			78	97	100		V
		4.6	59			72	96	100		
		5.1	60			74	95	100		
		5.3	69			63	89	100		
24	5.8	0.6	50			78*				wet sieve
		1.2	56			70*				
		2.3	55			74*				
		3.4	59			65*				
		4.6	58			58*				
		5.0	68			68	97	100		V
		5.4	76			58	90	100		
30	5.9	0.6	50			77*				wet sieve
		1.2	53			70*				
		2.3	56			66*				
		3.5	61			65*				
		4.7	74			56*				
		5.3	72			63	90	100		V
		5.5	89			52	75	100		
36	5.9	0.6	52			70*				wet sieve
		1.2	48			70*				
		2.3	45			73*				
		3.5	57			65*				
		4.7	69			56*				
		5.3	74			63	91	100		V
		5.5	81			54	81	100		
42	5.8	0.6	47			77*				wet sieve
		1.2	48			77*				
		2.3	53			71*				

Table 17, **Suspended Load Data,** Canal 13 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		3.4	50			66*				
		4.6	53			66*				
		5.0	60			58*				
		5.4	78			59	80	100		V
54	3.9	0.8	43			77*				
		1.6	49			74*				
		2.3	43			72*				
		3.1	52			69*				
		3.5	46			68*				

Samples marked with asterisk were wet sieved only with 62.5 micron sieve; these samples contained insufficient sand for visual tube analysis.

Suspended Sediment Data, Canal 14

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
6	5.8	1.2	31		81*					wet sieve
		1.2	32		74*					
		3.5	33		79*					
		4.6	38		78*					
		5.2	48		75	96	100			V
		5.4	43		80	99	100			
15	8.6	0.9	28		82*					wet sieve
		1.7	27		78*					
		3.4	35		75*					
		5.2	39		82	95	100			V

Table 17, **Suspended Load Data,** Canal 14 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		6.7	42		78	96	100			
		7.7	48		65	88	100			
		8.2	86		38	62	100			
25	8.8	0.9	30		72*					wet sieve
		1.8	38		71*					
		3.5	47		77*					
		5.3	44		68	91	100			V
		7.0	46		66	89	100			
		7.9	69		52	66	100			
		8.4	102		34	49	91	100		
30	9.0	0.9	30		73*					wet sieve
		1.8	37		71*					
		3.6	43		61*					
		5.4	52		66	86	100			V
		7.2	64		59	83	100			
		8.1	94		42	59	99	100		
		8.6	403		9	20	66	99	100	
35	8.6	0.9	30		85	100				V
		1.7	42		75	96	100			
		3.4	44		72	93	100			
		5.2	53		64	91	100			
		6.9	69		51	74	100			
		7.7	86		44	64	97	100		
		8.2	787		4	9	81	100		
45	8.2	0.8	31		74*					wet sieve
		1.6	34		70*					
		3.3	36		68*					
		4.9	42		63*					V
		6.6	39		75	93	100			

Table 17, **Suspended Load Data,** Canal 14 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		7.4	49		65	96	100			
		7.8	58		51	84	100			
55	2.9	0.6	35		72*					wet sieve
		1.2	32		76*					
		1.7	32		70*					
		2.5	45		78	99	100			V

* % finer values marked with asterisk were determined by 62.5 micron wet sieve.
Two bottles (A-1 & A-2) labled 1.2 ft. sampling depth.

Suspended Sediment Data, Canal 15

Distance from bank to sampling station	Total depth	Depth below W.S.	Concentration P.P.M.	0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
4	3.8	0.3	29		85	99	100			VWM
		1.0	36		63	94	100			
		2.0	56		51	88	100			
		3.0	76		39	80	100			
		3.2	100		63	72	100			
		3.4	141		32	65	97	100		
10	4.3	0.6	27		61*					wet sieve
		2.0	36		49*					
		3.4	140		22	36	93	100		VWM
		3.8	162		18	29	89	100		
		3.9	163		18	32	88	100		
18	4.4	0.5	32		56*					wet sieve
		1.5	38		50*					
		2.2	51		40*					
		3.4	75		37	56	98	100		VWM
		3.9	100		29	45	91	100		
		4.0	134		24	41	86	100		

Table 17 , **Suspended Load Data,** Canal 15 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
26	4.6	0.5	28		51*					wet sieve
		1.0	33		49					
		2.5	42		48	74	100			VWM
		3.5	51		43	70	98	100		
		4.1	87		30	44	78	100		
		4.2	107		27	47	80	100		
34	4.8	0.5	29		76	92	100			
		0.9	34		63	99	100			
		2.8	43		56	88	99	100		
		3.8	56		44	71	97	100		
		4.3	70		33	59	93	100		
		4.4	74		34	60	93	100		
42	4.6	0.5	39		63	95	100			VWM
		1.65	47		50	88	99	100		
		2.6	59		49	90	100			
		3.6	88		31	57	96	100		
		4.1	99		34	62	97	100		
		4.2	122		30	52	97	100		
46	3.6	0.5	32		63	99	100			
		1.6	51		54	94	100			
		2.6	68		46	89	100			
		3.1	69		41	86	100			
		3.2	90		43	79	100			

Samples listed according to decreasing sample depth; both conc. and size analysis.
Suggest that sample depth is distance up from stream bed.
All samples sieved over 0.053 mm wet sieve prior to visual tube analysis except samples containing insufficient sand for v.a. tube analysis.
* Contained insufficient sand for v.a. tube analysis. Wet sieved W/62.5 micron sieve.

Table 17, **Suspended Load Data,** Canal 16

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
2	2.5	0.5	71			72	99	100		VWM
		1.0	75			71	100			
		1.5	78			70	100			
		2.1	103			58	99	100		
4	2.62	0.5	63			80	100			VWM
		1.06	74			68	95	100		
		1.6	83			65	96	100		
		2.0	89			56	91	100		
		2.25	112			53	90	100		
6	2.65	0.5	51			83	100			VWM
		1.06	78			83	100			
		1.6	59			66	99	100		
		2.0	67			75	98	100		
		2.25	84			65	96	100		
8	2.6	0.5	45			83	100			VWM
		1.06	47			86	100			
		1.6	57			77	100			
		2.0	56			79	100			
		2.25	63			70	100			
10	2.5	0.5	54			78	100			VWM
		1.0	55			82	100			
		1.5	54			78	100			
		1.8	68			66	100			
		2.1	63			70	100			
12	1.5	0.5	59			72	100			VWM
		0.9	54			74	100			
		1.1	59			79	100			

Sands separated from fines by 53 micron wet sieve prior to visual tube analysis.

Table 17, **Suspended Load Data,** Canal 17

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
4	3.0	0.6	31			91	99	100		VWM
		1.2	40			76*				wet sieve
		2.0	47			68	96	100		VWM
		2.6	40			78	98	100		
6	3.2	0.6	56			60	85	100		
		1.3	36			89	98	100		
		1.9	40			80*				wet sieve
		2.4	45			74	100			VWM
		2.8	37			82	92	100		
8	3.05	0.6	38			80*				wet sieve
		1.2	33			83	99	100		VWM
		1.9	38			73*				wet sieve
		2.6	42			73	96	100		VWM
10	2.8	0.6	41			76*				wet sieve
		1.1	45			73*				
		1.9	47			68	96	100		VWM
		2.4	58			67	96	100		

All samples wet sieved over 53 micron sieve proir to v.a. tube analysis except samples containing insufficient sand for v.a. tube analysis.

* Insufficient sand for complete v.a. tube analysis; wet sieve only over 62.5 micron sieve.

Table 17, **Suspended Load Data,** Canal 18

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
2	2.2	0.4	22			97				*sieve
		0.9	23			85				
		1.3	19			96				
		1.8	21			94				
4	2.7	0.5	20			96				*sieve
		1.1	22			96				
		1.6	22			97				
		2.0	20			92				
		2.3	19			82				
6	2.8	0.6	19			96				*sieve
		1.1	22			96				
		1.7	19			90				
		2.2	18			95				
		2.4	24			88				
8	2.7	0.5	19			94				*sieve
		1.1	20			94				
		1.7	19			93				
		2.2	22			82				
		2.4	17			85				
10	2.4	0.4	19			94				*sieve
		0.9	23			92				
		1.4	20			83				
		1.7	25			84				
		2.0	27			83				

* 62.5 micron wet sieve.

Table 17, **Suspended Load Data,** Canal 19

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.15	0.250	0.500	Method of analysis
2	2.5	0.5	84			94	100			V
		1.0	85			91	100			
		1.5	91			90	99	100		
		2.0	93			90	100			
		2.25	95			88	100			
7	3.1	0.6	84			90	100			V
		1.2	81			87	100			
		1.9	83			87	99	100		
		2.5	87			82	99	100		
		2.7	105			83	99	100		
10.7	3.4	0.7	92			94	100			V
		1.4	93			88	99	100		
		2.0	85			84	100			
		2.7	90			80	99	100		
		3.0	111			82	99	100		
14	3.4	0.7	94			86	100			V
		1.4	89			86	100			
		2.0	93			84	100			
		2.7	108			78	99	100		
		3.0	132			74	98	100		
17.5	3.4	0.7	71			90	100			V
		1.4	87			90	100			
		2.0	70			87	99	100		
		2.7	99			80	99	100		
		3.0	100			73	93	100		
21	3.4	0.7	72			90	100			V
		1.4	94			87	100			
		2.0	94			82	99	100		
		2.7	95			74	96	100		

Table 17, **Suspended Load Data,** , Canal 19 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.15	0.250	0.500	Method of analysis
		3.0	143			61	83	100		
26	2.6	0.5	77			88	100			V
		1.0	77			88	100			
		1.6	84			85	100			
		2.1	88			87	100			
		2.2	82			82	100			

Suspended Sediment Data, Canal 20

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
5	4.0	0.8	135			99	100			V
		1.6				98	100			
		2.4				98	100			
		3.2				97	100			
		3.6				96	100			
10	5.3	1.1				99	100			
		2.1				98	100			
		3.2				97	100			
		4.2				95	100			
		4.9				98	100			
15	5.3	1.1				98	100			V
		2.1				99	100			
		3.2				96	100			
		4.2				89	99	100		
		4.9				99	100			
20	5.15	1.0				97	100			V

Table 17, **Suspended Load Data,** Canal 20 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	Suspended Sediment % finer than indicated size in m.m. 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		2.1				97	100			
		3.1				95	100			
		4.1				87	100			
25	3.6	4.7				97	100			V
		0.7				96	100			
		1.4				94	100			
		2.2				95	100			
		2.9				93	100			
		3.2								

Suspended Sediment Data, Canal 21

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
4	2.7	0.5	58			*				
		1.1	64			98	100			V
		1.6	72			98	100			V
		2.3	71			97	100			V
8	4.2	0.8	59			*				
		1.7	65			*				
		2.5	67			*				
		3.4	69			98	100			V
		3.8	70			98	100			V
10	4.4	0.9	55			*				
		1.8	61			*				
		2.6	56			*				
		3.5	66			*				
		4.0	67			*				
12	4.0	0.8	57			*				
		1.6	62			*				
		2.4	60			*				

Table 17, **Suspended Load Data,** Canal 21 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		3.2	67			*				
		3.6	61			97	99	100		V
16	2.6	0.6	56			*				
		1.1	60			*				
		1.7	62			98	100			V
		2.2	62			97	99	100		V

Suspended sediment % finer than indicated size in m.m.

* Insufficient material for v.a. analysis.

Suspended Sediment Data, Canal 22

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
5	2.6	0.5	81		96	100				V
		1.0	92		95	100				
		1.6	96		97	100				
		2.2	101		96	100				
15	3.4	0.7	103		94	100				V
		1.4	106		94	100				
		2.0	110		94	100				
		2.7	132		87	98	100			
		3.0	148		76	97	100			
25	3.2	0.6	101		92	99	100			V
		1.3	103		90	97	100			
		1.9	118		92	98	100			
		2.6	132		81	92	96	99	100	

Suspended sediment % finer than indicated size in m.m.

Table 17, **Suspended Load Data,** Canal 22 cont.

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
		2.8	133		77	91	98	100		
35	3.3	0.7	94		94	100				V
		1.3	98		94	100				
		2.0	103		92	100				
		2.6	109		94	99	100			
		2.9	114		87	98	100			
45	2.4	0.5	88		96	98	100			V
		1.0	84		96	100				
		1.5	81		95	100				
		2.0	82		97	99	100			

Suspended sediment % finer than indicated size in m.m.

Suspended Sediment Data, Canal 23

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Concentration P.P.M.	0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
7	2.5	0.5				84	95	100		V
		1.0				84	97	100		
		1.5				84	98	100		
		2.1				69	86	99	100	
15	2.7	0.5				77	95	100		V
		1.1				69	89	100		
		1.6				65	93	100		
		2.1				54	74	99	100	
		2.3				40	66	99	100	
25	3.0	0.6				85	97	100		V
		1.2				78	92	100		
		1.8				72	88	99	100	

Suspended sediment % finer than indicated size in m.m.

Table 17, **Suspended Load Data,** Canal 23 cont.

Distance from bank to sampling station	Total depth	Sampling point: Depth below W.S.	Sampling point: Concentration P.P.M.	Suspended sediment data % finer than indicated size in m.m.: 0.016	0.031	0.062	0.125	0.250	0.500	Method of analysis
		2.4				63	81	98	100	
		2.6				49	71	98	100	
35	3.3	0.7				87	98	99	100	V
		1.3				84	97	100		
		2.0				77	94	100		
		2.6				72	89	99	100	
		2.9				65	85	100		
45	2.8	0.6				85	100			V
		1.1				83	96	100		
		1.7				75	93	100		
		2.2				70	87	100		
		2.4				61	82	98	100	
55	3.0	0.6				87	100			V
		1.0				78	91	99	100	
		1.8				75	90	100		
		2.4				58	80	100		
		2.6				27	52	96	100	
62	2.6	0.5				89	99	100		V
		1.0				85	100			
		1.6				83	100			
		2.2				77	95	100		

Table 17, **Suspended Load Data,** Canal 24

Distance from bank to sampling station	Total depth	Sampling point Depth below W.S.	Sampling point Concentration P.P.M.	Suspended sediment % finer than indicated size in m.m. 0.031	0.062	0.125	0.250	0.500	1.000	Method of analysis
5	3.6	0.7	59		75	100				V
		1.4	67		62	97	100			
		2.2	85		55	96	100			
		2.9	137		43	94	100			
		3.2	224		29	95	100			
10	3.7	0.7	41		84	99	100			V
		1.5	51		66	93	100			
		2.2	75		54	82	100			
		3.0	129		32	71	99	100		
		3.3	293		18	54	96	100		
15	3.8	0.8	56		64	85	100			V
		1.5	70		52	74	100			
		2.2	95		41	70	100			
		3.0	144		28	65	98	100		
		3.4	236		18	53	96	100		
20	3.8	0.8	42		81	97	100			V
		1.5	49		69	94	100			
		2.2	67		51	79	100			
		3.0	116		33	65	97	100		
		3.4	417		11	35	92	100		
25	3.7	0.7	52		68	88	99	100		V
		1.5	60		60	94	100			
		2.2	101		45	86	98	100		
		3.0	139		35	85	100			
		3.3	208		27	82	100			

Table 18, Total Load Data and Particle Size Distribution

Canal No.	Concentration	.002	.004	.008	.016	.031	.062	.125	.250	.50	1.00	Method of Analysis**	Average Diameter
		Percent Finer than Size Indicated in mm											
1	$\boxed{99}$ 448	20.3	33.6	35.1	49.2	70.3	84.0	92.8	100	100		VPWCM	0.0165
3	115	30.9	35.7	38.0	49.7	58.5	90.8	99.9	100			VPWCM	0.016
4	370	16.7	18.5	25.7	33.4	44.7	91.2	98.2	99.5	100		VPWCM	0.033
7	254	27.5	34.4	41.9	53.9	67.7	83.1	86.5	91.9	985	100	VPWCM	0.013
10*	52	37	47	---	71	---	98	100				VPWCM	0.0048
12	99.1	2.9	3.7	4.9	5.1	5.8	9.2	10.6	12.0	50.	100	VPWCM	0.500
14	185	26.1	27.8	31.0	36.2	39.7	68.9	85.1	91.1	100		VPWCM	0.040
16	249	23.5	24.9	27.1	32.7	37.9	64.8	93.3	99.3	100		VPWCM	0.042
18	406	26.1	36	44.5	58.4	74.3	92.9	96.5	98.9	99.	100	VPWCM	0.0105
19*	123	20	24	---	35	---	66	85	97	99	100	VPWCM	0.048
20*	131	17	22	---	38	---	93	99	99	100		VPWCM	0.020
21*	44	26	28	---	44	---	98	100				VPWCM	0.0175
22*	100	2.5	32	---	48	---	81	93	98	100		VPWCM	0.0172

* Sampled during the Summer of 1954 (Larger samples were taken, see page)

** V = Visual Acumulation Tube, P = Pipette, W = in distilled water,
C = Chemically Dispersed, M = Mechanically Dispersed.

Table 19

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 1

Dist. from bank = 1.0'		Dist. from bank = 4'		Dist. from bank = 8'		Dist. from bank = 14'		Dist. from bank = 20'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	100	2.362	100	4.699	100	4.699	99.55	4.699	98.85
1.168	99.84	1.168	99.74	2.362	99.13	2.362	99.07	2.362	93.73
0.589	98.59	0.589	96.34	1.168	96.84	1.168	71.46	1.168	78.50
0.295	94.67	0.295	70.94	0.589	72.34	0.589	28.49	0.589	37.40
0.147	72.27	0.147	32.24	0.295	40.14	0.295	10.70	0.295	15.75
0.074	27.37	0.074	18.69	0.147	13.96	0.147	2.34	0.147	3.73
				0.074	5.81	0.074	0.74	0.074	0.71
0.1030	26.81			0.053	4.79	0.053	0.62	0.053	0.57
0.0726	25.03			0.044	2.55	0.044	0.37	0.044	0.24
0.0520	22.47								
0.0372	17.30								
0.0237	7.78								
0.0170	3.47								
0.0121	1.73								

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 1 cont.

Dist. from bank = 24'

D, mm	% Finer
4.699	100
2.362	99.47
1.168	98.28
0.589	76.26
0.295	39.82
0.147	15.55
0.074	4.70
0.053	1.99
0.044	0.53

Canal 2

Dist. from bank = 27'

D, mm	% Finer
4.699	100
2.362	96.85
1.168	92.13
0.589	76.47
0.295	46.44
0.147	21.34
0.074	12.69
0.0855	11.9
0.0603	11.9
0.0383	8.0
0.0288	5.7
0.0169	3.4
0.0118	2.3
0.0083	1.7

Dist. from bank = 2''

D, mm	% Finer
19	88.72
12.7	78.26
9.5	72.48
4.699	64.93
2.362	60.92
1.168	58.70
0.589	55.06
0.295	51.75
0.147	46.65
0.074	26.28
0.0736	23.9
0.0545	21.5
0.0416	16.9
0.0314	12.1
0.0203	7.3
0.0149	5.3
0.0108	3.6
0.0077	2.7
0.0055	2.0

Dist. from bank = 10'

D, mm	% Finer
12.7	95.61
9.5	95.61
4.699	93.70
2.362	92.60
1.168	92.25
0.589	91.80
0.295	87.00
0.147	40.17
0.074	37.09
0.092	30.5
0.065	27.4
0.048	17.8
0.036	9.9

Dist. from bank = 20'

D, mm	% Finer
1.168	100
0.589	99.26
0.295	90.02
0.147	70.02
0.074	29.53
0.088	24.6
0.063	21.8
0.047	13.9
0.034	8.1
0.022	4.2

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 2 cont.

		Dist. from bank = 30'		Dist. from bank = 40'		Dist. from bank = 50'		Dist. from bank = 60'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	96.98	4.699	97.20	19.05	88.96	12.7	100	4.699	100
2.362	87.15	2.362	93.36	12.7	88.96	9.5	97.29	2.362	99.94
1.168	79.51	1.168	91.23	9.5	87.80	4.699	94.63	1.168	99.93
0.589	68.21	0.589	85.49	4.699	85.12	2.362	92.33	0.589	99.60
0.295	49.82	0.295	78.93	2.362	83.76	1.168	90.58	0.295	98.97
0.147	1.20	0.147	1.91	1.168	82.67	0.589	86.78	0.147	97.96
0.074	0.11	0.074	0.28	0.589	78.31	0.295	82.87	0.074	60.67
0.053	0.06	0.053	0.16	0.295	69.73	0.147	76.54		
		0.044	0.07	0.147	19.50	0.074	36.35	0.0695	52.5
		pan	0.01	0.074	8.51			0.0535	44.6
						0.071	31.7	0.0417	32.8
				0.091	6.27	0.054	27.7	0.0320	20.9
						0.041	21.5	0.0203	15.4
						0.031	15.5	0.0151	7.0
						0.020	9.3	0.0108	5.0
						0.015	6.3		
						0.011	4.5		
						0.008	2.9		

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL
Canal 3

Dist. from bank = 10'

D, mm	% Finer
0.589	99.41
0.295	94.60
0.147	75.84
0.074	36.87
0.085	32.2
0.061	30.7
0.045	23.9
0.033	17.0
0.021	9.7
0.015	6.8
0.011	5.3
0.0078	3.9

Dist. from bank = 20'

D, mm	% Finer
4.699	100
2.362	98.25
1.168	91.38
0.589	54.97
0.295	34.49
0.147	6.68
0.074	2.91
0.0990	2.67
0.0703	2.4
0.0498	2.2
0.0354	1.9
0.0221	1.3
0.0157	1.0

Dist. from bank = 21'

D, mm	% Finer
2.362	99.85
1.168	99.55
0.589	97.93
0.295	91.23
0.147	77.63
0.074	51.27
0.0772	47.6
0.0566	43.1
0.0420	36.0
0.0304	26.6
0.0205	16.0
0.0150	11.1
0.0107	8.1
0.0077	5.5

Dist. from bank = 30'

D, mm	% Finer
2.362	99.31
1.168	97.10
0.589	74.72
0.295	27.11
0.147	9.84
0.074	8.44
0.0990	7.6
0.0701	7.5
0.0498	7.0
0.0354	6.3
0.0220	4.85
0.0158	3.54
0.0113	2.90
0.0080	2.27

Dist. from bank = 40'

D, mm	% Finer
4.699	100
2.362	99.41
1.168	97.52
0.589	80.05
0.295	76.80
0.147	41.03
0.074	4.51
0.101	4.07
0.0715	3.92
0.507	3.48
0.0364	2.74
0.0223	2.50
0.0159	2.01

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 3 cont.

Dist. from bank = 45'

D, mm	% Finer
1.168	100
0.589	99.77
0.295	98.70
0.147	96.19
0.074	67.54
0.053	65.43

D, mm	% Finer
0.0721	62.7
0.0545	55.2
0.0415	44.1
0.0320	30.8
0.0214	14.6
0.0157	8.55
0.0113	5.33
0.0080	3.04

Dist. from bank = 50'

D, mm	% Finer
4.699	100
2.362	99.77
1.168	99.12
0.589	88.43
0.295	50.17
0.147	7.41
0.074	3.64

D, mm	% Finer
0.1002	3.15
0.0708	2.86
0.0356	2.28

Dist. from bank = 60'

D, mm	% Finer
4.699	100
2.362	99.71
1.168	99.33
0.589	90.46
0.295	59.00
0.147	12.81
0.074	4.59

D, mm	% Finer
0.0995	4.80
0.0702	4.45
0.0500	3.90

Dist. from bank = 70'

D, mm	% Finer
1.168	100
0.589	99.67
0.295	98.67
0.147	93.14
0.074	27.39

D, mm	% Finer
0.0930	23.2
0.0676	16.7
0.0490	11.50
0.0352	7.90
0.0219	6.35
0.0155	5.04

Dist. from bank = 78'

D, mm	% Finer
2.362	100
1.168	99.81
0.589	98.54
0.295	96.31
0.147	91.66
0.074	43.84

D, mm	% Finer
0.0840	39.3
0.0606	35.9
0.0453	26.8
0.0337	17.7
0.0214	10.9
0.0156	6.35
0.0110	5.21

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 4

Dist. from bank = 2'		Dist. from bank = 8'		Dist. from bank = 16'		Dist. from bank = 22'		Dist. from bank = 28'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	100	4.699	100	4.699	100	4.699	100	1.168	100
2.362	99.80	2.362	99.85	2.362	99.84	2.362	97.71	0.589	99.91
1.168	99.75	1.168	99.75	1.168	99.60	1.168	97.43	0.295	99.49
0.589	99.18	0.589	99.03	0.589	96.04	0.589	92.90	0.147	97.72
0.295	93.49	0.295	94.10	0.295	85.98	0.295	67.02	0.074	86.33
0.147	80.09	0.147	82.73	0.147	71.02	0.147	42.93		
0.074	61.56	0.074	66.23	0.074	54.31	0.074	33.76		

Dist. from bank = 2'		Dist. from bank = 8'		Dist. from bank = 16'		Dist. from bank = 22'		Dist. from bank = 28'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
0.0913	55.12	0.0535	55.45	0.0807	51.10	0.0888	30.81	0.0944	79.05
0.0653	50.96	0.0409	45.63	0.0590	46.73	0.0639	28.78	0.0672	76.28
0.0473	43.68	0.0315	34.08	0.0439	38.63	0.0463	25.96	0.0490	63.79
0.0347	31.82	0.0207	21.03	0.0329	28.66	0.0340	21.12	0.0294	44.38
0.0220	20.80	0.0152	13.86	0.0214	16.20	0.0223	11.88	0.0225	37.45
0.0158	13.52	0.0104	9.47	0.0156	9.97	0.0164	6.16	0.0167	15.81
0.0113	9.77	0.0079	6.93	0.0113	6.23	0.0117	5.02	0.0119	11.10
0.0081	6.86	0.0057	4.04	0.0078	4.49	0.0083	3.78	0.0085	6.94
0.0057	4.78	0.0040	2.31	0.0058	2.49	0.0059	2.99	0.0057	4.16
0.0041	3.12	0.0027	1.38			0.0041	2.64	0.0039	3.61
						0.0029	1.14		

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 4 cont.

Dist. from bank = 36'

D, mm	% Finer
2.362	100
1.168	99.96
0.589	98.74
0.295	84.46
0.147	69.25
0.074	36.48
0.0754	32.85
0.0564	30.19
0.0427	25.21
0.0326	18.91
0.0216	10.62
0.0159	6.64
0.0116	2.99
0.0083	1.66
0.0061	1.00

Dist. from bank = 42'

D, mm	% Finer
2.362	100
1.168	100
0.589	99.77
0.295	94.31
0.147	85.47
0.074	69.02
0.0560	56.87
0.0427	47.19
0.0329	34.48
0.0216	21.18
0.0158	14.16
0.0114	8.83
0.0083	5.45
0.0060	3.02
0.0045	1.82

Canal 5

Dist. from bank = 2'

D, mm	% Finer
1.168	100
0.589	99.69
0.295	98.56
0.147	95.40
0.074	81.91
0.0756	73.7
0.0550	69.0
0.0405	60.80
0.0302	48.5
0.0195	34.6
0.0142	28.1
0.0103	21.6
0.0074	17.5
0.0053	12.6
0.00118	8.94

Dist. from bank = 8'

D, mm	% Finer
1.168	100
0.589	91.35
0.295	94.28
0.147	82.49
0.074	65.94
0.0704	58.2
0.0517	51.6
0.0388	46.2
0.0296	36.4
0.0196	24.4
0.0142	18.3
0.0103	14.0
0.0074	10.7
0.0054	7.90

Dist. from bank = 16'

D, mm	% Finer
4.699	100
2.362	99.51
1.168	98.81
0.589	94.70
0.295	89.16
0.147	82.31
0.074	72.58
0.0776	64.5
0.0559	61.4
0.0403	56.6
0.0298	48.2
0.0198	35.8
0.0140	28.2
0.0102	22.0
0.00735	16.6
0.00527	12.8
0.00379	8.14

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 5 cont.								Canal 6	
Dist. from bank = 24'		Dist. from bank = 32'		Dist. from bank = 40'		Dist. from bank = 45'		Dist. from bank = 20'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	100	1.168	100	1.168	100	1.168	100	4.699	96.76
1.168	99.73	0.589	99.46	0.589	99.22	0.589	99.85	2.362	56.70
0.589	97.54	0.295	96.78	0.295	91.28	0.295	98.68	1.168	18.10
0.295	92.46	0.147	91.42	0.147	77.86	0.147	94.13	0.589	11.94
0.147	84.43	0.074	86.97	0.074	64.76	0.074	74.03	0.295	6.92
0.074	75.26							0.147	4.44
		0.0726	76.5	0.0755	56.2	0.0497	58.6	0.074	1.62
0.0756	65.7	0.0524	73.5	0.0547	52.7	0.0384	48.0	0.053	1.30
0.0546	63.0	0.0384	67.3	0.0405	45.6	0.0295	35.8	0.044	0.66
0.0400	56.2	0.0287	56.4	0.0295	35.2	0.0196	22.4		
0.0291	47.4	0.0185	44.5	0.0196	25.8	0.0144	16.3		
0.0190	37.2	0.0158	34.6	0.0145	16.5	0.0104	11.9		
0.0139	29.0	0.0093	26.1	0.0105	11.4	0.00745	9.55		
0.0101	23.2	0.0049	17.6	0.00755	8.35	0.00534	7.1		
0.0073	18.1	0.0024	12.1						
0.00524	13.7								
0.00352	10.0								

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 6

Dist. from bank = 30'		Dist. from bank = 40'		Dist. from bank = 40'		Dist. from bank = 50'		Dist. from bank = 60'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	100	4.699	100	2.362	100	4.699	100	4.699	100
2.362	99.71	2.362	99.9	1.168	98.80	2.362	99.78	2.362	98.57
1.168	98.63	1.168	99.4	0.589	47.23	1.168	97.94	1.168	94.55
0.589	52.43	0.589	49.8	0.295	9.07	0.589	47.24	0.589	64.90
0.295	11.76	0.295	12.1	0.147	1.06	0.295	15.60	0.295	33.98
0.147	0.86	0.147	0.9	0.074	0.46	0.147	2.65	0.147	6.19
0.074	0.79	0.074	0.4	0.053	0.32	0.074	1.40	0.074	0.74
0.053	0.65	0.053	0.3	0.044	0.05	0.053	1.18	0.053	0.53
0.044	0.29	0.044	0.2			0.044	0.66	0.044	0.37

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 7

Dist. from bank = 1'	
D, mm	% Finer
2.362	100
1.168	99.85
0.589	96.53
0.295	88.18
0.147	68.70
0.074	47.30
0.0715	45.2
0.0523	42.5
0.0385	38.6
0.0289	32.6
0.0186	25.4
0.0143	20.2
0.0102	15.7
0.00735	12.5
0.00540	8.66
0.00386	5.68

Dist. from bank = 4'	
D, mm	% Finer
1.168	100
0.589	98.96
0.295	94.22
0.147	81.99
0.074	55.29
0.0834	52.8
0.0610	49.7
0.0435	43.9
0.0320	34.6
0.0207	23.8
0.0150	16.5
0.0108	11.55
0.0078	8.30
0.0055	6.80

Dist. from bank = 8'	
D, mm	% Finer
2.362	100
1.168	99.77
0.589	93.30
0.295	65.30
0.147	40.97
0.074	29.44
0.0926	28.10
0.0658	26.6
0.0470	24.4
0.0348	18.55
0.0215	13.4
0.0152	11.4
0.0109	9.05
0.00774	7.02

Dist. from bank = 17'	
D, mm	% Finer
4.699	100
2.362	99.81
1.168	99.17
0.589	84.99
0.295	27.59
0.147	8.19
0.074	6.50
0.0989	6.16
0.0700	5.96
0.0495	5.91
0.0352	5.77
0.0218	4.72
0.0154	4.24

Dist. from bank = 26'	
D, mm	% Finer
2.362	100
1.168	99.39
0.589	84.49
0.295	25.07
0.147	7.75
0.074	6.35
0.0998	5.93
0.0707	5.73
0.0503	5.34
0.0356	4.75

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 7 cont.						Canal 8			
Dist. from bank = 30'		Dist. from bank = 33'		Dist. from bank = 1'		Dist. from bank = 4'		Dist. from bank = 12'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
1.168	99.92	2.362	100	2.362	97.25	4.699	100	4.699	97.63
0.589	97.31	1.168	99.89	1.168	94.15	2.362	93.48	2.362	89.47
0.295	92.45	0.589	97.76	0.589	84.24	1.168	90.55	1.168	68.80
0.147	77.34	0.295	93.71	0.295	74.37	0.589	83.64	0.589	28.44
0.074	48.64	0.147	85.56	0.147	62.88	0.295	73.49	0.295	7.42
		0.074	50.91	0.074	53.97	0.147	58.23	0.147	0.56
0.0854	45.6					0.074	50.35	0.074	0.12
0.0586	42.5	0.0869	45.2	0.0765	48.7			0.053	0.07
0.0437	34.2	0.0620	42.7	0.0526	43.7	0.0858	47.37	0.044	0.02
0.0322	26.9	0.0468	32.6	0.0359	37.7	0.0614	45.45		
0.0205	19.1	0.0337	20.8	0.0209	29.6	0.0445	41.60		
0.0148	14.3	0.0216	10.08	0.0143	24.6	0.0325	35.20		
0.0107	10.95	0.0153	8.30	0.0098	20.9	0.0209	26.37		
0.00766	8.32	0.0110	6.10	0.0066	15.7	0.0152	21.38		
0.00545	7.10			0.0042	11.1	0.0110	16.26		
				0.0030	5.0	0.0079	12.54		
				0.0019	0.5	0.0057	9.60		
						0.0041	7.68		
						0.0029	4.74		
						0.0023	4.23		
						0.0009	2.56		

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 8 cont.

Dist. from bank = 24'		Dist. from bank = 29'		Dist. from bank = 41'		Dist. from bank = 49'		Dist. from bank = 52'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	98.77	4.699	100	4.699	100	2.362	100	4.699	100
2.362	93.62	2.362	98.16	2.362	98.55	1.168	99.73	2.362	98.06
1.168	80.25	1.168	92.55	1.168	93.40	0.589	97.50	1.168	96.77
0.589	42.26	0.589	62.28	0.589	66.03	0.295	81.61	0.589	91.59
0.295	13.22	0.295	18.44	0.295	24.07	0.147	40.45	0.295	84.64
0.147	0.81	0.147	0.82	0.147	1.19	0.074	16.07	0.147	74.22
0.074	0.04			0.074	0.11	0.053	12.68	0.074	53.33
				0.053	0.06	0.044	7.23		
				0.044	0.01			0.0539	47.64
								0.0412	43.64
								0.0304	35.94
								0.0201	25.94
								0.0149	19.34
								0.0110	13.68
								0.0080	10.38
								0.0050	5.66
								0.0042	5.19
								0.0016	0.94

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 9

Dist. from bank = 1' D, mm	% Finer	Dist. from bank = 4' D, mm	% Finer	Dist. from bank = 12' D, mm	% Finer	Dist. from bank = 22' D, mm	% Finer	Dist. from bank = 32' D, mm	% Finer
4.699	100	4.699	99.98	4.699	100	4.699	100	4.699	100
2.362	99.16	2.362	99.95	2.362	99.74	2.362	99.76	2.362	99.48
1.168	96.83	1.168	99.23	1.168	98.38	1.168	98.74	1.168	97.75
0.589	88.38	0.589	93.39	0.589	80.98	0.589	80.33	0.589	78.56
0.295	78.06	0.295	80.53	0.295	39.81	0.295	33.29	0.295	41.63
0.147	61.51	0.147	50.23	0.147	4.36	0.147	1.85	0.147	2.36
0.074	53.79	0.074	41.37	0.074	0.98	0.074	0.15	0.074	0.16
				0.053	0.72	0.053	0.10	0.053	0.11
				0.044	0.40	0.044	0.05	0.044	0.06

Dist. from bank = 1' D, mm	% Finer	Dist. from bank = 4' D, mm	% Finer
0.057	52.0	0.0785	40.8
0.042	46.9	0.0571	39.0
0.032	38.0	0.0427	33.9
0.021	26.2	0.0322	27.9
0.016	20.0	0.0208	20.2
0.011	14.9	0.0147	15.0
0.0083	11.3	0.0107	12.7
0.0059	8.2	0.00761	9.0
0.0047	6.7	0.00655	8.4
0.0032	4.6	0.00467	6.5
0.0015	2.6	0.00254	3.9
		0.00147	2.2

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 9 cont.				Canal 10					
Dist. from bank = 40'		Dist. from bank = 43'		Dist. from bank = 2'		Dist. from bank = 8'		Dist. from bank = 16'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	100	4.699	100	4.699	100	4.699	100	4.699	100
2.362	99.8	2.362	99.91	2.362	97.87	2.362	99.08	2.362	97.20
1.168	98.8	1.168	99.45	1.168	94.22	1.168	97.51	1.168	91.06
0.589	96.5	0.589	98.99	0.589	81.78	0.589	69.11	0.589	60.68
0.295	80.9	0.295	98.16	0.295	64.87	0.295	25.08	0.295	40.88
0.147	38.5	0.147	95.88	0.147	45.54	0.147	9.27	0.147	20.33
0.074	21.2	0.074	85.68	0.074	26.89	0.074	4.02	0.074	12.03

0.095	21.2	0.0409	70.3	0.0926	23.9	0.0992	9.76	0.1001	8.28
0.0685	19.4	0.0297	60.0	0.0656	22.6	0.0706	8.93	0.0714	8.06
0.0492	17.5	0.0204	44.4	0.0474	19.9	0.0507	5.54	0.0509	5.77
0.0358	14.4	0.0140	32.6	0.0342	14.85				
0.0226	10.4	0.0111	27.4	0.0214	10.9				
0.0165	8.0	0.0081	22.2	0.0154	6.90				
0.0112	6.2	0.0058	17.0						
0.00841	4.3	0.0042	13.8						
0.00494	3.2	0.0031	9.9						
0.00166	1.1	0.0025	8.4						
		0.0024	8.1						
		0.0014	5.9						

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 10 cont.								Canal 11	
Dist. from bank = 20'		Dist. from bank = 24'		Dist. from bank = 32'		Dist. from bank = 38'		Dist. from bank = 2'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	100	4.699	100	4.699	98.75	4.699	100	4.699	100
2.362	97.82	2.362	96.59	2.362	94.02	2.362	99.87	2.362	97.36
1.168	92.22	1.168	91.43	1.168	85.88	1.168	99.51	1.168	92.49
0.589	58.46	0.589	61.84	0.589	55.89	0.589	96.75	0.589	74.26
0.295	34.19	0.295	35.60	0.295	25.17	0.295	86.18	0.295	53.95
0.147	23.91	0.147	11.76	0.147	4.06	0.147	59.38	0.147	37.06
0.074	13.32	0.074	4.69	0.074	0.89	0.074	35.24	0.074	26.27
0.053	4.05	0.053	1.42	0.053	0.22			0.053	25.57
0.044	0.58	0.044	0.21	0.044	0.07	0.090	32.1	0.044	25.23
pan	0	pan	0	pan	0	0.0638	30.8		
						0.0460	26.9	0.0914	23.0
						0.0336	20.5	0.0649	21.85
						0.0215	12.55	0.0470	17.3
						0.0155	8.04	0.0339	13.12
						0.0111	5.53	0.0212	9.52
								0.0152	7.30

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL
Canal 11 cont.

Dist. from bank = 10'		Dist. from bank = 20'		Dist. from bank = 30'		Dist. from bank 40'		Dist. from bank = 44'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	99.45	4.699	99.67	4.699	99.14	4.699	99.63	2.362	100
2.362	95.92	2.362	95.44	2.362	90.14	2.362	96.27	1.168	99.96
1.168	88.30	1.168	86.11	1.168	74.94	1.168	89.79	0.589	98.84
0.589	54.58	0.589	51.11	0.589	43.24	0.589	64.83	0.295	94.38
0.295	8.74	0.295	8.61	0.295	14.84	0.295	27.14	0.147	81.61
0.147	1.12	0.147	0.89	0.147	2.94	0.147	10.48	0.074	44.45
0.074	0.15	0.074	0	0.074	0.34	0.074	5.90		
								0.0851	40.5
						.0991	4.04	0.0608	38.9
								0.0441	33.8
								0.0321	28.0
								0.0211	20.0
								0.0150	10.75
								0.0109	6.10

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 12

Dist. from bank =		Dist. from bank = 2'		Dist. from bank = 10'		Dist. from bank = 20'		Dist. from bank = 30'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
38.1	95.08	4.699	100	9.525	97.98	19.05	93.25	9.525	83.78
26.67	84.23	2.362	99.84	4.699	92.89	12.70	88.26	4.699	80.91
18.85	74.53	1.168	99.41	2.362	89.58	9.525	85.54	2.362	77.85
13.33	64.38	0.589	97.54	1.168	88.65	4.699	80.24	1.168	76.48
9.42	58.84	0.295	95.04	0.589	86.20	2.362	77.89	0.589	68.03
4.699	45.72	0.147	87.39	0.295	79.51	1.168	76.65	0.295	46.10
2.362	38.62	0.074	48.79	0.147	68.66	0.589	73.41	0.147	21.29
1.168	37.20			0.074	47.98	0.295	52.06	0.074	16.57
0.589	32.85	0.0842	45.0			0.147	27.06		
0.295	15.35	0.0610	40.2	0.0791	44.4	0.074	17.71	0.0952	14.4
0.147	6.65	0.0404	30.8	0.0572	41.1			0.0679	13.2
0.074	1.52	0.0336	20.2	0.0427	33.5	0.090	15.05	0.0491	10.4
		0.0217	9.28	0.0320	24.3	0.0641	14.4	0.0356	6.58
		0.0155	5.90	0.0206	14.0	0.0470	10.45	0.0230	3.64
				0.0152	8.0132	0.0342	7.20		
				0.0109	5.32	0.0216	4.58		
						0.0155	3.28		

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 12 cont.

Dist. from bank = 40'

D, mm	% Finer
9.525	95.38
4.699	88.55
2.362	83.16
1.168	77.03
0.589	56.76
0.295	36.15
0.147	11.95
0.074	6.50
0.100	5.43

Dist. from bank = 50'

D, mm	% Finer
19.05	99.95
12.70	91.89
9.53	91.21
4.699	89.80
2.362	89.28
1.168	89.00
0.589	87.88
0.295	85.82
0.147	76.07
0.074	50.64
0.0769	46.7
0.0561	43.7
0.0424	34.8
0.0316	26.6
0.0210	13.6
0.0156	5.82

Dist. from bank = 58'

D, mm	% Finer
2.362	100
1.168	99.10
0.589	99.55
0.295	66.55
0.147	33.14
0.074	29.34
0.0987	26.4
0.0689	23.5
0.0502	16.1
0.0367	8.74
0.0229	3.54

Canal 13

Dist. from bank

D, mm	% Finer
26.67	93.17
18.85	83.39
13.33	67.45
9.42	55.93
4.699	40.03
2.362	31.41
1.168	27.69
0.589	23.26
0.295	11.42
0.147	3.69
0.074	1.59

Dist. from bank = 2'

D, mm	% Finer
4.699	100
2.362	99.35
1.168	99.14
0.589	97.68
0.295	96.77
0.147	88.22
0.074	64.20
0.0844	59.6
0.0610	54.7
0.0541	45.1
0.0339	30.6
0.0222	13.55
0.0156	6.3

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 13 cont.

Dist. from bank = 10'		Dist. from bank = 20'		Dist. from bank = 30'		Dist. from bank = 40'		Dist. from bank = 50'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
38.10	75.70	12.70	89.22	12.70	91.21	12.70	85.25	38.1	100
25.40	65.87	9.53	80.52	9.53	85.93	9.53	68.69	25.4	88.93
19.05	46.45	4.699	70.23	4.699	80.46	4.699	47.57	19.05	84.13
12.70	41.06	2.362	66.57	2.362	75.76	2.362	42.41	12.70	72.43
9.53	35.42	1.168	64.91	1.168	70.62	1.168	41.01	9.53	58.80
4.699	32.58	0.589	64.84	0.589	55.87	0.589	31.67	4.699	49.72
2.362	32.27	0.295	57.86	0.295	35.07	0.295	25.87	2.362	47.80
1.168	32.13	0.147	40.37	0.147	21.67	0.147	14.06	1.168	47.12
0.589	31.80	0.074	30.39	0.074	15.27	0.074	9.64	0.589	45.38
0.295	30.78							0.295	40.38
0.147	26.54	0.0973	27.2	0.1006	13.9	0.0920	8.79	0.147	30.44
0.074	20.59	0.0646	25.4	0.0715	12.6	0.0655	8.35	0.074	20.62
		0.0497	20.8	0.051	10.6	0.0475	6.94		
0.0527	18.9	0.0360	14.4	0.0367	6.55	0.0342	5.57	0.0798	19.4
0.0404	15.95	0.0225	8.55	0.023	3.60	0.0219	3.14	0.0580	18.0
0.0311	11.80					0.0157	2.35	0.0429	15.2
0.0212	6.32					0.0112	1.59	0.0321	11.4
0.0163	3.46							0.0211	6.41
0.0114	2.04							0.0153	4.39
0.0081	1.30							0.0111	2.66

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 13 cont.						Canal 14			
Dist. from bank = 58'				Dist. from bank = 2'		Dist. from bank = 10'		Dist. from bank = 20'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	96.10	4.699	98.68	4.699	100	4.699	100	4.699	100
2.362	95.55	2.362	98.35	2.362	99.89	2.362	99.74	2.362	98.83
1.168	95.23	1.168	98.09	1.168	99.60	1.168	99.64	1.168	98.49
0.589	93.87	0.589	87.89	0.589	97.57	0.589	98.41	0.589	88.57
0.295	91.38	0.295	30.59	0.295	94.46	0.295	90.09	0.295	60.92
0.147	84.63	0.147	13.18	0.147	64.84	0.147	26.69	0.147	20.12
0.074	55.57	0.074	8.53	0.074	25.89	0.074	11.06	0.074	8.23
0.0735	51.0	0.0992	6.75	0.~~090~~	21.9	0.0964	9.50	0.0976	6.48
0.0541	47.1	0.0712	6.10	0.0638	20.2	0.0686	9.36	0.0694	5.67
0.0411	38.4	0.0505	5.26	0.0471	14.0	0.0491	6.81	0.0496	4.07
0.0314	27.9	0.0362	3.52	0.0342	9.12	0.0352	5.28		
0.0212	12.6			0.0216	5.64	0.0224	3.76		
0.0154	7.55			0.0155	4.35				
0.0111	3.64								

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 14 cont.								Canal 15	
Dist. from bank = 30'		Dist. from bank = 40'		Dist. from bank = 50'		Dist. from bank = 59'			
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	100	9.53	98.74	26.67	82.40	18.85	90.04	4.699	100
2.362	95.69	4.699	97.23	18.85	73.94	12.70	73.04	2.362	99.51
1.168	86.13	2.362	93.79	13.33	64.19	9.53	60.25	1.168	98.96
0.589	64.53	1.168	90.37	9.53	50.99	4.699	58.85	0.589	95.98
0.295	40.58	0.589	73.45	4.699	37.14	2.362	32.93	0.295	90.36
0.147	3.08	0.295	51.75	2.362	31.33	1.168	31.59	0.147	78.78
0.074	0.98	0.147	11.40	1.168	29.41	0.589	30.55	0.074	59.05
		0.074	3.33	0.589	28.45	0.295	29.59		
				0.295	27.63	0.147	26.67	0.0807	56.7
				0.147	15.03	0.074	13.92	0.0588	52.0
				0.074	7.73			0.0430	46.6
						0.0792	12.8	0.0328	40.0
				0.0858	7.08	0.0578	11.2	0.0200	30.6
				0.0620	6.38	0.0430	9.14	0.0147	25.2
				0.0452	5.20	0.0320	6.80	0.0106	21.1
				0.0330	4.01	0.0202	4.82	0.0076	17.3
				0.0209	2.84	0.0146	4.01	0.0054	12.2
				0.0151	2.20	0.0105	2.92	0.0039	4.44

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL
Canal 15 cont.

Dist. from bank = 7'						Dist. from bank			
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	99.74	4.699	100	4.699	100	4.699	100	4.699	97.77
1.168	99.54	2.362	98.77	2.362	98.25	2.362	98.82	2.362	91.69
0.589	99.06	1.168	96.94	1.168	94.13	1.168	94.30	1.168	82.95
0.295	97.66	0.589	41.94	0.589	54.03	0.589	58.40	0.589	56.15
0.147	64.36	0.295	1.19	0.295	3.23	0.295	11.40	0.295	37.47
0.074	37.36	0.147	0.19	0.147	0.14	0.147	0.88	0.147	25.46
		0.074	0	0.074	0	0.074	0.13	0.074	17.66
0.0934	34.1								
0.0665	31.5							0.0983	15.9
0.0482	26.0							0.0704	14.55
0.0348	20.7							0.0504	12.15
0.0218	15.7							0.0364	9.55
0.0158	10.4							0.0226	6.56
0.0113	7.4							0.0162	4.56
0.0081	4.41							0.0116	3.48
								0.00824	2.58

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 15 cont.				Canal 16: Dist. from bank = 2'		Canal 16: Dist. from bank = 4'		Canal 16: Dist. from bank = 7'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	98.92	0.589	100	4.699	100	2.362	97.56	2.362	98.54
2.362	97.36	0.295	99.43	2.362	99.92	1.168	94.06	1.168	95.48
1.168	96.93	0.147	88.83	1.168	99.80	0.589	83.73	0.589	84.46
0.589	96.09	0.074	55.93	0.589	99.35	0.295	65.66	0.295	67.16
0.295	94.36			0.295	98.28	0.147	44.58	0.147	44.96
0.147	77.88	0.0888	51.4	0.147	96.24	0.074	23.78	0.074	24.38
0.074	60.88	0.0644	45.7	0.074	45.04	0.053	23.00	0.053	23.44
		0.0464	36.0	0.053	42.60			0.044	22.11
0.0826	56.7	0.0412	27.0			0.0901	20.6		
0.0601	52.0	0.0220	18.9	0.0813	41.3	0.0648	18.65	0.091	21.0
0.0444	44.5	0.0158	13.3	0.0592	36.9	0.0475	14.1	0.0655	18.8
0.0326	35.8	0.0113	10.7	0.0447	28.0	0.0347	9.95	0.0479	13.9
0.0210	26.0	0.0081	8.26	0.0338	18.2	0.0221	5.92	0.0348	10.3
0.0153	19.4			0.0219	9.91	0.0158	3.78	0.0219	6.67
0.0112	12.7			0.0145	5.40	0.0102	2.36	0.0157	4.44
0.0805	7.85			0.0114	3.93			0.0113	2.68

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 16 cont.		Canal 17							
Dist. from bank = 10'		Dist. from bank = 12'		Dist. from bank = 1'		Dist. from bank = 4'		Dist. from bank = 6½'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	99.55	1.168	99.97	1.168	100	9.53	97.04	2.362	99.72
1.168	99.31	0.589	99.70	0.589	99.65	4.699	96.47	1.168	98.74
0.589	98.53	0.295	98.91	0.295	98.68	2.362	95.55	0.589	89.44
0.295	95.68	0.147	96.53	0.147	95.86	1.168	95.32	0.295	62.49
0.147	85.38	0.074	58.23	0.074	34.56	0.589	94.76	0.147	34.80
0.074	34.48			0.053	32.56	0.295	92.92	0.074	21.84
0.053	32.93	0.0824	52.0	0.044	29.10	0.147	86.77	0.053	16.86
0.044	31.17	0.0603	47.7			0.074	32.77	0.044	16.53
		0.0448	37.2	0.0903	30.5	0.053	31.61		
0.0886	29.4	0.0334	24.8	0.0646	28.1	0.044	18.46	0.0945	19.75
0.0643	27.3	0.0219	11.6	0.0475	20.3			0.0676	18.0
0.0479	18.6	0.0157	7.26	0.0347	13.7	0.0891	29.7	0.0488	14.3
0.0348	12.1	0.01125	4.54	0.0220	7.15	0.0640	27.2	0.0351	11.0
0.0222	5.72			0.0158	4.76	0.0476	19.3	0.0221	7.26
0.0159	3.48					0.0352	11.9	0.0157	5.67
						0.0223	6.51	0.0112	4.20
						0.0159	5.34		

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 17 cont.				Canal 18					
Dist. from bank = 9'		Dist. from bank = 12'		Dist. from bank = 2'		Dist. from bank = 4'		Dist. from bank = 6'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	97.74	2.362	98.06	0.589	99.64	2.362	99.94	2.362	98.26
1.168	96.85	1.168	96.21	0.295	51.09	1.168	99.32	1.168	94.62
0.589	91.97	0.589	88.86	0.147	37.84	0.589	98.51	0.589	62.13
0.295	82.77	0.295	77.13	0.074	35.94	0.295	97.13	0.295	39.93
0.147	71.29	0.147	61.76	0.053	35.67	0.147	75.38	0.147	19.72
0.074	23.54	0.074	26.36	0.044	35.14	0.074	29.60	0.074	12.12
0.053	21.89	0.053	24.62			0.053	28.05	0.053	11.57
0.044	19.20	0.044	22.09			0.044	24.54	0.044	11.28
0.0936	20.4	0.0909	22.6	0.0826	32.0	0.0902	25.7	0.0982	9.35
0.0609	19.1	0.0652	20.6	0.0594	29.4	0.0649	24.1	0.0701	8.65
0.0485	14.2	0.0472	17.1	0.0444	23.3	0.0471	19.2	0.0491	7.95
0.0352	9.65	0.0342	12.7	0.0330	16.4	0.0342	14.1	0.0354	6.18
0.0220	6.36	0.0215	8.54	0.0214	8.55	0.0218	6.78		
0.0150	4.00	0.0155	5.94	0.0155	4.02	0.0156	4.32		
		0.0111	4.16						

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 18 cont.

Dist. from bank = 8'	
D, mm	% Finer
19.05	93.06
12.70	93.06
9.53	90.91
4.699	90.34
2.362	89.25
1.168	87.55
0.589	79.31
0.295	71.07
0.147	42.03
0.074	37.18
0.053	25.80
0.044	24.73
═════	═════
0.0900	32.5
0.0643	30.8
0.0465	25.8
0.0336	20.1
0.0213	13.0
0.0155	7.87
0.0110	4.95

Dist. from bank = 10'	
D, mm	% Finer
0.589	99.75
0.295	99.17
0.147	86.14
0.074	34.54
0.053	32.97
0.044	31.08
═════	═════
0.0876	29.6
0.0635	25.9
0.0470	18.1
0.0346	10.8
0.0218	6.01

Canal 19

Dist. from bank = 4'	
D, mm	% Finer
1.168	99.83
0.589	94.16
0.295	59.36
0.147	34.33
0.074	21.75
0.053	20.80
0.044	20.06
═════	═════
0.0977	19.05
0.0695	17.7
0.0495	15.55
0.0355	12.1
0.0222	8.68
0.0158	6.06

Dist. from bank = 7'	
D, mm	% Finer
2.362	99.93
1.168	99.22
0.589	81.32
0.295	43.02
0.147	24.02
0.074	14.68
0.053	13.83
0.044	13.38
═════	═════
0.0995	12.45
0.0707	11.6
0.0506	9.40
0.0358	7.30
0.0226	4.60

Dist. from bank = 14'	
D, mm	% Finer
2.362	90.75
1.168	72.67
0.589	38.07
0.295	19.97
0.147	2.40
0.074	0.09
0.053	0.01

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

From dunes near		Canal 19 cont. Dist. from bank = 21'		Dist. from bank = 24'		Canal 20 Dist. from bank = 2'		Dist. from bank = 5'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
1.168	99.29	4.699	98.05	2.362	99.07	0.589	99.73	0.589	99.25
0.589	59.29	2.362	84.57	1.168	97.66	0.295	97.99	0.295	97.03
0.295	4.69	1.168	64.52	0.589	80.84	0.147	93.59	0.147	92.93
0.147	1.24	0.589	32.52	0.295	49.44	0.074	84.90	0.074	88.28
0.074	1.13	0.295	13.58	0.147	18.22	0.053	82.47	0.053	86.59
0.053	1.09	0.147	2.88	0.074	12.89	0.044	77.49	0.044	85.10
0.044	1.07	0.074	1.12	0.053	12.62				
pan	1.05	0.053	1.07	0.044	12.49	0.0738	77.2	0.0775	80.0
						0.0537	72.5	0.0557	76.5
				0.1000	10.3	0.0407	60.0	0.0417	64.3
				0.0708	9.70	0.0314	41.6	0.0316	46.8
				0.0503	9.14	0.0210	20.3	0.0208	27.0
				0.0356	7.50	0.0153	13.35	0.0152	16.1
				0.0223	6.05	0.0110	8.09	0.0110	10.77
				0.0158	5.06	0.0078	5.60	0.0078	6.66

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL
Canal 20 cont.

Dist. from bank = 10'		Dist. from bank = 15'		Dist. from bank = 20'		Dist. from bank = 25'		Dist. from bank = 28'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
0.589	99.24	2.362	99.28	0.589	99.46	0.589	99.63	0.589	99.76
0.295	96.98	1.168	98.77	0.295	97.09	0.295	97.49	0.295	97.58
0.147	92.33	0.589	95.67	0.147	91.20	0.147	94.17	0.147	93.35
0.074	82.79	0.295	90.79	0.074	80.64	0.074	90.33	0.074	88.75
0.053	81.12	0.147	82.95	0.053	80.09	0.053	88.63	0.053	87.31
0.044	79.12	0.074	77.03	0.044	78.16	0.044	86.94	0.044	85.39
		0.053	76.31						
0.0721	75.5	0.044	75.76	0.0772	74.2	0.0728	83.0	0.0740	81.2
0.0534	69.0			0.0561	69.5	0.0532	77.5	0.0545	74.8
0.0402	58.1	0.0804	72.3	0.0415	60.6	0.0403	66.3	0.0412	62.8
0.0306	43.5	0.0581	68.0	0.0315	46.2	0.0306	51.3	0.0314	46.7
0.0204	26.0	0.0428	59.3	0.0209	27.5	0.0222	32.1	0.0210	26.2
0.0150	16.95	0.0320	46.3	0.0153	18.15	0.0151	18.8	0.0153	17.05
0.0108	11.60	0.0208	32.1	0.0111	11.52	0.0109	14.34	0.0111	11.35
0.00845	8.70	0.0154	22.4	0.0080	7.10	0.0079	9.83	0.0079	7.86
0.00552	6.54	0.0111	15.4	0.0055	5.16	0.0056	5.86	0.00565	4.97
		0.00795	10.5						
		0.00570	7.01						

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.
SIZE ANALYSIS OF BED AND SIDE MATERIAL
Canal 21

Dist. from bank = 2'		Dist. from bank = 5'		Dist. from bank = 10'		Dist. from bank = 15'		Dist. from bank = 18'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
0.589	99.67	0.589	99.92	2.362	99.10	1.168	99.85	0.589	99.72
0.295	97.10	0.295	97.82	1.168	97.94	0.589	98.83	0.295	97.54
0.147	93.02	0.147	93.12	0.589	95.59	0.295	95.87	0.147	94.17
0.074	86.85	0.074	87.47	0.295	94.40	0.147	90.57	0.074	90.25
				0.147	83.41	0.074	85.04		
0.0718	80.0	0.0746	77.0	0.074	76.53			0.0725	82.0
0.0531	73.2	0.0541	72.3			0.0766	77.6	0.0532	75.8
0.0399	60.2	0.0407	61.2	0.0740	70.0	0.0554	72.5	0.0400	66.2
0.0312	43.5	0.0310	43.7	0.0540	65.0	0.0416	60.1	0.0305	48.2
0.0208	23.7	0.0206	26.0	0.0405	54.9	0.0314	44.1	0.0202	28.9
0.0152	15.2	0.0152	15.22	0.0380	41.5	0.0207	25.2	0.0148	19.85
0.0109	10.7	0.0110	8.84	0.0205	22.5	0.0151	16.0	0.0107	14.0
0.0078	7.13	0.00785	5.71	0.0150	14.6	0.0108	11.5	0.0077	9.47
				0.0108	9.88	0.00775	8.08		
				0.00776	5.58				

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 22

Dist. from bank = 3'		Dist. from bank = 5'		Dist. from bank = 10'		Dist. from bank = 20'		Dist. from bank = 25'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
2.362	97.82	12.70	97.63	2.362	98.61	2.362	98.61	2.362	90.91
1.168	95.86	9.53	95.37	1.168	97.69	1.168	95.29	1.168	81.53
0.589	89.36	4.699	93.18	0.589	95.78	0.589	63.89	0.589	51.53
0.295	77.27	2.362	91.36	0.295	67.70	0.295	25.81	0.295	26.03
0.147	54.47	1.168	89.25	0.147	45.65	0.147	4.88	0.147	4.03
0.074	38.57	0.589	82.40	0.074	37.00	0.074	0.33	0.074	0.65
0.053	37.79	0.295	69.58	0.053	36.10			0.053	0.35
0.044	37.11	0.147	32.93	0.044	35.42			0.044	0.05
		0.074	26.27					pan	0
		0.053	25.78						
		0.044	25.15						

Dist. from bank = 3'		Dist. from bank = 5'		Dist. from bank = 10'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
0.0878	33.0	0.0903	22.5	0.0851	32.8
0.0626	32.6	0.0645	20.5	0.0612	30.2
0.0454	26.7	0.0472	14.4	0.0460	20.0
0.0332	19.6	0.0346	8.75	0.0351	5.46
0.0212	11.15	0.0217	4.68		
0.152	7.53				

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 22 cont.						Canal 23			
Dist. from bank = 30'		Dist. from bank = 40'		Dist. from bank = 45'		Dist. from bank = 3'		Dist. from bank = 15'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	98.57	4.699	93.10	9.53	98.53	9.53	98.56	4.699	99.88
2.362	94.27	2.362	80.60	4.699	95.08	4.699	96.08	2.362	98.81
1.168	87.90	1.168	71.20	2.362	89.93	2.362	91.08	1.168	96.85
0.589	41.70	0.589	50.98	1.168	85.12	1.168	86.48	0.589	84.55
0.295	8.28	0.295	22.63	0.589	73.91	0.589	72.57	0.295	54.55
0.147	0.93	0.147	5.91	0.295	63.51	0.295	39.37	0.147	7.05
0.074	0.06	0.074	1.00	0.147	37.01	0.147	8.97	0.074	0.07
0.053	0	0.053	0.50	0.074	22.10	0.074	2.89		
		0.044	0.10	0.053	21.53	pan	2.26		
		pan	0	0.044	20.94				
				0.0908	19.2				
				0.0654	17.75				
				0.0475	13.9				
				0.0343	10.08				
				0.0216	5.95				

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 23 cont.

Dist. from bank = 25'		Dist. from bank = 35'		Dist. from bank = 45'		Dist. from bank = 55'		Dist. from bank = 66'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	98.84	4.699	98.54	4.699	99.24	4.699	99.6	4.699	99.15
2.362	95.63	2.362	91.10	2.362	95.95	2.362	97.84	2.362	94.04
1.168	91.48	1.168	80.79	1.168	88.60	1.168	92.84	1.168	87.96
0.589	73.48	0.589	56.19	0.589	56.77	0.589	70.00	0.589	72.66
0.295	33.88	0.295	25.37	0.295	19.95	0.295	28.25	0.295	52.63
0.147	2.48	0.147	2.14	0.147	2.04	0.147	4.30	0.147	31.75
0.074	0.22	0.074	0.05	0.074	0.34			0.074	17.75
								0.0915	15.77
								0.0665	14.88
								0.0472	11.25
								0.0341	7.58

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 24

Dist. from bank = 2'		Dist. from bank = 5'		Dist. from bank = 10'		Dist. from bank = 20'		Dist. from bank = 25'	
D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer	D, mm	% Finer
4.699	99.20	4.699	94.96	2.362	99.73	2.362	99.33	1.168	99.56
2.362	97.93	2.362	93.44	1.168	98.88	1.168	97.87	0.589	98.04
1.168	97.43	1.168	92.70	0.589	92.22	0.589	91.36	0.295	79.41
0.589	96.63	0.589	92.04	0.295	59.12	0.295	64.82	0.147	39.92
0.295	92.74	0.295	89.34	0.147	12.86	0.147	12.78	0.074	2.28
0.147	77.12	0.147	77.40	0.074	0.34	0.074	0.37	0.053	0
0.074	42.36	0.074	41.54	0.053	0	0.053	0		
		0.053	40.27						
0.0880	37.5	0.044	38.80						
0.0635	35.0								
0.0472	26.8	0.0895	36.2						
0.0347	18.45	0.0640	33.6						
0.0218	11.6	0.0485	26.7						
0.0159	8.47	0.0345	18.7						
0.0112	6.56	0.0218	12.1						
0.0079	5.30	0.0156	8.41						
		0.0112	6.35						
		0.0080	4.82						
		0.0054	3.78						

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 19 cont.

SIZE ANALYSIS OF BED AND SIDE MATERIAL

Canal 24 cont.

Dist. from bank = 15'		Dist. from bank = 27'	
D, mm	% Finer	D, mm	% Finer
2.362	98.65	2.362	98.18
1.168	94.48	1.168	98.01
0.589	78.12	0.589	97.52
0.295	47.70	0.295	95.33
0.147	9.85	0.147	84.61
0.074	0.33	0.074	59.61
0.053	0	0.053	58.44
		0.044	54.97
		0.0844	33.9
		0.061	32.0
		0.045	26.95
		0.033	20.10
		0.021	12.63
		0.016	8.02
		0.011	5.71
		0.008	4.97
		0.006	3.04
		0.005	2.85

Data above double line is sieve analysis data.
Data below double line is hydrometer analysis data.

Table 20, Standard Deviation of Bed & Side Material

Canal No.	Distance from bank	Size in mm Corresponding to % Passing d_{15}**	d_{50}	d_{75}	d_{85}	$= \frac{\frac{d_{85}}{d_{50}}+\frac{d_{50}}{d_{15}}}{2}$
1	1'	.034	.104	.154	.198	2.47
	4'	.060	.201	.317	.390	2.64
	8'	.152	.364	.615	.743	2.22
	14'	.382	.890	1.250	1.670	2.11
	20'	.285	.712	1.075	1.460	2.27
	24'	.143	.355	.574	.692	2.22
	27'	.092	.316	.565	.795	2.97
2	2'	.037	.243	10.7		36.52
	10'	.042	.168	.235	.281	2.83
	20'	.049	.104	.168	.236	2.20
	℄	.210	.298	.890	1.900	3.90
	30'	.196	.242	.284	.570	1.97
	40'	.116	.228	.453	4.500	
	50'	.030	.092	.143	.428	3.82
	60'	.020	.064	.087	.100	2.38
3	10'	.030	.092	.144	.190	2.59
	20'	.202	.503	.793	.970	2.21
	21'	.019	.071	.140	.205	3.27
	30'	.190	.420	.590	.720	1.96
	40'	.100	.173	.254	.660	2.27
	45'	.022	.048	.083	.100	2.14
	50'	.178	.295	.437	.540	1.74
	60'	.155	.263	.395	.495	1.78
	70'	.061	.090	.112	.126	1.44
	78'	.029	.079	.107	.125	2.22
4	2'	.018	.063	.118	.178	3.16
	8'	.0162	.045	.103	.162	3.18
	16'	.0203	.075	.172	.278	3.70
	22'	.0262	.178	.345	.440	4.63
	28'	.0157	.034	.065	.078	2.17
	36'	.0275	.097	.185	.297	3.29
	42'	.0165	.046	.092	.142	2.94
5	2'	.0063	.031	.066	.082	3.79
	8'	.0113	.0475	.104	.163	3.82
	16'	.0065	.0317	.086	.183	5.32
	24'	.0058	.032	.072	.152	5.13
	32'	.0037	.0225	.061	.090	5.00
	40'	.0132	.0485	.126	.202	3.92
	45'	.0132	.0403	.076	.099	2.75
6	20'	.850	2.04	2.82	3.30	2.01
	30'	.320	.568	.720	.805	1.60
	40'	.318	.590	.700	.770	1.58
	40'	.350	.603	.738	.820	1.54
	50'	.290	.605	.750	.840	1.73
	60'	.200	.422	.690	.845	2.05

Table 20 cont., Standard Deviation of Bed & Side Material

Canal No.	Distance from bank	Size in mm Corresponding to % Passing d_{15}**	d_{50}	d_{75}	d_{85}	$=\frac{\frac{d_{85}}{d_{50}}+\frac{d_{50}}{d_{15}}}{2}$
7	1'	0.095	0.110	0.177	0.254	1.73
	4'	0.0137	0.063	0.119	0.168	3.64
	8'	0.0252	0.191	0.354	0.446	4.95
	17'	0.202	0.380	0.508	0.590	1.71
	26'	0.211	0.388	0.511	0.595	1.68
	30'	0.016	0.076	0.139	0.196	3.72
	33'	0.0274	0.073	0.115	0.145	2.34
8	1'	0.0062	0.086	0.310	0.618	10.5
	4'	0.0099	0.072	0.328	0.670	5.8
	12'	0.409	0.850	1.390	1.950	2.19
	24'	0.315	0.670	1.050	1.420	2.12
	29'	0.280	0.495	0.735	0.920	1.81
	41'	0.260	0.454	0.696	0.834	1.79
	49'	0.067	0.169	0.256	0.427	2.52
	52'	0.012	0.066	0.153	0.308	5.08
9	1'	0.0112	0.050	0.255	0.452	6.74
	4'	0.0147	0.145	0.255	0.341	6.10
	12'	0.233	0.432	0.550	0.640	1.66
	22'	0.252	0.371	0.493	0.652	1.61
	32'	0.212	0.368	0.650	0.765	1.91
	40'	0.0385	0.175	0.263	0.332	3.22
	43'	0.0048	0.0231	0.047	0.071	3.94
10	2'	0.035	0.172	0.441	0.678	4.43
	8'	0.200	0.440	0.640	0.731	1.93
	16'	0.098	0.410	0.762	0.963	3.26
	20'	0.085	0.463	0.762	0.940	3.74
	24'	0.167	0.434	0.752	0.950	2.39
	32'	0.253	0.580	0.910	1.150	2.13
	38'	0.0252	0.114	0.210	0.281	3.49
11	2'	0.0396	0.251	0.607	0.830	4.82
	10'	0.343	0.560	0.843	1.070	1.72
	20'	0.347	0.582	0.892	1.120	1.80
	30'	0.300	0.680	1.170	1.790	2.45
	40'	0.186	0.452	0.746	0.990	2.31
	44'	0.0179	0.081	0.126	0.168	3.30
12*	B'	0.240	7.00	18.20	25.00	13.83
13*	B'	0.37	7.6	15.5	20.00	11.46
14	2'	0.0496	0.114	0.174	0.214	2.09
	10'	0.092	0.185	0.237	0.281	1.76
	20'	0.160	0.250	0.399	0.523	1.82
	30'	0.211	0.390	0.790	1.120	2.36
	40'	0.162	0.292	0.620	0.898	2.44
	50'	0.147	9.08	19.50	30.5	32.58 G
	59'	0.079	3.71	13.20	16.25	25.69 G
15		0.0065	0.053	0.129	0.205	6.01
		0.0213	0.102	0.168	0.196	3.35

Table 20 cont., Standard Deviation of Bed & Side Material

Canal No.	Distance from bank	Size in mm Corresponding to % Passing d_{15}**	d_{50}	d_{75}	d_{85}	$=\frac{\frac{d_{85}+d_{50}}{d_{50}+d_{15}}}{2}$
15 cont.		0.45	0.630	0.790	0.891	1.40
		0.394	0.567	0.770	0.918	1.53
		0.320	0.531	0.745	0.900	1.68
		0.079	0.572	0.930	1.340	4.79
		0.0125	0.058	0.131	0.186	3.92
		0.0176	0.082	0.104	0.131	3.13
16	2'	0.0291	0.077	0.098	0.112	2.05
	4'	0.051	0.175	0.415	0.630	3.51
	7'	0.051	0.172	0.392	0.608	3.46
	10'	0.040	0.090	0.123	0.146	1.93
	12'	0.025	0.072	0.090	0.106	2.17
17	1'	0.037	0.084	0.104	0.118	1.84
	4'	0.040	0.090	0.121	0.142	1.91
	(℄)6½'	0.053	0.216	0.383	0.503	3.21
	9'	0.051	0.109	0.181	0.341	2.63
	12'	0.041	0.118	0.265	0.457	3.37
18	2'	0.031	0.275	0.348	0.380	5.12
	4'	0.037	0.101	0.146	0.181	2.26
	6'	0.098	0.410	0.715	0.832	3.11
	8'	0.025	0.177	0.420	0.930	6.17
	10'	0.042	0.089	0.121	0.143	1.86
19	4'	0.0465	0.230	0.366	0.435	3.42
	7'	0.077	0.331	0.513	0.630	3.10
	14'	0.263	0.745	1.250	1.790	2.66
	℄ +	0.400	0.540	0.673	0.750	1.37
	21'	0.319	0.860	1.640	2.400	2.74
	24'	0.100	0.279	0.505	0.654	2.58
20	2'	0.0166	0.035	0.064	0.074	2.12
	5'	0.0144	0.045	0.054	0.043	2.04
	10'	0.0134	0.034	0.071	0.084	2.50
	15'	0.0119	0.039	0.041	0.174	4.02
	20'	0.0133	0.034	0.081	0.094	2.65
	25'	0.0115	0.030	0.050	0.068	2.43
	28'	0.0137	0.036	0.057	0.039	1.85
21	2'	0.015	0.034	0.058	0.065	2.09
	5'	0.015	0.034	0.065	0.060	2.01
	10'	0.0153	0.039	0.077	0.158	3.29
	15'	0.0141	0.035	0.065	0.074	2.30
	18'	0.0114	0.033	0.052	0.078	2.63
22	10'	0.0393	0.170	0.330	0.395	3.32
	20'	0.227	0.443	0.660	0.810	1.89
	25'	0.235	0.580	0.980	1.450	2.48
	30'	0.365	0.700	0.920	1.110	1.75
	40'	0.232	0.580	1.520	2.870	3.72
	45'	0.0525	0.205	0.640	1.150	4.76

Table 20 cont., Standard Deviation of Bed & Side Material

Canal No.	Distance from bank	Size in mm Corresponding to % Passing d_{15}**	d_{50}	d_{75}	d_{85}	$=\frac{\frac{d_{85}}{d_{50}}+\frac{d_{50}}{d_{15}}}{2}$
23	3'	0.180	0.369	0.660	1.08	2.49
	15'	0.179	0.283	0.458	0.604	1.66
	25'	0.224	0.390	0.615	0.855	1.96
	35'	0.244	0.520	0.980	1.510	2.51
	45'	0.264	0.532	0.830	1.050	1.99
	55'	0.223	0.425	0.660	0.858	1.96
	66'	0.073	0.271	0.640	0.995	3.69
24	2'	0.028	0.086	0.138	0.195	2.67
	5'	0.026	0.086	0.139	0.220	2.93
	10'	0.154	0.239	0.337	0.443	1.70
	15'	0.171	0.322	0.535	0.727	2.07
	20'	0.156	0.250	0.365	0.472	1.74
	25'	0.108	0.173	0.269	0.334	1.76
	27'	0.0247	0.031	0.109	0.149	3.02

** d_{15} = Size for which 15% passed and etc.

* = Based on one large sample.

G = Gravel

\+ = Taken from dune near ℄.

Table 21, Size Analysis of Bed & Side Material Based on V. A. Tube

Canal No. 4

Distance from S. Bank = 2'		Distance from S. Bank = 8'		Distance from S. Bank = 16'		Distance from S. Bank = 22'		Distance from S. Bank = 28'		Distance from S. Bank = 36'		Distance from S. Bank = 42'	
Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer
2.000	----	2.000	---	2.000	100	2.000	100	2.000	---	2.000	---	2.000	---
1.000	100	1.000	100	1.000	98	1.000	99	1.000	---	1.000	100	1.000	100
0.500	99	0.500	99	0.500	94	0.500	92	0.500	100	0.500	98	0.500	99
0.250	92	0.250	94	0.250	80	0.250	62	0.250	99	0.250	85	0.250	95
0.125	83	0.125	87	0.125	69	0.125	43	0.125	98	0.125	75	0.125	91
0.062	58	0.062	71	0.062	49	0.062	33	0.062	87	0.062	46	0.062	75
0.031	37	0.031	41	0.031	29	0.031	22	0.031	47	0.031	25	0.031	40
0.016	25	0.016	26	0.016	18	0.016	15	0.016	24	0.016	17	0.016	25
0.008	18	0.008	19	0.008	13	0.008	11	0.008	16	0.008	13	0.008	17
0.004	13	0.004	14	0.004	9	0.004	9	0.004	10	0.004	10	0.004	11
0.002	9	0.002	10	0.002	6	0.002	6	0.002	7	0.002	8	0.002	7

Table 21 cont., Size Analysis of Bed & Side Material Based on V. A. Tube

Canal No. 11

Distance from N. Bank=2.0' Dia. in mm	% finer	Distance from N. Bank=10.0' Dia. in mm	% finer	Distance from N. Bank=20.0' Dia. in mm	% finer	Distance from N. Bank=30.0' Dia. in mm	% finer	Distance from N. Bank =40' Dia. in mm	% finer	Distance from N. Bank =41' Dia. in mm	% finer
4.000	99	4.000	100	4.000	99	4.000	99	4.000	100	4.000	100
2.000	97	2.000	93	2.000	89	2.000	92	2.000	94	2.000	99
1.000	88	1.000	79	1.000	71	1.000	73	1.000	82	1.000	99
0.500	76	0.500	51	0.500	39	0.500	49	0.500	63	0.500	98
0.250	56	0.250	6	0.250	10	0.250	6	0.250	30	0.250	93
0.125	42	0.125	1	0.125	1	0.125	1	0.125	17	0.125	84
0.062	27	0.062	1	0.062	0	0.062	0	0.062	5	0.062	36
0.031	16	0.031	1					0.031	4	0.031	26
0.016	12	0.016	1					0.016	3	0.016	20
0.008	11	0.008	1					0.008	2	0.008	16
0.004	9	0.004	1					0.004	2	0.004	12
0.002	7	0.002	0					0.002	1	0.002	9

Table 21 cont., Size Analysis of Bed & Side Material Based on V. A. Tube

Canal No. 19

Distance from W. Bank = 4'		Distance from W. Bank = 7'		Distance from W. Bank = 14'		Distance from W. Bank = 21'		Distance from W. Bank = 24'		Centerline from Dune	
Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer	Dia. in mm	% finer
2.000	100	2.000	100	4.000	98	4.000	96	4.000	100	2.000	100
1.000	99	1.000	98	2.000	85	2.000	76	2.000	99	1.000	95
0.500	95	0.500	85	1.000	56	1.000	49	1.000	96	0.500	71
0.250	63	0.250	46	0.500	38	0.500	31	0.500	86	0.250	2
0.125	41	0.125	25	0.250	18	0.250	11	0.250	53	0.125	0
0.062	20	0.062	12	0.125	4	0.125	2	0.125	26		
0.031	14	0.031	8	0.062	2	0.062	1	0.062	9		
0.016	10	0.016	6	0.031	2	0.031	1	0.031	7		
0.008	8	0.008	5	0.016	2	0.016	1	0.016	6		
0.004	6	0.004	4	0.008	1	0.008	1	0.008	4		
0.002	4	0.002	4	0.004	1	0.004	1	0.004	4		
				0.002	1	0.002	1	0.002	4		

Table 22, Standard Deviation of Bed & Side Material
Based on V. A. Tube

Canal No.	Distance from Bank	d_{15} V.A. Tube	d_{85} V.A. Tube	d_{50} V.A. Tube	$\frac{\frac{d_{85}}{d_{50}}+\frac{d_{50}}{d_{15}}}{2}$
4	2'	.0053	.142	.0475	5.97
	8'	.0045	.112	.0375	6.66
	16'	.0108	.300	.064	5.30
	22'	.0160	.395	.1059	6.86
	28'	.0071	.058	.032	3.15
	36'	.012	.250	.067	4.65
	42'	.0064	.091	.0375	4.14
11	2'	.027	.810	.185	5.61
	10'	.315	1.26	.495	2.06
	20'	.295	1.65	.630	2.38
	30'	.317	1.45	.510	2.22
	40'	.114	1.15	.380	3.17
	44'	.007	.131	.074	6.17
19	4'	.0367	.365	.168	3.37
	7'	.0728	.500	.266	2.76
	14'	.228	2.000	.800	3.00
	21'	.361	2.50	1.03	2.69
	24'	.083	.485	.233	2.44
	℄ from dume	.325	.675	.430	1.45

Table 23, Summary of Mean Sizes & Standard Deviations
Obtained by the Two Methods of Analysis

Dist. from bank	Mean Dia. (mm) sieve & hydr.	Mean Dia. (mm) V.A. Tube	% Diff. in mean dia.	Sieve & hydr.	V.A. Tube	% Diff.
		Canal No. 4				
2'	.056	.0475	-15.2	3.16	5.97	-47.0
8'	.046	.0375	-18.5	3.18	6.66	-52.3
16'	.066	.064	- 3.03	3.70	5.30	-30.0
22'	.140	.1059	-23.3	4.63	6.86	-32.5
28'	.034	.032	-5.9	2.17	3.15	-31.0
36'	.094	.067	-28.7	3.29	4.65	-29.3
42'	.046	.0375	-18.5	2.94	4.14	-29.0
		Canal No. 11				
2'	0.22	.185	-15.9	4.82	5.61	-14.1
10'	0.56	.495	-11.6	1.72	2.06	-16.5
20'	0.60	.630	+ 5.0	1.80	2.38	-24.4
30'	0.75	.510	-32.0	2.45	2.22	+10.4
40'	0.45	.380	-15.6	2.31	3.17	-27.1
44'	0.072	.074	-2.8	3.30	6.17	-46.5
		Canal No. 19				
4'	0.21	.168	-20.0	3.42	3.37	+1.46
7'	0.335	.266	-21.2	3.10	2.76	+12.3
14'	0.77	.800	+3.9	2.66	3.00	-11.3
21'	0.87	1.03	+18.4	1.37	2.69	-49.0
24'	0.290	.233	-19.7	2.74	2.44	+10.9
℄ from dune	0.54	.430	-20.4	2.58	1.45	+43.8

Table 24, Computation of Suspended Sediment Load

Canal No. 5

Distance from bank	Depth	Sample Depth	Conc. PPM	Vel @ Pt.	PPMxV	A	A(PPMxV)ave
6	5.2	1.0	86	1.82	156.5		
		2.1	90	1.96	176.4		
		3.1	95	1.89	179.5		
		4.2	99	1.16	115.0		
		4.8	92	1.16	106.7		
					734.1		
					ave=146.8	38.5	5,650
14	6.0	1.2	89	2.39	212.5		
		2.4	80	2.55	204.0		
		3.6	97	2.55	247.4		
		4.8	115	2.22	255.0		
		5.4	130	1.99	258.5		
		5.6	133	1.92	255.3		
					1432.7		
					ave=238.8	33.0	7,880
18	6.0	1.2	75	2.55	196.0		
		2.4	86	2.68	230.5		
		3.6	111	2.65	294.0		
		4.8	128	2.45	313.5		
		5.4	139	2.25	313.0		
		5.6	172	2.20	378.0		
					1725.0		
					ave=282.5	22.4	6,440

Table 24 cont., Computation of Suspended Sediment Load Canal No. 5

Distance from bank	Depth	Sample Depth	Conc. PPM	Vel @ Pt.	PPMxV	A	A(PPMxV)ave
22	6.0	1.2	85	2.65	225.0		
		2.4	98	2.58	253.0		
		3.6	125	2.58	322.5		
		4.8	131	2.35	307.5		
		5.4	135	2.19	295.5		
		5.6	185	2.06	381.0		
					1784.5		
					ave= 297.4	22.4	6,670
26	6.0	1.2	81	2.65	214.5		
		2.4	85	2.65	225.0		
		3.6	120	2.62	314.5		
		4.8	132	2.49	328.5		
		5.4	139	2.35	326.5		
		5.6	203	2.12	431.0		
					1840.0		
					ave= 306.6	33.6	10,300
34	6.0	1.2	88	2.39	210.5		
		2.4	105	2.39	251.0		
		3.6	131	2.35	308.0		
		4.8	153	2.16	330.5		
		5.4	181	2.05	371.0		
		5.6	201	2.02	406.0		
					1877.0		
					ave= 312.8	43.6	13,620
42	4.3	0.9	105	1.73	181.7		
		1.7	102	1.86	189.8		
		2.6	109	1.86	203.0		
		3.4	124	1.63	202.0		
		3.9	136	1.59	216.0		
					992.5		5,620
		Tons/day	151.0	ave. 119.3	ave= 198.5	28.3	=56,180

Table 25. Summary of Suspended & Total Sediment Loads

Canal No.	Total Sediment Load * PPM Average	Q	Constant	Tons/Day	Suspended Sediment Load Tons/Day
1	448.0	177.0	0.00269	213.5	47.1
2	--	--	--	--	319.5
3	115.0	1031.0	0.00269	320.0	103.2
4	370.0	445.0	0.00269	443.0	156.8
5	--	--	--	--	151.0
6	--	--	--	--	--
7	254.0	146.26	0.00269	100.0	20.05
8	--	--	--	--	22.90
9	--	--	--	--	38.70
10	52.0	170.8	0.00269	23.8	40.30
11	--	--	--	--	51.30
12	99.1	883.0	0.00269	235.0	72.1
13	--	--	--	--	102.5
14	185.0	1039.0	0.00269	516.0	157.2
15	--	--	--	--	90.3
16	249.0	55.0	0.00269	36.8	7.8
17	--	--	--	--	5.6
18	406.	43.0	0.00269	47.0	1.7
19	123.	198.6	0.00269	65.6	44.3
20	131.	370.0	0.00269	130.5	88.8
21	44.0	113.0	0.00269	13.38	16.8
22	100.0	226.9	0.00269	61.0	55.8
23	--	--	--	--	97.3
24	--	--	--	--	45.9

* Only 13 Canals were sampled for total load.

TABLE 26, TRACTIVE FORCE COMPUTATIONS

S = .00033
T = 79 F
K = 0.65

Canal 1

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
4	2.6	2.2	1.8	0.4	0.104	0.054	0.166
7	2.8	2.50	2.27	0.23	0.034	0.058	0.172
10	3.0	2.45	2.58	0.13	0.011	0.062	0.179
13	3.04	2.65	2.83	0.18	0.021	0.063	0.180
16	3.0	2.60	2.80	0.20	0.026	0.062	0.179
19	3.0	2.68	2.87	0.19	0.023	0.062	0.179
22	2.9	2.31	2.50	0.19	0.023	0.060	0.175
25	2.6	2.10	1.85	0.25	0.0406	0.054	0.166
26	2.4	1.92	1.70	0.22	0.0314	0.050	0.160
27	2.05	1.70	1.50	0.20	0.0260	0.042	0.148

S = .000132
T = 68.68 F
K = 0.65

Canal 2

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	2.35	1.60	1.42	0.18	0.021	0.0193	0.099
6	4.2	2.12	1.90	0.22	0.0314	0.0346	0.1335
10	5.0	2.29	1.07	0.22	0.0315	0.0412	0.1458
15	5.2	2.58	2.39	0.19	0.0234	0.0427	0.1487
20	5.8	2.48	2.28	0.20	0.0260	0.0477	0.1570
25	6.4	2.22	2.00	0.22	0.0315	0.0526	0.1650
30	6.5	2.38	1.99	0.39	0.0989	0.0535	0.1660
35	6.5	2.42	2.24	0.18	0.0211	0.0535	0.1660
40	6.2	2.18	1.95	0.23	0.0344	0.0510	0.1622
45	5.7	2.21	2.00	0.21	0.0286	0.0469	0.1556
50	5.3	2.21	2.00	0.21	0.0286	0.0436	0.1500
55	4.1	1.87	1.62	0.25	0.0450	0.0338	0.1320
57.5	3.0	1.61	1.40	0.21	0.027	0.0247	0.1128
60	1.6	2.05	1.72	0.33	0.071	0.0132	0.0824

S = .00008
T = 71.31 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 3

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1	2.3	0.64	0.50	0.14	0.0129	0.011	0.077
2	4.6	0.59	0.40	0.19	0.0234	0.023	0.109
6	7.0	1.02	0.83	0.19	0.0234	0.035	0.134
10	7.7	1.2	1.0	0.20	0.0260	0.038	0.141
16	8.3	1.69	1.52	0.17	0.0188	0.041	0.146
22	8.7	1.53	1.33	0.20	0.0260	0.043	0.150
28	8.5	1.61	1.40	0.21	0.0286	0.042	0.148
34	8.5	1,50	1.30	0.20	0.0260	0.042	0.148
40	8.4	1.58	1.35	0.23	0.0344	0.042	0.147
46	8.3	1.65	1.49	0.16	0.0166	0.041	0.146
52	8.4	1.56	1.32	0.24	0.0390	0.042	0.147
58	8.4	1.56	1.39	0.17	0.0188	0.042	0.147
64	8.3	1.46	1.29	0.17	0.0188	0.041	0.146
70	7.9	1.12	0.90	0.22	0.0314	0.039	0.143
74	6.5	1.09	0.88	0.21	0.0287	0.032	0.130
78	4.1	0.93	0.82	0.11	0.008	0.020	0.103

S = .000063
T = 73.6 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 4

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1	1.85	1.18	1.09	0.09	0.005	0.007	0.062
2	2.40	1.32	1.20	0.12	0.009	0.009	0.070
6	4.50	1.44	1.15	0.29	0.055	0.018	0.096
10	5.50	1.60	1.32	0.28	0.051	0.022	0.106
14	5.90	1.95	1.75	0.20	0.026	0.023	0.110
18	6.20	2.00	1.72	0.28	0.047	0.024	0.112
22	6.20	1.91	1.62	0.29	0.055	0.024	0.112
26	6.20	1.96	1.75	0.21	0.029	0.024	0.112
30	6.10	1.74	1.55	0.19	0.023	0.024	0.112
34	6.00	1.60	1.33	0.27	0.047	0.024	0.111
38	5.50	1.37	1.14	0.23	0.0344	0.022	0.106
42	4.00	1.22	1.00	0.22	0.0314	0.016	0.090
S = .000074							
T = 71.8 F			Canal 5				
K = 0.65							
1		0.73	0.30	0.43	0.120		
2	3.7	0.87	0.43	0.44	0.126	0.017	0.093
6	5.2	0.90	0.46	0.44	0.126	0.024	0.111
10	5.7	1.48	1.02	0.46	0.138	0.026	0.116
14	6.0	1.11	0.90	0.21	0.029	0.028	0.119
18	6.0	2.34	2.19	0.15	0.015	0.028	0.119
22	6.0	2.25	2.05	0.20	0.026	0.028	0.119
26	6.0	2.37	2.23	0.14	0.013	0.028	0.119
30	6.0	2.25	2.10	0.15	0.015	0.028	0.119
34	6.0	2.11	2.00	0.11	0.008	0.028	0.119
38	5.4	1.84	1.64	0.20	0.026	0.025	0.113
42	4.3	1.57	1.33	0.24	0.0374	0.020	0.101
45	2.9	1.41	1.20	0.21	0.0286	0.013	0.089

S = .00008
T = 71 F
K = 0.65

TABLE 26, TRACTIVE **FORCE** COMPUTATIONS

Canal 6

Dist. from bank	Depth	V_2 @ $Y_2=0.8$	V_1 @ $Y_1=0.4$	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
4	1.2	1.17	0.73	0.44	0.1260	0.0060	0.0557
8	2.9	1.31	1.09	0.22	0.0314	0.0145	0.0865
12	4.8	1.32	1.10	0.22	0.0314	0.0240	0.1113
16	6.4	1.41	1.06	0.35	0.0800	0.0319	0.1286
20	7.7	1.69	1.49	0.20	0.0260	0.0384	0.1410
30	7.4	1.69	1.51	0.18	0.0211	0.0369	0.1382
35	8.3	1.47	1.23	0.24	0.0390	0.0414	0.1463
40	8.3	1.47	1.23	0.24	0.0390	0.0414	0.1463
50	7.9	1.29	1.04	0.25	0.0407	0.0394	0.1428
55	7.5	1.60	1.41	0.19	0.0234	0.0374	0.1392
60	7.7	1.50	1.34	0.16	0.0166	0.0384	0.1410
65	7.9	1.52	1.38	0.14	0.0128	0.0394	0.1428
70	7.5	1.33	1.16	0.17	0.0187	0.0374	0.1392
75	5.7	1.20	1.04	0.16	0.0167	0.0284	0.1213
80	3.3	1.11	0.85	0.26	0.0439	0.0165	0.0923

$S = .000135$
$T = 76$ F
$K = 0.65$

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 7

Dist. from bank	Depth	V_2 @ $Y_2=0.8$	V_1 @ $Y_1=0.4$	$V_2 - V_1$	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	2.60	1.03	0.79	0.24	0.0374	0.0220	0.107
4	2.90	1.36	1.10	0.26	0.0437	0.0244	0.112
6	3.40	1.33	1.00	0.33	0.0709	0.0286	0.122
8	3.50	1.26	1.10	0.16	0.0166	0.0295	0.124
10	3.55	1.28	1.00	0.28	0.0473	0.0299	0.125
12	3.50	1.37	1.18	0.19	0.0234	0.0295	0.124
14	3.50	1.49	1.30	0.19	0.0234	0.0295	0.124
16	3.55	1.40	1.18	0.22	0.0315	0.0299	0.125
18	3.50	1.37	1.13	0.24	0.0390	0.0295	0.124
20	3.50	1.46	1.26	0.20	0.0260	0.0295	0.124
22	3.50	1.42	1.26	0.16	0.0166	0.0295	0.124
24	3.50	1.41	1.23	0.18	0.0211	0.0295	0.124
26	3.55	1.35	1.16	0.19	0.0234	0.0299	0.125
28	3.50	1.28	1.10	0.18	0.0211	0.0295	0.124
30	3.35	1.25	1.11	0.14	0.0129	0.0282	0.121
32	2.80	1.20	1.05	0.15	0.0146	0.0260	0.111

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 8

S = .00029
T = 79.9 F
K = 0.65

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	T_o=K$(V_2-V_1)^2$	T_o=γDS	U_*=$(gDS)^{1/2}$
2	2.00	1.56	1.44	0.12	0.0094	0.036	0.137
4	2.70	1.50	1.25	0.25	0.0406	0.049	0.159
8	2.60	1.81	1.61	0.20	0.0260	0.047	0.156
12	2.50	1.80	1.71	0.09	0.0053	0.045	0.153
16	2.50	1.63	1.49	0.14	0.0128	0.045	0.153
20	2.20	1.51	1.10	0.41	0.1092	0.040	0.144
24	2.40	1.65	1.60	0.05	0.0016	0.043	0.150
28	2.45	1.74	1.62	0.12	0.0094	0.044	0.152
32	2.30	1.78	1.61	0.17	0.0188	0.042	0.147
36	2.50	1.71	1.53	0.18	0.0211	0.045	0.153
40	2.60	1.58	1.40	0.18	0.0211	0.047	0.156
44	2.80	1.18	0.90	0.28	0.0510	0.051	0.162
48	1.80	1.29	1.02	0.27	0.0474	0.033	0.130

Canal 9

S = .000191
T = 76.95 F
K = 0.65

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	T_o=K$(V_2-V_1)^2$	T_o=γDS	U_*=$(gDS)^{1/2}$
2	1.90	0.75	0.53	0.22	0.0314	0.0226	0.1083
4	2.85	0.79	0.59	0.20	0.0260	0.0340	0.1328
8	3.00	1.18	1.00	0.18	0.0211	0.0358	0.1363
12	3.00	1.38	1.23	0.15	0.0146	0.0358	0.1363
16	3.10	1.42	1.24	0.18	0.0211	0.0369	0.1385
20	3.00	1.48	1.30	0.18	0.0211	0.0358	0.1363
24	2.90	1.45	1.25	0.20	0.0260	0.0346	0.1340
28	2.85	1.40	1.15	0.25	0.0407	0.0339	0.1328
32	2.75	1.55	1.34	0.21	0.0286	0.0328	0.1305
36	2.80	1.46	1.24	0.22	0.0315	0.0334	0.1317
40	2.45	1.22	1.07	0.15	0.0146	0.0292	0.1231
42	1.50	1.04	0.83	0.21	0.0286	0.0179	0.0963

S = .0002821
T = 74.70 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 10

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	1.80	1.03	0.93	0.10	0.0065	0.031	0.128
3	2.25	1.26	1.16	0.10	0.0065	0.039	0.143
4	2.50	1.57	1.50	0.07	0.0023	0.044	0.151
8	2.80	1.87	1.72	0.15	0.0146	0.049	0.159
12	2.90	1.91	1.80	0.11	0.0079	0.051	0.162
16	3.00	1.90	1.79	0.11	0.0079	0.053	0.165
20	2.80	1.91	1.79	0.12	0.0094	0.049	0.159
24	3.00	1.77	1.57	0.20	0.0260	0.053	0.165
28	2.90	1.80	1.56	0.24	0.0390	0.051	0.162
32	3.00	1.69	1.48	0.21	0.0286	0.053	0.165
36	2.50	1.21	1.12	0.09	0.0053	0.049	0.151
37	2.05	0.93	0.82	0.11	0.0079	0.036	0.136
38	1.70	0.79	0.66	0.13	0.0109	0.030	0.124
S = .0002684							
T = 74.5 F			Canal 11				
K = 0.65							
2	2.2	1.69	1.49	0.20	0.0260	0.037	0.138
5	2.8	1.84	1.68	0.16	0.0166	0.047	0.156
10	3.0	1.98	1.80	0.18	0.0210	0.050	0.161
15	2.9	1.90	1.79	0.11	0.0079	0.049	0.158
20	2.9	1.70	1.56	0.14	0.0127	0.049	0.158
25	3.0	1.74	1.47	0.27	0.0473	0.050	0.161
30	2.5	1.49	1.15	0.34	0.0751	0.042	0.147
35	2.6	1.64	1.47	0.17	0.0188	0.044	0.150
40	2.4	1.78	1.60	0.18	0.0210	0.040	0.144
44	1.9	0.87	0.57	0.30	0.0585	0.032	0.128
45	0.7	0.86	0.70	0.16	0.0167	0.012	0.078

TABLE 26, TRACTIVE FORCE COMPUTATIONS

S= .000181
T = 58.6 F
K = 0.65

Canal 12

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	2.0	0.81	0.71	0.10	0.0065	0.023	0.108
5	4.0	1.58	1.41	0.17	0.0187	0.045	0.153
10	5.9	1.60	1.43	0.17	0.0187	0.067	0.186
15	7.1	1.86	1.70	0.16	0.0167	0.080	0.204
20	7.6	2.20	2.00	0.20	0.0260	0.086	0.211
25	8.3	2.18	2.00	0.18	0.0211	0.094	0.220
30	8.5	2.08	1.80	0.28	0.0473	0.096	0.223
35	8.3	2.22	1.94	0.28	0.0473	0.094	0.220
40	8.1	2.20	1.95	0.25	0.0407	0.092	0.218
45	7.8	2.05	1.78	0.27	0.0473	0.088	0.214
50	7.2	1.70	1.42	0.28	0.0510	0.081	0.205
55	5.1	1.11	0.76	0.35	0.0796	0.058	0.173
58	3.0	---	---	---	-----	0.034	0.133

S = .000166
T = 59.3 F
K = 0.65

Canal 13

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
3	2.8	1.73	1.45	0.28	0.0510	0.029	0.122
6	4.0	1.98	1.71	0.27	0.0474	0.041	0.147
12	5.5	2.23	2.00	0.23	0.0344	0.057	0.172
18	5.7	2.60	2.40	0.20	0.0260	0.059	0.175
24	5.8	2.52	2.33	0.19	0.0234	0.060	0.176
30	5.9	2.52	2.32	0.20	0.0260	0.061	0.178
36	5.9	2.50	2.25	0.25	0.0407	0.061	0.178
42	5.8	2.50	2.30	0.20	0.0260	0.060	0.176
48	5.5	2.44	2.25	0.19	0.0234	0.057	0.172
54	3.9	1.81	1.53	0.28	0.0510	0.040	0.144
57	2.6	1.55	1.30	0.25	0.0406	0.027	0.118

$S = .00012$
$T = 71.3$ F
$K = 0.65$

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 14

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1.0	1.4	1.37	1.17	0.20	0.0260	0.015	0.074
2.5	3.5	1.43	1.11	0.32	0.0660	0.026	0.117
6.0	5.8	1.61	1.34	0.27	0.0474	0.043	0.150
10.0	7.7	1.80	1.54	0.26	0.0437	0.058	0.173
15.0	8.6	2.13	1.87	0.26	0.0439	0.064	0.183
20.0	8.6	2.08	1.78	0.30	0.0585	0.064	0.183
25.0	8.8	1.98	1.59	0.39	0.0989	0.066	0.185
30.0	9.0	2.04	1.70	0.34	0.0751	0.067	0.187
35.0	8.6	2.24	2.00	0.24	0.0390	0.064	0.183
40.0	8.5	2.24	2.00	0.24	0.0390	0.064	0.182
45.0	8.2	2.09	1.88	0.21	0.0286	0.061	0.179
50.0	5.8	1.70	1.32	0.38	0.0938	0.043	0.150
55.0	2.9	1.70	1.58	0.12	0.0094	0.022	0.106

S = .000369
T = 63 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 15

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1	1.60	1.87	1.47	0.40	0.104	0.029	0.138
2	3.25	1.42	0.90	0.52	0.178	0.075	0.197
4	4.00	1.67	1.29	0.38	0.094	0.092	0.218
6	4.30	1.90	1.64	0.26	0.044	0.099	0.226
10	4.60	2.40	2.10	0.30	0.059	0.106	0.234
14	4.90	2.43	2.06	0.37	0.089	0.113	0.242
18	4.80	2.48	2.11	0.37	0.089	0.110	0.239
22	5.00	2.46	2.13	0.33	0.071	0.115	0.242
26	5.40	2.16	1.58	0.58	0.219	0.124	0.253
30	5.20	2.43	2.10	0.33	0.071	0.120	0.249
34	4.90	2.47	2.28	0.19	0.023	0.113	0.242
38	5.00	2.48	2.08	0.40	0.104	0.115	0.242
42	4.90	2.16	1.83	0.33	0.071	0.120	0.242
46	4.25	1.84	1.53	0.31	0.062	0.098	0.223
49	3.40	1.60	1.20	0.40	0.104	0.078	0.201
50	2.40					0.055	0.169

TABLE 26, TRACTIVE FORCE COMPUTATIONS

$S = .0002533$
$T = 67.65$ F
$K = 0.65$

Canal 16

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1	1.85	1.83	1.71	0.12	0.0094	0.029	0.123
2	2.50	2.03	1.80	0.23	0.0344	0.040	0.143
3	2.65	2.07	1.82	0.25	0.0407	0.042	0.147
4	2.60	2.02	1.83	0.19	0.0234	0.041	0.146
6	2.65	2.20	2.02	0.18	0.0211	0.042	0.147
8	2.65	2.12	1.90	0.22	0.0315	0.042	0.147
10	2.50	1.82	1.53	0.29	0.0546	0.040	0.143
11	2.20	1.77	1.55	0.22	0.0314	0.035	0.134
12	1.50	1.60	1.40	0.20	0.0260	0.024	0.111
13	0.90	1.18	1.09	0.09	0.0053	0.014	0.086

$S = .000387$
$T = 69.95$ F
$K = 0.65$

Canal 17

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	2.50	1.47	1.28	0.19	0.0234	0.060	0.177
4	3.00	1.91	1.56	0.35	0.0796	0.022	0.194
6	3.20	2.06	1.70	0.36	0.0843	0.077	0.205
8	3.05	2.06	1.78	0.28	0.0473	0.074	0.196
10	2.80	1.81	1.63	0.18	0.0210	0.068	0.187
12	1.60	1.52	1.36	0.16	0.0167	0.039	0.142

S = .000294
T = 69.9 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 18

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1	1.50	1.49	1.25	0.24	0.037	0.028	0.119
2	2.20	1.60	1.40	0.20	0.026	0.040	0.144
3	2.50	1.68	1.44	0.24	0.037	0.046	0.154
4	2.70	1.71	1.50	0.21	0.029	0.050	0.160
6	2.80	1.94	1.76	0.18	0.021	0.053	0.163
8	2.70	1.85	1.65	0.20	0.026	0.050	0.160
9	2.55	1.69	1.52	0.17	0.019	0.047	0.155
10	2.40	1.37	1.20	0.17	0.019	0.044	0.151
11	2.15	1.28	1.10	0.18	0.021	0.039	0.143

S = .00030175
T = 73.4 F
K = 0.65

Canal 19

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1.0	2.0	0.72	0.52	0.22	0.031	0.038	0.140
2.0	2.5	0.75	0.51	0.24	0.037	0.047	0.156
4.0	2.8	1.75	1.52	0.23	0.034	0.053	0.161
7.0	3.1	2.22	2.01	0.21	0.029	0.058	0.174
10.5	3.4	2.77	2.61	0.16	0.017	0.070	0.182
14.0	3.4	2.99	2.82	0.17	0.019	0.064	0.182
17.5	3.4	2.84	2.62	0.22	0.032	0.064	0.182
21.0	3.4	2.76	2.54	0.22	0.032	0.064	0.182
24.0	3.2	2.42	2.18	0.24	0.039	0.060	0.177
26.0	2.8	1.10	0.94	0.16	0.017	0.053	0.161
27.0	2.5	0.88	0.71	0.17	0.018	0.047	0.156

S = .0001136
T = 78.3 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 20

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
2	2.00	1.34	1.23	0.11	0.008	0.014	0.086
5	4.00	1.85	1.70	0.15	0.015	0.028	0.121
10	5.30	2.07	1.92	0.15	0.015	0.038	0.139
15	5.30	2.02	1.85	0.17	0.019	0.038	0.139
20	5.15	1.88	1.66	0.22	0.032	0.037	0.137
25	3.60	1.71	1.55	0.16	0.017	0.026	0.115
28	2.00	1.42	1.30	0.12	0.009	0.014	0.086

S = .0001102
T = 78.4 F
K = 0.65

Canal 21

2	1.7	1.75	1.00	0.15	0.015	0.012	0.078
4	2.7	2.01	1.83	0.18	0.021	0.019	0.098
6	3.8	2.04	1.87	0.17	0.019	0.026	0.116
8	4.2	2.19	2.02	0.17	0.019	0.029	0.122
10	4.4	2.30	2.10	0.20	0.026	0.030	0.125
12	4.4	2.37	2.17	0.20	0.026	0.030	0.125
14	3.4	2.10	1.89	0.21	0.029	0.023	0.110
16	2.8	1.70	1.52	0.18	0.021	0.019	0.100
18	1.5	1.39	1.11	0.28	0.051	0.011	0.073

TABLE 26, TRACTIVE FORCE COMPUTATIONS

S = .000218
T = 81.3 F
K = 0.65

Canal 22

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
3	1.60	0.75	0.40	0.35	0.080	0.022	0.106
4	2.18	1.20	1.00	0.20	0.026	0.030	0.124
6	2.80	1.23	1.03	0.20	0.026	0.038	0.141
10	3.20	1.60	1.40	0.20	0.026	0.044	0.150
15	3.40	1.63	1.39	0.24	0.039	0.046	0.155
20	3.20	1.67	1.44	0.23	0.034	0.044	0.150
25	3.20	1.69	1.45	0.24	0.039	0.044	0.150
30	2.80	1.91	1.63	0.28	0.047	0.038	0.141
35	3.30	1.74	1.54	0.20	0.026	0.045	0.153
40	3.20	1.60	1.38	0.22	0.032	0.044	0.150
45	2.70	0.90	0.64	0.26	0.044	0.037	0.138
47	2.30	0.83	0.47	0.36	0.083	0.031	0.127

S = .000388
T = 81.9 F
L = 0.65

Canal 23

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
3	2.6	1.49	1.32	0.17	0.019	0.063	0.181
7	2.5	2.10	1.93	0.17	0.019	0.061	0.177
15	2.7	1.79	1.65	0.14	0.013	0.065	0.184
25	3.0	1.76	1.44	0.32	0.067	0.073	0.194
35	3.3	1.80	1.61	0.19	0.023	0.080	0.218
45	2.8	1.82	1.57	0.25	0.041	0.068	0.187
55	3.0	1.88	1.58	0.30	0.059	0.073	0.194
62	2.9	1.70	1.49	0.21	0.029	0.070	0.191
66	2.7	1.60	1.38	0.22	0.032	0.065	0.184
68	2.4	1.53	1.32	0.21	0.029	0.058	0.173

S = .000216
T = 80.1 F
K = 0.65

TABLE 26, TRACTIVE FORCE COMPUTATIONS

Canal 24

Dist. from bank	Depth	V_2 @ Y_2=0.8	V_1 @ Y_1=0.4	V_2-V_1	$T_o=K(V_2-V_1)^2$	$T_o=\gamma DS$	$U_*=(gDS)^{1/2}$
1.0	1.9	0.81	0.50	0.31	0.062	0.025	0.115
2.0	2.4	1.04	0.77	0.27	0.048	0.032	0.129
5.0	3.6	1.56	1.33	0.23	0.034	0.049	0.159
8.0	3.6	2.05	1.90	0.15	0.015	0.049	0.159
10.0	3.7	1.89	1.56	0.33	0.071	0.050	0.161
15.0	3.8	2.06	1.85	0.21	0.029	0.051	0.163
20.0	3.8	1.86	1.58	0.28	0.047	0.051	0.163
22.5	3.5	1.92	1.66	0.26	0.044	0.047	0.156
25.0	3.7	1.85	1.62	0.23	0.034	0.050	0.161
27.5	3.4	1.60	1.36	0.24	0.037	0.046	0.154
28.5	2.7	1.52	1.28	0.24	0.037	0.036	0.137

Table 27, Tractive Force Computations Based on Zero Momentum Transfer

Canal No.	Area A_1	Area A_2	A_2/A_1	$\tau = \gamma DS$ Bed	$\tau = \frac{A_2}{A_1} \gamma DS$
1	8.24	4.45	0.54	0.0620	.0335
2	33.5	23.1	0.69	0.0485	.0342
3	18.27	15.71	0.86	0.0420	.0361
4	33.07	18.82	0.57	0.0240	.0137
5	57.12	27.96	0.49	0.0280	.0137
6	19.35	16.25	0.84	0.0392	.0329
7	7.36	5.99	0.814	0.0297	.0252
8	6.30	4.16	0.66	0.0453	.0288
9	32.2	29.0	0.90	0.0349	.0314
10	8.00	7.01	0.88	0.0504	.0444
11	9.57	7.62	0.80	0.0460	.0368
12	66.05	32.94	0.50	0.0898	.0449
13	49.0	38.7	0.79	0.0600	.0474
14	39.09	26.10	0.67	0.0640	.0429
15	15.73	8.99	0.57	0.1160	.0661
16	7.95	3.59	0.45	0.0400	.0180
17	12.00	6.59	0.55	0.0726	.0400
18	7.00	2.56	0.36	0.0490	.0177
19	13.92	9.80	0.70	0.0605	.0424
20	12.08	7.00	0.58	0.0366	.0212
21	19.73	7.89	0.40	0.0298	.0119
22	8.35	7.19	0.86	0.0433	.0372
23	16.70	15.6	0.935	0.0685	.0640
24	9.64	6.30	0.66	0.0495	.0327

Table 28, Summary of Simons & Bender Data and Computed Parameters

Canal No.	Q	A	V	$S \times 10^3$	R	P	D	W_T	$W = \frac{A}{D}$
1	177.0	73.0	2.42	0.330	2.37	30.8	2.92	27.0	25.0
2	773.0	311.0	2.48	0.130	4.78	65.0	5.85	62.0	53.2
3	1031.0	602.9	1.71	0.058	6.70	90.0	8.29	80.0	72.8
4	445.0	231.6	1.92	0.063	4.66	49.6	6.01	44.0	38.5
5	510.0	242.6	2.10	0.074	4.63	52.2	5.81	47.0	41.8
6	950.0	531.3	1.79	0.058	6.36	83.5	7.66	86.0	69.4
7	146.3	107.5	1.36	0.135	2.83	38.0	3.51	34.0	30.6
8	191.0	120.7	1.58	0.290	2.20	54.8	2.63	53.0	45.9
9	160.0	114.8	1.39	0.190	2.47	46.4	2.93	44.0	39.2
10	170.8	102.1	1.67	0.237	2.46	41.5	2.91	39.5	35.2
11	198.0	117.7	1.68	0.268	2.43	48.4	2.81	46.0	41.9
12	883.0	391.1	2.26	0.181	6.01	65.0	7.88	60.0	49.6
13	751.0	292.3	2.57	0.166	4.64	63.2	5.73	60.0	51.1
14	1039.0	413.8	2.51	0.120	6.23	66.4	8.50	61.0	48.6
15	600.0	234.7	2.55	0.369	4.10	57.4	4.90	54.0	48.0
16	55.0	29.9	1.84	0.253	1.82	16.5	2.61	14.0	11.45
17	56.0	31.5	1.78	0.387	1.90	16.6	3.01	13.0	10.47
18	43.0	27.6	1.56	0.294	1.82	15.2	2.64	12.5	10.47
19	198.6	82.3	2.42	0.302	2.61	31.5	3.31	27.5	24.90
20	236.0	119.2	1.98	0.114	3.57	33.5	5.25	30.0	22.70
21	113.0	56.3	2.01	0.110	2.58	21.8	4.33	20.0	13.00
22	226.9	137.0	1.65	0.218	2.68	51.2	3.33	49.0	41.20
23	363.3	191.5	1.90	0.388	2.63	72.8	2.95	69.0	65.00
24	180.6	97.0	1.86	0.216	2.85	34.0	3.67	29.5	26.40

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	W_T/D	W/D	P/R	Water Temp. F^o	$VW \times 10^{-7}$	$b=V^2/D$	$s=V^3/W$	$U^*=\sqrt{gDS}$	$\frac{C}{\sqrt{g}}=\frac{V}{U^*}$	$R^2S \times 10^3$
1	9.24	8.57	13.00	79.0	0.644	2.020	0.5680	0.176	13.75	1.86
2	10.60	9.10	13.60	69.0	1.230	1.052	0.2860	0.157	15.80	2.98
3	9.65	8.79	13.44	72.0	1.210	0.353	0.0686	0.125	13.70	2.60
4	7.32	6.41	10.62	73.8	0.740	0.612	0.1840	0.110	17.45	1.37
5	8.10	7.19	11.28	73.0	0.870	0.760	0.2210	0.118	17.80	1.59
6	11.24	9.05	13.13	74.0	1.242	0.420	0.0826	0.120	14.93	2.35
7	9.69	8.72	13.43	77.0	0.428	0.527	0.0823	0.124	10.98	1.80
8	20.18	17.45	24.90	77.0	0.748	0.950	0.0858	0.156	10.05	1.40
9	15.00	12.65	18.80	77.0	0.562	0.660	0.0684	0.134	10.40	1.16
10	13.60	12.10	16.86	79.0	0.626	0.962	0.1320	0.149	11.20	1.44
11	16.37	14.90	19.90	79.0	0.748	1.001	0.1130	0.156	10.75	1.58
12	7.61	6.31	10.82	62.0	0.948	0.647	0.2330	0.214	10.55	6.54
13	10.48	8.93	13.62	61.5	1.120	1.150	0.3330	0.175	14.70	3.57
14	7.18	5.72	10.65	71.0	1.170	0.742	0.3250	0.181	13.90	4.66
15	11.02	9.80	14.00	63.0	1.056	1.330	0.3460	0.242	10.50	6.21
16	5.37	4.39	9.06	69.0	0.197	1.300	0.5420	0.146	12.60	8.38
17	4.32	3.48	8.73	71.0	0.179	1.050	0.5400	0.194	9.17	1.40
18	4.73	3.97	8.35	70.0	0.155	0.917	0.3630	0.158	9.87	9.75
19	8.31	7.53	12.08	73.0	0.596	1.480	0.5700	0.180	13.45	2.06
20	5.72	4.33	9.40	78.0	0.473	0.746	0.3430	0.139	14.25	1.45
21	4.62	3.00	8.45	79.0	0.278	0.930	0.6230	0.124	16.20	0.73
22	14.71	12.36	19.10	82.0	0.747	0.814	0.1092	0.153	10.80	1.57
23	23.4	22.00	27.70	83.0	1.372	1.220	0.1060	0.192	9.90	2.68
24	8.03	7.20	11.92	82.0	0.540	0.940	0.2440	0.160	11.60	1.76

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	D^2Sx10^3	$\frac{V^2}{gDS}x10^2$	Bed Material d_{15},mm	d_{50},mm	d_{85},mm		Side Material d_{15},mm	d_{50},mm	d_{85},mm
1	2.80	1.87	0.240	0.580	1.140	2.21	0.062	0.207	0.462
2	4.43	2.50	0.123	0.208	1.500	2.68	0.029	0.133	0.264
3	3.97	1.88	0.124	0.253	0.527	2.19	0.039	0.087	0.147
4	2.27	2.96	0.022	0.096	0.274	3.45	0.017	0.0515	0.161
5	2.48	3.17	0.0054	0.0287	0.142	5.15	0.011	0.0419	0.136
6	3.37	2.22	0.388	0.805	1.230	1.75	gravel	gravel	gravel
7	1.69	1.21	0.146	0.318	0.545	2.78	0.038	0.0806	0.191
8	2.00	1.01	0.316	0.617	1.280	1.98	0.024	0.098	0.506
9	1.62	1.07	0.232	0.390	0.685	1.73	0.017	0.098	0.295
10	1.99	1.25	0.161	0.465	0.945	2.69	0.030	0.143	0.479
11	2.10	1.16	0.294	0.568	1.240	2.07	0.029	0.166	0.499
12	1.12	1.11	0.290*	7.00*	25.00*	13.83	0.031	0.109	0.327
13	5.41	2.15	0.370*	7.60*	20.00*	11.46	0.027	0.060	0.141
14	8.62	1.91	0.178	0.311	0.848	2.21	0.071	0.149	0.247
15	8.82	1.11	0.311	0.575	1.010	2.35	0.014	0.074	0.180
16	1.72	1.58	0.051	0.173	0.619	3.49	0.031	0.079	0.121
17	3.48	0.84	0.052	0.163	0.422	2.87	0.040	0.077	0.239
18	2.04	0.97	0.053	0.229	0.648	3.85	0.037	0.182	0.266
19	3.29	1.81	0.327	0.715	1.648	2.01	0.074	0.286	0.573
20	3.12	2.02	0.013	0.360	0.117	3.04	0.014	0.036	0.056
21	2.06	2.62	0.015	0.349	0.158	3.29	0.014	0.034	0.069
22	2.41	1.16	0.220	0.446	1.327	2.99	0.043	0.177	0.782
23	3.37	0.98	0.219	0.420	0.993	2.13	0.073	0.271	0.995
24	2.89	1.35	0.147	0.246	0.495	1.82	0.026	0.067	0.188

* Based on the analysis of one large sample.

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	Side Material	d_{85} Susp. Sed. mm	Lacey $f=\frac{3}{4}V^2/R$	$f^{5/3}/Q^{1/6}$	$d_{50}{}^{0.86}/Q^{0.21}$	$\frac{V}{gD}\ \frac{d\times10^5}{D}$	$S\ (\frac{D}{W})^{1/2}$
1	2.69	0.035	1.856	1.181	0.2113	16.10	0.1130
2	14.24	0.120	0.966	0.311	0.0642	2.10	0.0420
3	2.08	0.073	0.328	0.049	0.0712	1.03	0.0196
4	3.09	0.060	0.594	0.152	0.0371	0.72	0.0248
5	3.57	0.071	0.714	0.202	0.0127	0.25	0.0276
6	--	--	0.378	0.063	0.1965	3.77	0.0210
7	2.86	0.016	0.492	0.134	0.1310	3.78	0.0457
8	5.97	0.070	0.852	0.319	0.218	17.80	0.0694
9	5.00	0.045	0.589	0.178	0.1531	6.24	0.0520
10	3.96	0.041	0.850	0.324	0.1756	9.10	0.0681
11	4.06	0.095	0.873	0.331	0.202	13.80	0.0669
12	13.83	0.074	0.637	0.152	1.290	41.50	0.0718
13	11.46	0.099	1.068	0.370	1.420	82.20	0.0555
14	15.53	0.143	0.758	0.198	0.0848	1.67	0.0502
15	4.10	0.165	1.190	0.461	0.1620	7.82	0.1179
16	2.11	0.075	1.396	0.895	0.0954	4.36	0.1210
17	2.56	0.078	1.251	0.744	0.0903	3.20	0.2070
18	3.49	0.048	1.004	0.538	0.1273	4.80	0.1481
19	3.03	0.061	1.685	0.979	0.2460	28.00	0.1101
20	2.22	0.043	0.824	0.291	0.0182	0.34	0.0549
21	2.26	0.029	1.176	0.596	0.0206	0.45	0.0636
22	4.26	0.054	0.764	0.258	0.1598	7.00	0.0621
23	3.69	0.099	1.025	0.390	0.1322	9.10	0.0953
24	2.87	0.140	0.910	0.360	0.1005	3.72	0.0837

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	$\frac{U^*D}{\nu}$	$\tau=\gamma DS$ Bed	$\tau=\gamma RS$	$\tau=K(V_2-V_1)^2$	τ on bed zero momentum	$\tau=(\gamma DS)_{ave}$
1	.545	0.0620	0.0510	0.0230	.0335	.0570
2	.855	0.0485	0.0394	0.0369	.0342	.0400
3	1.000	0.0420	0.0340	0.0252	.0361	.0358
4	.655	0.0240	0.0182	0.0378	.0137	.0191
5	.672	0.0280	0.0217	0.0175	.0137	.0244
6	.913	0.0392	0.0297	0.0273	.0329	.0314
7	.450	0.0297	0.0248	0.0263	.0252	.0284
8	.423	0.0453	0.0412	0.0290	.0288	.0436
9	.405	0.0349	0.0300	0.0256	.0314	.0319
10	.451	0.0504	0.0446	0.0170	.0444	.0452
11	.466	0.046	0.0426	0.0279	.0368	.0410
12	1.452	0.0898	0.0654	0.0383	.0449	.0720
13	.860	0.0600	0.0478	0.0286	.0474	.0500
14	1.470	0.0640	0.0467	0.0591	.0429	.0506
15	1.035	0.1160	0.0940	0.0884	.0661	.0975
16	.355	0.0400	0.0305	0.0292	.0180	.0350
17	.558	0.0726	0.0461	0.0658	.0400	.0650
18	.393	0.0490	0.0344	0.0236	.0177	.0440
19	.585	0.0605	0.0533	0.0286	.0424	.0560
20	.764	0.0366	0.0296	0.0216	.0212	.0278
21	.570	0.0298	0.0187	0.0236	.0119	.0222
22	.562	0.0433	0.0416	0.0347	.0372	.0384
23	.635	0.0685	0.0576	0.0328	.0640	.0675
24	.650	0.0495	0.0417	0.0391	.0327	.0441

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	$\frac{C/\sqrt{g}}{\sqrt{8}}-2\ \mathrm{Log}\ \frac{2R}{d}$	$8N_R(\frac{d}{R})/C/\sqrt{g}$	$(RS)^{1/2}x10^2$	$V/32.63\ \mathrm{Log}\ 12.27x\frac{D}{d}$	$P/Q^{1/2}$
1	-1.92	10.06	2.80	1.65	2.32
2	-2.69	28.20	2.50	1.62	2.48
3	-3.56	28.40	1.97	1.19	2.76
4	-2.78	9.70	1.71	--	2.35
5	-3.70	3.06	1.85	--	2.32
6	-2.09	89.40	1.92	1.19	2.71
7	-3.58	37.68	1.95	0.90	3.14
8	-3.11	92.60	2.52	1.10	3.97
9	-3.46	49.80	2.16	0.93	3.67
10	-3.06	68.40	2.42	1.13	3.18
11	-3.03	87.70	2.56	1.15	3.44
12	-1.70	1535.00	3.30	1.91	2.22
13	+0.06	1053.00	2.78	2.27	2.30
14	-3.26	50.10	2.73	1.61	2.08
15	-3.58	111.50	3.89	1.66	2.34
16	-3.15	21.80	2.15	1.20	2.22
17	-4.46	28.10	2.71	1.13	2.22
18	-3.89	31.90	2.32	1.02	2.32
19	-3.94	118.3	2.80	1.67	2.23
20	-4.53	4.87	2.02	--	2.18
21	-3.59	4.24	1.68	--	2.05
22	-3.32	69.60	2.42	1.10	3.40
23	-3.67	83.00	3.19	1.26	3.82
24	-3.60	40.20	2.48	1.20	2.53

Table 28 cont., Summary of Simons & Bender Data and Computed Parameters

Canal No.	$\frac{W}{VD}$	$\frac{d}{D} \times 10^3$	Estimated Dune Height	n	Ri	Suspended Load Tons/day	Total Load Tons/day
1	3.55	0.65	0.10	0.0198	0.00112	47.1	213.5
2	3.67	0.1167	0.30	0.0186	0.2020	319.5	--
3	5.10	0.1001	0.50	0.0236	0.0339	103.2	320.0
4	3.34	0.0524	0	0.0171	0.1880	156.8	443.0
5	3.42	0.01616	0	0.0170	0.1520	151.0	--
6	5.06	0.331	0.5	0.0217	0.00416	--	--
7	6.41	0.298	0.1	0.0221	0.0099	20.05	100.0
8	11.04	0.770	0.5	0.0271	0.0099	22.90	--
9	9.10	0.436	0.4	0.0268	0.00657	38.70	--
10	7.25	0.525	0.4	0.0250	0.00359	40.30	28.8
11	8.87	0.664	0.5	0.0261	0.01045	51.30	--
12	2.79	2.92	0	0.0292	0.0088	72.10	235.0
13	3.47	4.35	0	0.0207	0.0204	102.5	--
14	2.28	0.110	0.4	0.0219	0.0351	157.2	516.0
15	3.84	0.385	0.4	0.0287	0.0363	90.3	--
16	2.38	0.217	0.1	0.0192	0.0217	7.8	36.8
17	1.95	0.177	0.1	0.0252	0.00338	5.6	--
18	2.54	0.284	0.1	0.0244	0.00209	1.7	47.0
19	3.12	0.710	0.1	0.0202	0.0012	44.3	65.6
20	2.19	0.0225	0	0.0187	0.0185	88.8	130.5
21	1.49	0.0264	0	0.0146	0.00729	16.8	13.38
22	7.50	0.440	0.20	0.0256	0.00477	55.8	61.0
23	11.59	0.466	0.60	0.0294	0.0313	97.3	--
24	3.67	0.220	0.30	0.0235	0.3480	45.9	--

Table 29, U.S.B.R. Canal Data and Computed Parameters

Canal No.	Max Sustained Q	Q	A	V	$S \times 10^3$	P	R	D	W_T
1	1500	1500.	255.	5.88	2.80	72.0	3.54	4.87	73.
2	729	668.	114.	5.83	3.76	50.3	2.27	2.81	55.
4	768	768.	117.5	6.53	3.59	47.2	2.49	3.11	48.
5	448	448.2	76.5	5.82	3.68	35.1	2.18	2.50	40.
6	159	159.	34.5	4.59	2.95	18.35	1.88	1.88	21.7
7	96	95.6	22.	4.36	2.90	16.75	1.31	1.73	15.9
8	46	46.	15.3	3.00	3.16	19.15	0.80	0.96	19.2
10	16.6	16.6	5.7	2.90	9.65	11.87	0.48	0.60	11.1
11	203	203.	52.3	3.88	2.35	33.75	1.55	1.88	32.3
12	135	128.	32.	4.00	2.43	22.81	1.40	1.77	21.9
14	127	110.	33.4	3.29	1.36	22.0	1.52	2.00	21.4
15	500	477.	98.8	4.84	1.99	38.0	2.60	3.05	39.4
17	531	531.	96.4	5.51	2.74	43.4	2.22	2.60	41.
18	278	235.	62.	3.80	0.80	29.8	2.08	2.94	25.

Canal No.	$W=\frac{A}{D}$	P/R	$VW/\nu \times 10^{-7}$	$U^* = \sqrt{gDS}$	$\frac{C}{\sqrt{g}} = \frac{V}{U^*}$	$R^2 S \times 10^3$	$D^2 S \times 10^3$	$V^2/gDS \times 10^3$
1	65	20.35	4.06	.662	8.89	35.1	66.3	.0789
2	48	22.20	3.03	.584	10.0	19.4	29.7	.100
4	42	18.93	2.96	.600	10.89	22.3	34.8	.1183
5	34	16.1	2.20	.545	10.69	17.5	23.0	.1143
6	17	9.77	0.964	.423	10.84	10.43	10.4	.118
7	11	12.8	0.656	.401	10.88	4.98	8.53	.1178
8	15	23.9	0.545	.312	9.62	2.02	2.91	.0922
10	7	24.7	0.305	.432	6.72	2.22	3.47	.0452
11	27	21.78	1.18	.377	10.29	5.47	8.32	.106
12	17	16.3	0.829	.286	14.00	4.77	7.60	.1965
14	17	14.48	0.666	.296	11.11	3.14	5.44	.1238
15	33	14.6	1.80	.442	10.94	13.46	18.5	.120
17	35	19.55	2.14	.478	11.52	13.5	18.5	.1326
18	20	14.3	0.8975	.275	13.81	3.46	6.90	.191

Table 29 cont., U.S.B.R. Canal Data and Computed Parameters

Canal No.	Bed Material d mm	Lacey f	$f^{5/3}/Q^{1/6}$	T=γDS Bed	T=γRS	$\frac{C/\sqrt{g}}{\sqrt{8}}-2\text{Log}\frac{2R}{d}$	$8R_{*}(\frac{d}{D})/C/\sqrt{g}$
1	82	7.33	8.25	0.84	.620	+0.30	47,750.
2	77	11.60	20.20	0.92	.532	+1.03	39,300.
4	76	12.80	23.40	0.80	.557	+1.28	39,700.
5	53.8	11.60	21.60	0.60	.500	+1.00	25,700.
6	41.8	8.40	15.00	0.39	.320	+0.97	15,510.
7	41.2	10.90	25.60	0.36	.237	+1.27	14,500.
8	39.1	8.43	18.60	0.31	.158	+1.21	10,710.
10	64	13.10	45.60	0.75	.288	+1.05	24,210.
11	48	7.31	11.40	0.38	.227	+1.04	15,910.
12	34	8.57	16.00	0.31	.212	+2.08	7,900.
14	20.1	5.33	7.50	0.15	.129	+0.61	5,200.
15	50	6.75	8.64	0.45	.323	+0.87	19,400.
17	38.1	10.30	18.20	0.47	.380	+0.97	16,030.
18	21.1	5.20	6.33	0.16	.104	+1.33	5,090.

Canal No.	$(RS)^{1/2}x10^2$	$V/32.63\ \text{Log}\ 12.27x\frac{D}{d}x10^2$		$U^{*}D/\nu$	$\frac{d}{D}$
1	9.96	7.67	.031	$1.572x10^5$	16.8
2	9.25	8.37	.027	$.801x10^5$	27.4
4	9.46	9.16	.025	$.910x10^5$	24.4
5	8.96	7.98	.026	$.665x10^5$	21.5
6	7.45	6.32	.022	$.388x10^5$	22.2
7	6.16	6.09	.022	$.338x10^5$	23.8
8	5.03	4.68	.024	$.146x10^5$	40.7
10	6.81	5.75	.031	$.127x10^5$	106.7
11	6.04	5.48	.025	$.346x10^5$	25.5
12	5.84	5.36	.023	$.247x10^5$	19.2
14	4.54	3.92	.022	$.289x10^5$	10.1
15	7.19	6.29	.026	$.658x10^5$	16.4
17	7.80	7.02	.024	$.607x10^5$	14.7
18	4.08	4.28	.018	$.394x10^5$	7.2

Table 30, Punjab Canal Data & Computed Parameters

Canal No.	Q	A	V	$Sx10^3$	R	P
1	22.5	16.05	1.40	.33	1.36	11.83
2	9,005.39	2,778.09	3.25	.19	9.48	292.99
3	4,463.36	1,534.37	2.91	.20	7.57	203.03
4	532.46	235.44	2.27	.23	3.80	61.76
5	289.60	134.26	2.16	.22	2.80	47.87
6	551.63	236.14	2.34	.22	3.46	68.51
7	1,080.90	426.48	2.54	.21	4.72	90.18
8	2,824.31	988.90	2.86	.21	6.87	144.02
9	4,419.80	1,521.58	2.90	.20	7.39	206.19
10	40.35	23.38	1.53	.31	1.50	17.63
11	28.96	21.79	1.33	.28	1.34	16.27
12	59.41	39.52	1.50	.26	1.62	24.39
13	2,102.43	789.94	2.66	.18	6.10	129.42
14	40.03	26.59	1.50	.29	1.58	16.87
15	272.75	119.76	2.28	.17	3.00	39.99
16	27.26	21.06	1.31	.33	1.29	16.10
17	5.79	5.31	1.09	.30	0.79	6.71
18	15.95	11.90	1.34	.27	1.23	9.66
19	27.18	19.29	1.41	.31	1.34	14.38
20	611.42	209.76	2.27	.15	4.16	64.83
21	659.61	287.31	2.30	.15	4.49	63.97
22	735.75	326.11	2.25	.14	4.51	72.43
23	19.18	13.96	1.37	.27	1.29	10.80
24	544.26	253.37	2.14	.15	4.16	60.96
25	493.00	230.75	2.14	.15	3.78	60.99
26	7.81	7.13	1.09	.34	0.89	8.05
27	1,186.65	476.98	2.49	.13	5.24	90.94
28	768.23	331.75	2.32	.16	4.45	74.26
29	55.48	35.59	1.56	.28	1.73	20.59
30	354.48	164.27	2.16	.20	2.92	56.25
31	1,407.05	558.66	2.52	.17	5.52	100.92
32	133.19	71.03	1.88	.20	2.80	25.32
33	44.61	31.04	1.43	.22	1.80	17.19
34	784.51	366.06	2.15	.14	4.48	81.64
35	440.33	207.98	2.12	.20	3.44	60.38
36	361.48	170.09	2.12	.16	3.79	44.85
37	80.14	46.81	1.72	.30	1.79	26.20
38	5,676.92	1,998.92	2.84	.13	9.37	213.24
39	42.32	30.22	1.40	.21	1.66	18.27
40	99.41	59.88	1.66	.17	2.25	26.44
41	5,810.25	2,024.00	2.87	.12	9.46	213.87
42	17.92	11.91	1.51	.29	1.22	9.70

Table 30 cont., Punjab Canal Data & **Computed Parameters**

Canal No.	D	W_T	$W=\frac{A}{\bar{D}}$	W_T/D	W/D	P/R
1	2.60	10.00	6.2	3.85	2.38	8.70
2	10.50	287.65	264.0	27.40	25.10	30.90
3	8.88	197.50	173.0	22.20	19.50	26.80
4	4.60	58.39	51.1	12.69	11.10	16.30
5	3.45	46.70	39.1	13.52	11.30	17.10
6	4.18	65.15	56.5	15.58	13.50	19.80
7	5.76	86.60	74.0	15.04	12.83	19.10
8	8.38	139.34	118.0	16.63	14.10	21.00
9	8.50	194.00	179.0	22.82	21.10	27.90
10	2.24	16.02	11.8	7.16	5.27	11.80
11	2.08	14.97	10.5	7.20	5.05	12.10
12	2.20	22.95	18.0	10.42	8.18	15.10
13	7.45	124.83	106.0	16.73	14.22	21.20
14	2.42	15.09	11.0	6.23	4.54	10.70
15	3.74	37.85	32.0	10.13	8.56	13.30
16	2.05	14.17	10.3	6.90	5.02	12.50
17	2.65	5.87	2.0	2.22	0.76	8.50
18	2.84	8.00	4.2	2.82	1.48	7.85
19	2.14	13.00	9.0	6.07	4.20	10.70
20	5.10	60.38	53.0	11.82	10.40	15.60
21	5.42	59.00	53.0	10.89	9.78	14.20
22	5.43	68.00	60.0	12.51	11.05	16.40
23	2.53	9.00	5.5	3.56	2.18	8.38
24	4.97	57.00	51.0	11.47	10.25	14.70
25	4.53	57.00	51.0	12.59	11.25	16.10
26	2.29	7.00	3.1	3.06	1.35	9.05
27	6.36	86.09	75.0	13.53	11.80	17.40
28	5.44	69.96	61.0	12.86	11.20	16.70
29	2.46	18.00	14.5	7.31	5.89	11.90
30	3.50	53.02	47.0	15.15	13.40	19.30
31	6.73	94.67	83.0	14.09	12.32	18.30
32	3.78	22.10	18.8	5.85	4.97	9.03
33	1.88	15.64	16.5	8.32	8.78	9.54
34	5.47	77.37	67.0	14.11	12.25	18.20
35	4.16	57.21	50.0	13.75	12.00	17.60
36	4.73	39.25	36.0	8.31	7.61	11.80
37	2.40	24.29	19.5	10.11	8.12	14.60
38	10.80	206.00	185.0	19.08	17.12	22.80
39	1.75	21.50	17.2	12.30	9.83	11.00
40	3.05	23.82	19.6	7.83	6.43	11.80
41	10.90	206.00	186.0	18.71	17.05	22.60
42	2.59	8.12	4.6	3.13	1.78	7.95

Table 30 cont., Punjab Canal Data & Computed Parameters

Canal No.	VW/ x10^{-7}	$b=V^2/D$	$s=V^3/W$	$U^*=\sqrt{gDS}$	$\frac{C}{\sqrt{g}}=\frac{V}{U^*}$
1	0.0818	0.753	.442	.166	8.43
2	8.1000	1.000	.129	.253	12.85
3	4.7500	0.948	.142	.239	12.15
4	1.0930	1.120	.229	.184	12.30
5	0.7930	1.350	.259	.154	14.00
6	1.2470	1.310	.227	.172	13.60
7	1.7700	1.115	.220	.197	12.90
8	3.1850	0.973	.197	.238	12.00
9	4.7100	0.987	.136	.234	12.40
10	0.1710	1.044	.304	.150	10.20
11	0.1318	0.851	.224	.138	9.64
12	0.2540	1.020	.187	.136	11.00
13	2.6600	0.941	.175	.208	12.80
14	0.1550	0.930	.306	.150	10.00
15	6.8800	1.385	.369	.143	16.00
16	0.1272	0.840	.218	.148	8.85
17	0.0208	0.445	.645	.160	6.81
18	0.0532	0.632	.572	.157	8.53
19	0.1192	0.925	.310	.147	9.60
20	1.1330	1.010	.220	.157	14.40
21	1.1500	0.975	.230	.162	14.20
22	1.2720	0.929	.190	.156	14.40
23	0.0713	0.743	.470	.148	9.27
24	1.0250	0.917	.191	.155	13.80
25	1.0270	1.007	.191	.148	14.50
26	0.0318	0.515	.416	.158	6.90
27	1.7650	0.972	.205	.163	15.30
28	1.3320	0.989	.205	.168	13.80
29	0.2130	0.988	.261	.149	10.50
30	0.9560	1.330	.213	.150	14.40
31	1.9750	0.938	.192	.191	13.20
32	0.3330	0.935	.353	.156	12.10
33	0.2230	1.082	.177	.116	12.30
34	1.3600	0.840	.148	.157	13.70
35	1.0000	1.080	.190	.164	12.90
36	0.7200	0.948	.264	.156	13.60
37	0.4280	1.232	.260	.153	11.20
38	3.8400	0.745	.123	.213	13.30
39	0.2270	1.120	.159	.109	12.80
40	0.3070	0.903	.234	.129	12.90
41	5.0300	0.752	.126	.206	13.90
42	0.0657	0.880	.743	.156	9.68

Table 30 cont., Punjab Canal Data & **Computed Parameters**

Canal No.	R^2Sx10^3	D^2Sx10^3	$V^2/_{gDS}x10^{-2}$	Bed Material d mm	Lacey f
1	0.607	2.22	0.7090	.26	1.072
2	17.000	2.09	1.630	.42	0.833
3	11.400	15.70	1.485	.42	0.833
4	3.310	4.85	1.512	.27	1.012
5	1.720	2.61	1.905	.26	1.246
6	2.620	3.85	1.850	.34	1.184
7	4.660	6.93	1.650	.41	1.020
8	9.840	14.70	1.438	.43	0.885
9	10.800	14.40	1.530	.41	0.847
10	0.697	1.55	1.045	.26	1.162
11	0.502	1.21	0.943	.23	0.982
12	0.682	1.26	1.220	.28	1.042
13	6.660	9.93	1.622	.34	0.870
14	0.718	1.69	0.996	.22	1.065
15	1.530	2.36	2.530	.26	1.298
16	0.548	1.39	0.791	.22	0.997
17	0.187	2.10	0.460	.15	1.125
18	0.408	2.18	0.728	.19	1.096
19	0.555	1.42	0.926	.19	1.110
20	2.580	3.90	2.095	.27	0.922
21	3.010	4.38	2.020	.29	0.877
22	2.830	4.12	2.065	.27	0.840
23	0.448	1.73	0.856	.20	1.088
24	2.580	3.69	1.900	.25	0.825
25	2.130	3.08	2.080	.25	0.907
26	0.269	1.77	0.471	.17	0.997
27	3.550	5.25	2.320	.31	0.885
28	3.150	4.72	1.920	.30	0.900
29	0.835	1.69	1.097	.26	1.050
30	1.700	2.44	2.065	.30	1.192
31	5.130	0.77	1.710	.35	0.855
32	1.560	2.84	1.450	.27	0.945
33	0.710	0.77	1.526	.23	0.847
34	2.800	4.18	1.863	.27	0.773
35	2.360	3.44	1.675	.29	0.975
36	2.290	3.55	1.845	.28	0.885
37	0.960	1.71	1.277	.36	1.238
38	11.300	15.10	1.775	.30	0.642
39	0.577	0.64	1.656	.20	0.885
40	0.864	1.58	1.650	.24	0.915
41	10.700	14.20	1.942	.30	0.650
42	0.428	1.94	0.940	.18	1.396

Table 30 cont., Punjab Canal Data & Computed Parameters

Canal No.	$f^{5/3}/Q^{1/6}$	$d^{0.86}/Q^{0.21}$	$V/\sqrt{gD}\frac{d}{D}\times 10^3$	$\frac{U^*D}{\nu}$	$T=\gamma DS$ Bed
1	.657	0.1670	0.0502	0.284	.0536
2	.162	0.0717	0.0231	2.500	.1248
3	.182	0.0813	0.0268	2.000	.1110
4	.357	0.0860	0.0360	0.800	.0661
5	.563	0.0956	0.0507	0.501	.0473
6	.463	0.1050	0.0538	0.680	.0574
7	.324	0.1050	0.0433	1.070	.0755
8	.217	0.0908	0.0292	1.880	.1100
9	.188	0.1005	0.0276	1.870	.1062
10	.694	0.1432	0.0084	0.317	.0433
11	.610	0.1388	0.0587	0.270	.0364
12	.544	0.1432	0.0742	0.282	.0358
13	.221	0.0813	0.0256	1.460	.0837
14	.600	0.1241	0.0506	0.342	.0438
15	.608	0.0955	0.0472	0.505	.0397
16	.575	0.1387	0.0565	0.286	.0423
17	.892	0.1340	0.0219	0.400	.0497
18	.733	0.1340	0.0307	0.421	.0478
19	.688	0.1195	0.0494	0.297	.0414
20	.299	0.0860	0.0307	0.755	.0477
21	.272	0.0860	0.0305	0.828	.0507
22	.249	0.0813	0.0277	0.799	.0476
23	.703	0.1340	0.0395	0.358	.0427
24	.254	0.0813	0.0278	0.726	.0466
25	.301	0.0813	0.0320	0.625	.0424
26	.706	0.1432	0.0285	0.342	.0486
27	.251	0.0813	0.0280	0.979	.0516
28	.276	0.0860	0.0316	0.861	.0544
29	.556	0.1340	0.0608	0.346	.0430
30	.504	0.1050	0.0570	0.496	.0438
31	.230	0.0860	0.0282	1.147	.0716
32	.402	0.1148	0.0398	0.557	.0472
33	.403	0.1290	0.0732	0.206	.0258
34	.215	0.8130	0.0252	0.811	.0478
35	.348	0.0955	0.0419	0.645	.0519
36	.306	0.0955	0.0334	0.697	.0473
37	.686	0.1626	0.0965	0.346	.0450
38	.101	0.0574	0.0138	0.217	.0877
39	.439	0.1147	0.0704	0.180	.0230
40	.400	0.1242	0.0432	0.371	.0324
41	.115	0.0574	0.0138	2.140	.0818
42	1.079	0.1241	0.0377	0.381	.0324

Table 30 cont., Punjab Canal Data & **Computed Parameters**

Canal No.	$T=\gamma RS$	$\frac{C/\sqrt{g}}{\sqrt{8}}-2\mathrm{Log}\frac{2R}{d}$	$8R_e(\frac{d}{R})/C/\sqrt{g}$	$(RS)^{1/2}\times 10^2$
1	.0280	-4.03	37.90	2.12
2	.1120	-3.74	93.10	4.25
3	.0945	-3.78	88.10	3.89
4	.0546	-3.41	43.80	2.76
5	.0384	-2.69	35.10	2.48
6	.0475	-2.79	51.30	2.76
7	.0620	-3.14	70.30	3.15
8	.0900	-3.74	90.00	3.76
9	.0920	-3.70	83.50	3.84
10	.0290	-3.50	34.20	2.16
11	.0234	-3.70	27.82	1.94
12	.0263	-3.21	33.41	2.05
13	.0685	-3.55	61.90	3.31
14	.0286	-3.76	35.20	2.14
15	.0318	-2.04	32.41	2.26
16	.0266	-3.98	28.52	2.06
17	.0148	-4.29	20.91	1.54
18	.0207	-4.22	26.16	1.86
19	.0259	-3.86	24.32	2.04
20	.0390	-2.85	37.30	2.50
21	.0420	-2.94	41.30	2.66
22	.0394	-2.92	36.90	2.52
23	.0217	-3.92	26.00	1.87
24	.0390	-3.13	33.95	2.50
25	.0354	-2.81	32.41	2.38
26	.0189	-4.55	23.40	1.74
27	.0425	-2.62	44.55	2.61
28	.0445	-3.03	44.12	2.67
29	.0303	-3.51	33.90	2.20
30	.0366	-2.45	39.20	2.42
31	.0586	-3.29	58.50	3.06
32	.0260	-3.32	36.80	2.37
33	.0246	-3.01	23.50	1.99
34	.0392	-3.16	37.20	2.51
35	.0430	-3.14	41.80	2.62
36	.0378	-3.02	38.21	2.46
37	.0335	-3.02	48.40	2.32
38	.0760	-3.86	56.30	3.49
39	.0218	-2.89	19.26	1.87
40	.0239	-3.00	27.25	1.96
41	.0710	-3.65	54.50	3.37
42	.0221	-3.80	24.60	1.88

Table 30 cont., Punjab Canal Data & **Computed Parameters**

Canal No.	V/32.63 Log 12.27x$\frac{D}{d}$	n	$\frac{W}{D}$	$P/Q^{1/2}$	$\frac{d}{D}$x10^3
1	0.90	.0220	1.70	2.395	0.328
2	1.97	.0280	7.73	3.062	0.131
3	1.79	.0280	6.69	3.030	0.156
4	1.39	.0220	4.89	2.670	0.192
5	1.36	.0202	5.24	2.820	0.248
6	1.48	.0215	5.77	2.920	0.267
7	1.55	.0238	5.06	2.740	0.233
8	1.77	.0272	4.92	2.700	0.168
9	1.78	.0275	7.26	3.090	0.158
10	0.99	.0224	3.44	2.770	0.380
11	0.86	.0228	3.79	3.020	0.362
12	0.98	.0220	5.46	3.160	0.417
13	1.61	.0175	5.35	2.825	0.150
14	0.96	.0219	3.02	2.665	0.298
15	1.42	.0177	3.75	2.420	0.228
16	0.85	.0244	3.83	3.080	0.351
17	0.67	.0202	0.69	2.780	0.185
18	0.83	.0215	1.10	2.420	0.219
19	0.90	.0226	2.98	2.760	0.292
20	1.38	.0207	4.58	2.610	0.173
21	1.40	.0216	4.26	2.490	0.176
22	1.36	.0213	4.91	2.660	0.163
23	0.86	.0212	1.59	2.460	0.260
24	1.29	.0220	4.80	2.610	0.165
25	1.30	.0207	5.27	2.740	0.181
26	0.68	.0232	1.24	2.860	0.244
27	1.51	.0205	4.74	2.630	0.161
28	1.42	.0220	4.83	2.680	0.181
29	1.04	.0230	3.78	2.760	0.347
30	1.37	.0199	6.22	2.980	0.281
31	1.54	.0240	4.90	2.680	0.171
32	1.17	.0222	2.69	2.190	0.234
33	0.94	.0228	6.14	2.570	0.400
34	1.29	.0222	5.70	2.910	0.162
35	1.32	.0226	5.68	2.880	0.229
36	1.30	.0252	3.59	2.360	0.194
37	1.15	.0220	4.72	2.925	0.492
38	1.64	.0265	6.03	2.825	0.091
39	0.92	.0216	7.02	2.805	0.376
40	1.04	.0201	3.87	2.640	0.258
41	1.66	.0253	5.95	2.800	0.090
42	0.94	.0192	1.18	2.290	0.228

Table 31, Sediment Concentrations, Punjab Canals

Channel	R.D.	No. of observations	M.V.P.	S.D. of M.V.P.	M.V.	V66D(C)	M.S.P.	S.D. of M.S.P.	M.S.	S.47D(C)
Lower Gugera Branch	6,000	6	.64	.102	2.65	2.63	.39	.118	.179	.191
Burala Branch	6,000	6	.64	.058	2.53	2.47	.53	.107	.152	.146
Mian Ali Branch	95,000	6	.76	.042	2.12	2.27	.57	.066	.233	.199
Shahkot Disty	12,000	6	.73	.021	1.84	1.96	.43	.055	.240	.256
Khurrianwala Distributary	5,000	6	.70	.028	2.06	2.13	.51	.028	.194	.182
Jhang Branch	7,260	4	.59	.070	3.03	2.91	.45	.013	.318	.325
Rakh Branch	7,260	3	.62	.050	2.70	2.62	.40	.032	.313	.339
Lower Gugera Branch	2,72,500	6	.60	.055	2.42	2.32	.42	.070	.289	.299
Lower Gugera Branch	2,59,000	1	.54		2.26	2.09	.43	--	.227	.237
Mean for all channels	---		.66	.058	--	--	.47	.079	--	--

Notation:
M.V.P. = Mean velocity point on the central vertical.
V.66D(C) = Velocity at .66D on the central vertical.
M.S.P. = Mean silt point on the central vertical.
M.S. = Mean silt intensity in gms/litre.
S.47D(C) = Silt intensity .47D on the central vertical.
M.V. = Mean Velocity.
S.D. = Standard Deviation.

Table 32, Sind Canal Data and Computed Parameters

Canal No.	Q	A	V	$Sx10^3$	R	P	D	$W=A/_D$	$P/_R$	$VW/_\rho \; x10^{-7}$
1	8,760	3,035	2.888	.0794	10.68	283.9	11.77	257.5	26.59	7.03
2	9,057	3,075	2.945	.0744	10.70	287.1	11.84	259.4	26.83	7.18
3	8,763	3,065	2.860	.0600	11.72	260.8	13.14	232.7	22.25	6.28
4	8,937	3,039	2.940	.0592	11.58	262.4	12.99	233.9	22.69	6.49
5	6,143	2,545	2.410	.0623	10.37	244.7	11.96	212.6	23.59	4.84
6	6,612	2,575	2.570	.0600	10.47	245.2	12.24	212.5	23.42	5.14
7	5,641	2,170	2.600	.0600	10.54	205.6	11.86	182.7	19.51	4.49
8	5,952	2,055	2,900	.0650	10.12	203.3	11.31	181.6	20.08	4.98
9	5,128	1,813	2.828	.0650	9.41	192.8	10.82	167.7	20.48	4.48
10	5,032	1,973	2.550	.0623	10.17	194.2	11.81	167.1	19.09	4.02
11	4,167	1,473	2.826	.0724	9.035	163.2	9.925	148.6	18.07	3.98
12	4,006	1,505	2.660	.0744	9.134	164.7	9.965	150.8	18.03	3.79
13	3,601	1,276	2.824	.0650	8.471	150.6	10.53	121.2	17.77	3.22
14	3,261	1,268	2.579	.0600	8.61	146.9	10.49	120.6	17.06	2.94
15	3,532	1,273	2.774	.0650	8.635	147.2	10.52	121.2	17.04	3.16
16	1,195	497	2.407	.0831	6.92	71,74	8.895	55.82	10.36	1.26
17	1,223	500	2.447	.0800	6.948	71.94	8.975	55.68	10.35	1.29
18	1,207	492	2.459	.0782	6.828	71.77	8.565	57.24	10.51	1.33
19	1,374	560	2.557	.0700	6.940	77.40	8.595	62.48	11.15	1.51
20	1,353	538	2.518	.0693	6.918	77.65	8.565	62.72	11.23	1.49
21	4,298	526	2.464	.0642	6.813	77.28	8.405	62.65	11.34	1.45
22	305	198	1.542	.0812	3.928	50.42	4.825	41.01	12.83	.595
23	311	197	1.575	.0773	3.932	50.27	4.795	41.23	12.78	.611
24	323	199	1,620	.0761	3.958	50.36	4.670	42.66	12.73	.652
25	3,153	1,216	2.595	.0995	8.620	141.1	10.60	114.8	16.37	2.82
26	3,011	812	3.705	.0773	7.58	107.3	9.170	88.69	14.16	3.09
27	2,157	675	3.192	.0700	6.915	97.69	8.300	81.41	14.13	2.45
28	2,360	698	3.380	.0715	7.09	98.54	8.580	81.41	13.90	2.60

Table 32 cont., Sind Canal Data and Computed Parameters

Canal No.	$b=V^2/D$	$s=V^3/W$	$U^*=\sqrt{gDS}$	$\frac{C}{\sqrt{g}}=\frac{V}{U^*}$	$R^2S\times10^3$	$D^2S\times10^3$	$V^2/gDS\times10^{-2}$	Bed Material d mm	Lacey f
1	.708	.0930	.173	16.7	9.05	10.95	2.77	.0987	0.5859
2	.732	.0984	.169	17.4	8.52	10.40	3.05	.1207	0.6077
3	.622	.1005	.159	18.0	8.22	10.32	3.22	.1445	0.5236
4	.663	.1080	.157	18.7	7.93	9.93	3.48	.1462	0.5599
5	.481	.0652	.155	15.5	6.66	8.92	2.40	.1213	0.4201
6	.539	.0797	.154	16.7	6.53	9.00	2.80	.1459	0.4731
7	.569	.0962	.152	17.1	6.66	8.40	2.95	.1132	0.4811
8	.742	.1336	.154	18.8	6.66	8.32	3.54	.0211	0.6233
9	.738	.1346	.150	18.9	5.72	7.61	3.53	.1063	0.6372
10	.550	.0993	.154	16.6	6.42	8.66	2.74	.0920	0.4795
11	.805	.1520	.152	18.5	5.87	7.10	3.45	.1642	0.6628
12	.711	.1245	.154	17.3	6.17	7.36	2.97	.1563	0.5811
13	.758	.1870	.149	18.9	4.66	7.21	3.63	.0909	0.7058
14	.632	.1410	.143	17.9	4.44	6.60	3.27	.0995	0.5792
15	.723	.1745	.149	18.6	4.83	7.21	3.45	.0944	0.6683
16	.647	.2470	.154	15.6	3.97	6.56	2.42	.0432	0.6277
17	.667	.2640	.152	16.1	3.84	6.42	2.59	.0507	0.6463
18	.703	.2580	.147	16.7	3.63	5.71	2.79	.0555	0.6643
19	.758	.2670	.139	18.4	3.36	5.17	3.38	.0872	0.7065
20	.738	.2540	.138	18.2	3.30	5.06	3.31	.0894	0.6876
21	.721	.2380	.132	18.6	2.96	4.52	3.49	.0898	0.6683
22	.491	.0891	.112	13.7	1.25	1.88	1.87	.0762	0.4538
23	.517	.0947	.110	14.3	1.19	1.78	2.07	.0742	0.4733
24	.561	.0993	.102	15.9	1.19	1.66	2.29	.0724	0.4973
25	.632	.1510	.184	14.1	7.36	11.15	1.97	.1957	0.5861
26	1.490	.5700	.151	24.5	4.43	6.50	6.00	.0933	1.3580
27	1.230	.3990	.137	23.3	3.33	4.82	5.46	.0375	1.1050
28	1.330	.4730	.140	24.1	3.68	5.25	5.76	.0346	1.2090

Table 32 cont., Sind Canal Data and Computed Parameters

Canal No.	$f^{5/3}/Q^{1/6}$	$d^{0.86}/Q^{0.21}$	$T=\gamma DS$	$T=\gamma RS$	$(RS)^{1/2}\times 10^2$	$\left(\frac{V}{32.63\,\mathrm{Log}\,12.27\frac{D}{d}}\right)10^2$	$P/Q^{1/2}$	W/VD
1	0.0902	0.02022	.0583	.0529	2.81	1.557	3.04	7.54
2	0.0957	0.0239	.0550	.0497	2.82	1.617	3.01	7.57
3	0.0748	0.0282	.0492	.0440	2.65	1.580	2.78	6.13
4	0.0838	0.0284	.0480	.0428	2.62	1.628	2.79	6.21
5	0.0554	0.0261	.0466	.0403	2.54	1.330	3.18	7.40
6	0.0664	0.0302	.0459	.0392	2.50	1.430	3.01	6.68
7	0.0702	0.0251	.0444	.0396	2.52	1.418	2.73	5.92
8	0.1070	0.0058	.0459	.0412	2.55	1.674	2.63	5.55
9	0.1140	0.0243	.0440	.0382	2.48	1.545	2.70	5.55
10	0.0713	0.0214	.0460	.0396	2.52	1.365	2.76	5.06
11	0.1260	0.0369	.0449	.0409	2.56	1.618	2.53	5.37
12	0.1020	0.0356	.0463	.0424	2.61	1.514	2.62	5.59
13	0.1430	0.0227	.0428	.0344	2.35	1.525	2.50	4.12
14	0.1050	0.0250	.0393	.0323	2.27	1.400	2.57	4.43
15	0.1310	0.0237	.0427	.0351	2.37	1.480	2.47	4.12
16	0.1420	0.0152	.0462	.0359	2.40	1.223	2.17	2.62
17	0.1480	0.0172	.0449	.0347	2.36	1.260	2.16	2.60
18	0.1550	0.0187	.0418	.0334	2.31	1.278	2.17	2.76
19	0.1690	0.0270	.0376	.0304	2.20	1.392	2.25	2.77
20	0.1610	0.0275	.0370	.0299	2.19	1.372	2.26	2.93
21	0.1550	0.0279	.0337	.0273	2.09	1.347	2.28	3.00
22	0.1030	0.0329	.0245	.0199	1.79	0.862	2.90	5.69
23	0.1165	0.0320	.0232	.0190	1.74	0.875	2.84	5.34
24	0.1190	0.0311	.0222	.0188	1.74	0.900	2.80	5.72
25	0.1070	0.0455	.0659	.0536	2.98	1.498	2.51	4.17
26	0.4500	0.0242	.0443	.0366	2.42	2.020	1.95	2.65
27	0.3280	0.0119	.0363	.0302	2.20	1.600	2.11	3.05
28	0.3770	0.0108	.0383	.0317	2.25	1.680	2.04	2.77

Table 33, Sediment Concentrations, Sind Canals

Channel	R.D.	Weight of Silt in Grams Perliter			Temp. C°
		Bed Sample	Berm Sample	Suspended Silt Sample	
Observation No. 3 Cold Weather 1934					
Rohri Canal	5,000	2.34	--	--	30.6
Rohri Canal	123,000	3.22	--	2.91	31.0
Rohri Canal	200,000	3.38	--	4.15	32.0
Rohri Canal	205,055	2.97	--	3.42	31.0
Rohri Canal	210,000	3.47	3.47	2.95	30.0
Rohri Canal	315,000	4.51	--	4.55	30.6
Rohri Canal	328,456	4.49	--	3.88	32.0
Rohri Canal	341,000	3.43	--	3.28	31.5
Rohri Canal	424,809	4.61	--	--	30.0
Rohri Canal	441,000	3.38	--	--	31.7
Observation No. 4 Cold Weather 1934					
Rohri Canal	5,000	0.15	0.15	0.15	21.1
Rohri Canal	123,000	0.17	0.17	0.18	20.6
Rohri Canal	200,000	0.14	0.14	0.18	18.0
Rohri Canal	205,055	0.17	--	0.11	18.9
Rohri Canal	210,000	0.10	--	0.13	18.3
Rohri Canal	315,000	0.15	--	--	14.4
Rohri Canal	328,456	0.08	0.08	0.08	14.4
Rohri Canal	341,000	0.20	--	--	11.1
Rohri Canal	424,809	0.11	--	0.13	15.0
Rohri Canal	441,000	0.30	--	0.29	15.6

Table 34, Imperial Valley Canal Data and Computed Parameters

Canal Name	Q ave	A ave	V ave	$Sx10^3$	R ave	P ave	D ave	W ave	R^2S	Concentration ppm
Almo canal Calamo Mocho	3402	720.5	4.13	0.255	5.82	12.4	6.20	117.0	.0086	8000
East Hi line @ "B" heading	10021	243.3	3.70	0.322	4.21	57.0	5.40	46.5	.0057	4300
Central Main canal @ boundary	600.7	139.6	3.29	0.440	3.09	44.0	4.28	38.0	.0042	4900
West side main canal @ drain	536.8	163.5	2.96	0.380	4.69	35.0	6.49	26.4	.00835	2500

Table 35, Values of Richardsons No. and $C/\sqrt{g}$ Based on U.S.G.S. & Colorado A&M Data

Cody Report Data		Missouri River Data		Colorado A&M Data: Flume Data, Plane Bed		Colorado A&M Data: Flume Data, Dunes	
$C/\sqrt{g}$	Ri*	$C/\sqrt{g}$	Ri	$C/\sqrt{g}$	Ri	$C/\sqrt{g}$	Ri
11.75	0.461	34.0	11.0	21.0	1.99	10.05	0.98
9.18	0.722	33.5	8.3	17.5	1.65	11.60	0.91
8.30	0.055	33.0	7.6	16.5	1.65	11.70	0.708
15.70	0.021	32.0	6.0	17.1	1.30	11.70	0.615
15.60	0.766	32.5	5.0	19.98	1.10	6.95	0.595
11.13	0.440	28.0	2.95	17.0	0.70	11.10	0.520
8.19	0.644	26.0	2.30	16.3	0.38	11.40	0.50
8.06	0.448	26.3	1.40			11.09	0.45
		17.9	1.00			9.60	0.45
		11.1	0.720			8.30	0.26
						8.80	0.22
						10.05	0.087

$$* \ Ri = \frac{w\, C_{10}}{U^*\, S}$$

Table 36, Summary of Measured & Computed Slopes, Punjab & Sind Canals

Punjab Canals

Canal	$S \times 10^3$ Measured	$S \times 10^3 = 2.09\ d^{0.86}/Q^{0.21}$
1	0.33	0.35
2	0.19	0.15
3	0.20	0.17
4	0.23	0.18
5	0.22	0.20
6	0.22	0.22
7	0.21	0.22
8	0.21	0.19
9	0.20	0.21
10	0.31	0.30
11	0.28	0.29
12	0.26	0.30
13	0.18	0.17
14	0.29	0.26
15	0.17	0.20
16	0.33	0.29
17	0.30	0.28
18	0.27	0.28
19	0.31	0.25
20	0.15	0.18
21	0.15	0.18
22	0.14	0.17
23	0.27	0.28
24	0.15	0.17
25	0.15	0.17
26	0.34	0.30
27	0.13	0.17
28	0.16	0.18
29	0.28	0.28
30	0.20	0.22
31	0.17	0.18
32	0.20	0.24
33	0.22	0.27
34	0.14	0.17
35	0.20	0.20
36	0.16	0.20

Punjab Canals cont.

Canal	$S \times 10^3$ Measured	$S \times 10^3 = 2.09\ d^{0.86}/Q^{0.21}$
37	0.30	0.34
38	0.13	0.12
39	0.21	0.24
40	0.17	0.26
41	0.12	0.12
42	0.21	0.20

Sind Canals

Canal	$S \times 10^3$ Measured	$S \times 10^3 = 2.09\ d^{0.86}/Q^{0.21}$
1	0.0794	0.042
2	0.0744	0.050
3	0.0600	0.059
4	0.0592	0.059
5	0.0623	0.055
6	0.0600	0.063
7	0.0600	0.052
8	0.0650	0.012
9	0.0650	0.051
10	0.0623	0.045
11	0.0724	0.072
12	0.0744	0.075
13	0.0650	0.047
14	0.0600	0.052
15	0.0650	0.050
16	0.0831	0.032
17	0.0800	0.036
18	0.0782	0.039
19	0.0700	0.057
20	0.0693	0.058
21	0.0642	0.058
22	0.0812	0.069
23	0.0773	0.067
24	0.0761	0.065
25	0.0995	0.095
26	0.0773	0.051
27	0.0700	0.025
28	0.0715	0.023