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Some Methods of Computing Retrogression in Channels Due to Change in Sediment Charge

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Synopsis

Some simple methods have been discussed and developed for predicting changes in hydraulic parameters relating to bed degradation of a canal receiving supply from a reservoir or a desilting device which reduces the silt charge to anything between 25 to 90% of the original charge.

Use is made of Lacey's silt factors f_{VR} and f_{RS}, and sediment-transport relations to estimate the probable changes in depth and slope gradient due to reduction in silt charge.

INTRODUCTION

The design criteria of the regime channels in Indo-Pakistan sub-continent is the Lacey theory. This theory with its set of relations was based on the data of stable channels that carried specific load pattern of sediment of coarse and medium sand in summer and winter periods. After the building of the dams, the situation will change considerably. Relatively silt-free water to a varying degree will be diverted into the existing stable or quasi-stable channels which will disturb the existing regime. As the incoming water will bring less silt than the carrying capacity of the channel, the fine and medium sediments in the bed of channel will get into suspension and be carried away resulting in a lowering of the bed. Moreover, the bed grade will gradually become coarse by the removal of fines from the bed by selective sorting. The depths will increase and slopes will flatten out; the bed and surface levels will retrogress. This process will continue till new equilibrium conditions of depth and slope are attained. The retrogression, if not provided for in the design of Hydraulic works, will expose the foundation and endanger the safety of the structure.

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The object of this paper is to develop some simple methods that could be used by a field Engineer to estimate the order of retrogression of levels when the sediment charge reduction is 25%, 50%, 75% and 90% of the original sediment intensities, so that provision may be kept in the design for the future safety of the control structure. For simplification it is assumed that the channel is divided into different reaches *i.e.*, from the control point to the next as shown in Fig. 1 and that a constant discharge passes between each pair of control works. The retrogression is maximum below the upper control structure and minimum on the upstream side of the lower control point.

The symbols used in this paper are defined in list given at the end.

The Channels in Regime and their Load Capacity

The existing channels in regime, specially the large canals from 5,000 cusecs to 20,000 cusecs, have their total load capacities as 100 to 500 ppm. These canals are generally called upon to carry silt charge much more than the optimum carrying capacity during the summer floods when river carries much heavier loads of coarse, medium and fine silt. In spite of silt control measures, the canal offtaking from a headworks gets a fair share of bed material above 0.06 mm. in suspension. Therefore in summer, some silting occurs but in winter the water is almost silt free and scouring takes place so that over a long period there is neither silting nor scouring and the channel's discharging capacity and levels are maintained. Such channels are said to be in regime. The regime will be disturbed when sediment charge is decreased in summer by drawing water from reservoir or due to bad sediment distribution at the offtake when excessive sediment charge enters the canal. It is desired to estimate the maximum retrogression of levels and change in slope with the decrease in silt charge in a given reach of canal assuming that discharge remains the same and channel-banks are firm.

For channels in regime, the depth and slope regime relationship is expressed in the form:—

$$S = K/R^{\frac{1}{2}}, \text{ where } K = 0.3 \text{ to } 0.5$$

The data of Imperial Valley Canals (California) has shown that with the reduction of the sediment load in the Colorado river due to silt deposition upstream of the dam in the reservoirs and sediment control works, the regime of the canals had altered. In the Imperial Valley, the slopes of the canals flattened as much as by two third and the depths increased by 100%. Lane* considers that similar changes are expected to occur in channels of West

*Lane, E. W. Comments on "*Concept of Regime Theory*" by Ning Chien, Transactions Am. S.C E. Vol. 122—1957.

Pakistan where storage dams or water reservoirs will be built and controlled supplies transporting comparatively less sediment will be made through link canals.

Factors affecting Bed Deformation in Alluvial Channels

An alluvial channel is deformed when a change occurs in its width B, depth D, side slopes (or area A), slope S, roughness or Manning's roughness factor N, the grain size and the effective mean protuberance height, K_s. Thus the variables of the alluvial channel defining the deformation of its shape are :

B, D, s, (or A), S, K_s. (or N).

The flow variables which tend to cause this deformation are the discharge Q (or $q = \frac{Q}{B}$, $V = \frac{Q}{A}$), the fluid density ρ_w (or specific weight $\frac{\gamma w}{g}$) and the viscosity μ of water depending on its temperature, thus the variables which cause the deformation are :

$$Q \text{ (or } q), V, \rho_w \text{ (or } \frac{\gamma w}{g}), \mu .$$

The actual deformation occurs due to the erosion or deposition of material on the bed or sides and would be affected by the size, characteristic and concentration of the bed and suspended load. These can be represented by m or d the mean grain diameter in mm or inches respectively or w the fall velocity, σ the standard deviation, ρ_s the density of the material ($\frac{\gamma_s}{g}$) and $\bar{C}$ the mean concentration of the grade size in question and concentration distribution of sediment; thus the variables relating to sediment are :

$$m \text{ (} w), \sigma , \rho_s \text{ (or } \frac{\gamma_w}{g}), \bar{C}, \frac{d\bar{c}}{dy}$$

All the variables put together, we have functional relationship :

$$f \left\{ B, D, s, (A), S, N \left(\frac{K_s}{D}\right), Q \text{ (or } q, V), \rho_w \text{ (or } \frac{\gamma w}{g}), \mu, \right.$$

$$\left. m \text{ (or } w), \sigma , \rho_s \text{ (or } \frac{\gamma_s}{g}) \ \bar{C}, \left(\frac{dc}{dy}\right) \right\}$$

The major independent variables that cause bed deformation and a change in depth D and slope S, are Q (q, V), m (w), $\bar{C}$.

The bed deformation can take two forms:

(a) accretion,

(b) degradation or retrogression.

The first case tends to occur when the silt transport capacity of a channel is less than the incoming silt required to be transported and degradation will

occur if reverse is the case; thus the condition of retrogression, accretion and stability for a given condition of flow and sediment characteristics is:

silt transport capacity of a channel.	$\gtrless$	the silt that is actually to be carried by the channel.	degradation Regime accretion.

In this paper considering Q to be constant the change in depth D and slope S are studied as a result of change (decrease) in the silt charge & grade.

Relation between Sediment Charge and Discharge Intensity

In the years 1961 to 1964 a comprehensive programme for observation of Hydraulic data of Irrigation canals of West Pakistan (known CHOP — Canal and Headworks Observation Programme) was undertaken by WAPDA in collaboration with Harza International and the West Pakistan Irrigation Research Institute. The CHOP data of selected sites for the year 1961 to 1964 pertaining to conditions when canals were running at full supply or near full supply discharge along with corresponding sediment charge has been used in the analysis. In Fig. 2, load in tons/ft./day (q_s') has been plotted against the discharge intensity—q, q_s/q represents the charge in tons/cus/day. It is noted that data can be split into 4 groups.

1. Full charge —the upper line represents about 1 ton/cfs/day. 1 ton=2000 lb.
2. Half charge —the middle line represents about 0.5 ton/cfs/day.
3. Low charge —the lower line represents 0.25 ton/cfs/day.
4. The lowest line represents 0.10 ton/cfs/day.

The full charge of 1 ton/cfs/day represents 6 cfs/cfs /day or 0.37 grm/litre or 370 ppm. Let full charge be represented as a unit charge M of one ton/ cfs/day for a stable regime channel.

In Fig. 3 the mean velocity V is plotted against the load carried, the relation obtained is of the form :

$$V=A+B\,(q_s \cdot w)^{\frac{1}{4}} \qquad \ldots\ldots\ldots(1)$$

where A is function of bed grade for incipient movement and was generally found to vary with bed grade as $A=Km^{\frac{1}{2}}$, where m is diameter in mm. A for the set of data was 0.6 and B=6.0. For velocity v between 2.5—4 ft/sec. we can write :

$$V \propto (q_s \cdot w)^{\frac{1}{4}} \qquad \ldots\ldots\ldots (2)$$

where q_s is the bed material in lbs./ft./second, and w the fall velocity of the sediment (d_{50}) and since $q_s/q = \bar{C}$; the charge in grms/litre on simplification (2) reduces to the form

$$V^3/R \propto (\bar{C}w) \qquad \ldots\ldots\ldots(3)$$

Inglis[2] has established that the bed grade change along a canal is related to discharge by the relation :—

$$m \propto Q^{1/10}$$

$$\text{or } w \propto m \propto Q^{1/10} \qquad \ldots\ldots\ldots(4)$$

will hold in the range of 0.06 mm to 0.4 mm, for the bed material range of the channels whose data is being analysed.

In fact not only the grade but also the silt carrying capacity and hence the silt charge may vary with discharge. The product $\bar{C}.\ w.$ or V^3/D can be taken to bear some relation to discharge.

The values V^2/D and V^3/D from different sources are plotted against Q in Fig. 4 (*a*, *b*). V^2/D varies inversely to discharge whereas V^3/D varies directly with the discharge showing a positive trend. It is seen that the data of V^3/D spreads over a wide band due to variation of rugosity coefficient and ($\bar{C}w$) yielding a relation of the form similar to one obtained by Inglis[2]

$$V^3/D \propto \bar{C}w \propto Q^{1/10} \qquad \ldots\ldots\ldots(5)$$

Let the upper limit in Fig. 4 (*b*) represent the highest value of V^3/D or ($\bar{C}w$). For the same value of Q, mean line will represent the average value and the lower line represents the lower limit of V^3/D or ($\bar{C}w$). The trend can be expressed as :—

$$V^3/D \propto (\bar{C}w) \propto Q^{1/10} \qquad \ldots\ldots\ldots(6)$$

$$\text{or } V^3/D = M'Q^{1/10} \qquad \ldots\ldots\ldots(7)$$

where M′ is fractional charge for a given grade.

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2. C.C. INGLIS: Divergence from Regime in Stable Channels in Alluvium. Central Board of Irrigation—India 1941.

Application of the Relation

It is assumed that the discharge, bed width and grade remaining the same, the admission of clear water into the canal results in a reduction of silt charge by as much as 25% to 90%. Considering Q as constant, the derived relation $V^3/D = M' Q^{3/5}$ is used to estimate the probable changes in depth. Multiplying both sides of relation (7) by the intensity $q = (VD) = 2.5 Q^{1/2}$ will yield

$$V^4 = M' . Q^{1/10} \quad \text{or} \quad V \propto (M')^{1/4} . Q^{.15}$$

Let us now take a regime channel with velocity V, depth D and M′=1, 3/4, 1/4 and 1/10 respectively and work out the changes in V and D with change in M′ (Table I).

TABLE I

Silt Reduction	Silt charge factor M′/M	Changed	
		Velocity	Depth
1. No silt reduction	1.0	1.0 V	1.0 D
2. 25% silt reduction	.75	0.94 V	1.07 D
3. 50% silt reduction	.5	0.86 V	1.16 D
4. 75% silt reduction	.25	0.74 V	1.35 D
5. 90% silt reduction	.1	0.60 V	1.67 D

where M=original regime charge factor.
M′=modified charge factor after change of silt charge.

It will be noted that velocities reduce by 6%, 14%, 26% and 40% after regime section obtains with time, the silt reduction of 25%, 50%, 75% and 90% respectively. The corresponding depths are increased by 7%, 16%, 35% and 67% respectively.

Effect of Degradation of the Bed Material Size

The sediment bed gradation analyses of L.C.C. and U.C.C. canals on different dates in the year 1964 when the canal is carrying heavy silt charge and relative silt-free water, are compared in Fig. 5 (*a*, *b*). It is noted that d_{50} varies with sediment load. The bed grade becomes finer during high concentra-

tion. Its standard deviation $\sigma = \frac{1}{2}\left(\frac{d_{50}}{d_{16}} + \frac{d_{84}}{d_{50}}\right)$ shifts towards a higher value from 1.2 to 1.5. This suggests that with clear water when fine grains are absent or removed from the bed, the mean grain size d_{50} approaches the value d_{84} or d_{90} of high silt concentrated flow.

Calculations of Slope

Regime slope formula $S \propto f^{5/3}/Q^{1/6}$ may be exact for some simple conditions of canals in regime. But in certain cases when sediment charge enters as a variable while discharge remains constant, the regime slope formula fails to predict the probable slope. With reduced sediment charge, the depth increases and slope flattens. From the above regime formula Q being constant $S \propto f^{5/3}$. Since from Lacey's $f \propto m^{1/2}$ and because m increases by selective sorting with decrease in silt charge resulting in increase in f, so S must also increase which is not factual. Inglis's relation of silt factor $f \propto = \frac{(cw)^{1/2}}{(gv)^{1/3}}$ is more realistic and depicts more faithfully the change in slope as affected by change in silt charge.

Assuming a gradual increase in size from 10 to 50% of the mean bed grade due to charge reduction of 25 to 90% and utilizing the transport relation of the authors[3] the probable slope for reduced charge has been calculated as below :

$$q^{2/3} \cdot \frac{S^*}{w^{\frac{1}{2}}} = A + B\,(\bar{C})^{2/3} \qquad \ldots\ldots\ldots(8)$$

where w is the fall velocity for d_{50} and A and B are constants.

In the lower range of sediment charge, the relation becomes

$$q^{2/3} \cdot \frac{S^*}{w^{\frac{1}{2}}} \propto (\bar{C})^{1/3} \qquad \ldots\ldots\ldots(9)$$

Since discharge intensity is constant, relative change in slope can be calculated by relation $S \propto w^{1/2} \cdot (\bar{C})^{1/3}$ as in Table II.

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3. Mushtaq Ahmad & A. Rehman—Design of Alluvial Channels as influenced by Sediment Charge

Proc. West Pakistan Engineering Congress, Vol. XLVI-1962.

TABLE II

Reduction in charge	Bed Grade ratio m'/m	$w^{\frac{1}{2}}$	$S \propto w^{\frac{1}{2}}(\bar{C})^{1/3}$	Reduction in slope
0 No reduction ..	1.0	1.1 $W^{\frac{1}{2}}$	1.0 S	0
25% reduction ..	1.1	1.087 $W^{\frac{1}{2}}$	0.99 S	1%
50% reduction ..	1.25	1.21 $W^{\frac{1}{2}}$	0.96 S	4%
75% reduction ..	1.33	1.275 $W^{\frac{1}{2}}$	0.81 S	19%
90% reduction ..	1.5	1.42 $W^{\frac{1}{2}}$	0.665 S	33%

where m = original regime grade.
m' = modified regime grade after selective sorting.

The slope reduction after new regime is established will be of the order of 1%, 4%, 19%, 33% for reduction of silt charge by 25%, 50%, 75% and 90%. It is noted that for 90% reduction in silt charge the observed slope may be 2/3rd of the existing slope.

Other Methods

Ning Chien's Method (f_{VR}—f_{RS})

Calculations of hydraulic parameters—depth and slope—can be made by Ning Chien's method where he relates f_{VR} and f_{RS} to bed material and its discharge. He analysed regime data on the basis of Einstein's bed load function. In the first step he neglected bank friction and within the range of the observed data up to (1957) he derived f_{VR} and f_{RS} as given below :—

when f_{VR} ranges between 0.4 to 4.4

$$f_{VR} = .75\frac{V^2}{R} = .061\,(\bar{C})^{.715} \qquad \ldots\ldots\ldots(10)$$

and when f_{RS} ranges between 1.25 to 1.50

$$f_{RS} = 192R^{\frac{1}{2}}S^{2/3} = 1.18\,(\bar{C})^{0.052} \qquad \ldots\ldots\ldots(11)$$

where $\bar{C}$ in ppm varies between 10 to 150.

By introducing the sediment size as an additional variable the trend remains the same and the relation proposed is :

$$f_{RS} = 2.2\,d^{0.45}\,(\bar{C})^{.052} \qquad \ldots\ldots\ldots(12)$$

Calculations have been made for silt factors f_{VR} and f_{RS} by reduction in silt charge and these are compared with the original values of f_{VR} and f_{RS} for normal silt charge in Table III.

TABLE III

Silt reduction %	Silt Charge factor m'/m	$f_{VR} \propto C^{.715}$	$f_{RS} \propto C^{.052}$	$(R^{\frac{1}{2}} S^*)$
0	1.0	1.0 f	1.0 f	1.0 $(R^{\frac{1}{2}} S^*)$
25	.75	.815 f	.98 f	.97$(R^{\frac{1}{2}} S^*)$
50	.50	.61 f	.965 f	.96$(R^{\frac{1}{2}} S^*)$
75	.25	.37 f	.93 f	.90$(R^{\frac{1}{2}} S^*)$
90	.10	.19 f	.87 f	.82$(R^{\frac{1}{2}} S^*)$

Knowing f_{VR} from Ning Chien's relation (10) for different silt charges, the value of R can be calculated from $R = 0.91\, q^{2/3}/f^{\frac{1}{3}}$. Substituting the value of R in $(R^{\frac{1}{2}}S^*)$, the slope can be computed. The computed values of R′ and S′ and the percentage reduction are given in Table IV.

TABLE IV

Reduction in silt %	Modified value of $\frac{Rm}{R}$	$\frac{S'}{S}$	$\frac{S''}{S}$	D′% Increase	S′% Decrease	S″% Decrease
0	1.0	1.0	1.0	—	—	—
25	1.07	0.935	0.965	+7	— 6.5	— 3.5
50	1.17	.875	0.92	+17	—12.5	— 8.5
75	1.4	.755	.845	+40	—26.0	—16.0
90	1.75	.625	.73	+75	—37.5	—25.0

R is the original regime Hydraulic radius for normal charge.
Rm is the modified regime Hydraulic radius after reduced charge,
S′ is slope using relation (11).
S″ is slope using relation (12).

Calculations Using Einsteins (ϕ—ψ) Curve

Sediment discharge per unit width is related to the entrainment function by Einstein's bed load curve between ϕ and ψ. In Figure 6 Einstein's (ϕ—ψ) —curve I— is compared with the curve II plotted for the same parameters, using Simon's[4] model data and curve III of the West Pakistan Canal and Headworks Observation Programme data (CHOP) relating to bed material charge above .06 mm. The parameter ϕ—refers to bed material transport intensity and is given by

$$\phi = \frac{q_s}{\gamma_s} \cdot \left(\frac{\rho}{\rho_s - \rho}\right)^{1/2} \cdot \left(\frac{1}{gd^3}\right)^{1/2} \qquad \ldots\ldots\ldots(13)$$

$$\text{and} \quad \psi = \frac{1}{T^*} \cdot \frac{\gamma_s - \gamma}{\gamma} \cdot d/\mathrm{RS} = 1.68\, d/\mathrm{RS}^* = 5.5\, m/\mathrm{RS}^* \qquad \ldots\ldots\ldots(14)$$

where q_s = bed material transport in lbs/ft. sec.
γ_s = specific weight of material for quartz sand.
= 165 lbs/cu/ft.
γ = specific weight of water.
$\frac{\rho}{\rho_s - \rho}$ = relative densities of material and fluid
for quartz sand and water = $\{1/(2.65\text{-}1)\}$.
g = accleration due to gravity.
S^* = slope per thousand (ft.)
d = bed grade dia in ft.
m = bed grade dia in mm.

The ψ' value from equation (14) is obtained by substituting R′ in place of R. The value of R′ is computed from

$$\frac{V}{\sqrt{gR'S}} = 5.75 \log (R'/K)_s + 6.25,$$

where $K_s = d_{65}$

Substituting values, the equation (13) reduces to

$$\phi = 4.35\, qs/m^{3/2} \qquad \ldots\ldots\ldots(15)$$

From Mayer Peter's data using Einstein function, Chien derived Equation for Curve I in Fig. 6

$$\phi = 8\,(1/\psi' - .047)^{3/2} \qquad \ldots\ldots\ldots(16)$$

4. Simons D. B.—Closure "Resistance to Flow in Alluvial Channels". Journal of Hyd. Division. *Proc. of Am. Sc. of C. E.* May, 1962, Part I-p.

But in the straight line portion of the (ϕ—ψ) curve the slope is 3/1 and for this portion Brown Einstein equation is:

$$\phi = 40\ (1/\psi')^3 \qquad \ldots\ldots\ldots(17)$$

The bed material discharge above .06 mm. observed in the West Pakistan canal data (CHOP) plotted as curve III in Fig. 6, conforms to the above equation except that the co-efficient is 200.

$$i.e.,\ \phi = 200\ (1/\psi')^3 \qquad \ldots\ldots\ldots(18)$$

The constant in the equation from the CHOP data is 5 times as given by Brown Einstein for straight portion of (ϕ—ψ) curve I.

Solving equation (18), using $\phi = (4.35\ qs/m^{3/2})$ and $1/\psi' = R'S^*/5.5m$, we get

$$q_s^{1/3} = 0.57\ R'S^*/\ m^{1/2} \qquad \ldots\ldots\ldots(19)$$

This relation can be used to study the relative effect of silt charge on slope.

Variation of Diameter with Silt Charge

If the representative mean grain diameter changes with sediment charge, the selection of suitable mean grade of the representative bed sample assumes importance. The order of variation of mean grain diameter has, therefore, to be assumed with the variation of sediment charge. On examination of the sediment and the hydraulic data of Upper Chenab Canal and Lower Chenab Canal, it is noted that :—

(*i*) Bed grade summation curves vary from season to season.

(*ii*) Mean grade is comparatively finer during high concentration due to addition of fines in the bed load. The summation curves shift towards the coarse side in winter due to the removal of fines from the bed.

(*iii*) The variation in the mean dia. may be as much as 30 to 70%.

(*iv*) Generally, from the CHOP data (Fig. 7), it has been found that $R' \approx 0.4R$ in the range of Froude No. between 0.15 to 0.2. Because R′ is only a fraction of R, changes in R′ will be much smaller for a given change in R. Now, if, R′S varies with sediment charge, the maximum change in S will be when R′ is supposed to remain constant. Therefore for such a case R′ may be taken as insignificantly varying with silt charge.

Now assuming that bed grade varies by 50% for 90% reduction in charge, from the expression directly derived from equation (19):

$$S^* \propto q_s^{1/3} \cdot m^{1/2} / R', \qquad ..(20)$$

the calculated slope is given in table V below :

TABLE V

Reduction in Charge %	Unit Charge C	Bed Grade $= m'/m.$	$S \propto \frac{m^{1/2} q_s^{1/3}}{R'}$	Slope Reduction %
0	1.0	1.0	1.000 S	0.0
25	0.75	1.1	0.995 S	4.5
50	0.50	1.25	0.895 S	10.5
75	0.25	1.33	0.730 S	27.0
90	0.10	1.50	0.570 S	43.0

Where m is the bed grade of original channel in regime and m' is the modified bed grade of channel in regime after reduction of charge.

It is noted that the slope flattens by 10% and 43% for 50% and 90% reduction in silt charge.

A Practical Example

Data for Upper Chenab Canal is given in Table VI.

TABLE VI

Discharge Q in cusecs	16000
$q = 0.4Q^{1/2}$	52
Slope S ‰	0.15
Depth D/ (in ft.)	13
Hyd. Radius R	12

[contd.

Bed grade m_{65}		0.24
m_{50}		0.23
m_{35}		0.21
Bed Material Discharge	qs = ton/cs/day	1
	qs = lb/ft./sec.	1.2
	$\bar{C}$ = gr/litre.	0.37
ϕ		52
R′		4.32 ft.
R S*		.65 ft.
V		4.0 ft./sec.
$\sqrt{g\,R'S}$		0.145
$\psi'=5.5\,m_{35}/R'S^*$		1.8
R′/Ks (where Ks = d_{65})		5500

In the data the various parameters are calculated and recorded. Sediment bed material observed during summer approaches a limit of as much as 500 p.p.m. with a slope steeper than originally designed at S = 1/6666 (or S* = .15). It is assumed that channels with unit charge capacity pass one ton per cusec per day, that equals C = 0.37 *gr*/litre for design slope.

Corresponding to 1-ton/(c. ft)/day or *qs*...1.2 lbs/ft./sec. with a discharge intensity of 52 cusecs/ft., we have

$$\phi = 4.35\, q_s / m_{35}^{3/2} = 52.$$

Shear intensity is computed from relation 14, using the logarithmic formula for mean velocity :

$$V/\sqrt{gR'S} = 5.75 \log_{10} (12.2\, R'/Ks) \qquad \ldots\ldots\ldots(21)$$

TABLE No. VII.—*Upper Chenab Canal*

Charge Reduction %	Unit Charge C	Unit Bed Grade	ϕ	ψ'	R′	R′S*	$\sqrt{gR'S}$	$V/\sqrt{gR'S}$ From Curve[1]	$V/\sqrt{gR'S}$ Cal :
1	2	3	4	5	6	7	8	9	10
0	1.00	1.0 *m*	52.0	1.8	4.32	.65	.145	21.0	21.0
25	0.75	1.1 *m*	34.0	2.06	4.32	.58	.137	19.7	19.5
50	0.50	1.25 *m*	18.5	2.54	4.32	.567	.135	17.0	18.9
75	0.25	1.33 *m*	8.4	3.33	4.32	.465	.122	14.5	17.5
90	0.10	1.5 *m*	2.86	4.70	4.32	.370	.109	12.0	16.0

R′/Ks	R″=(R—R′)	$\sqrt{gR''S}$	$V/\sqrt{gR''S}$	V	S*	D	R	Reduction Percentage Slope	% Increase in Depth
11	12	13	14	15	16	17	18	19	20
5500	7.68	.194	27.8	4.05	.150	13.0	12.0	0	0
5000	8.48	.193	27.5	3.76	.136	13.8	12.8	9.6%	6.15%
4400	9.00	.195	27.2	3.67	.132	14.0	13.3	12%	7.7%
4100	10.18	.188	27.0	3.30	.108	15.8	14.5	38%	21.4%
3700	11.88	.180	26.7	2.90	.086	17.8	16.2	43.5%	37.0%

1. Col. 9, 13 & 14, Einstein's Friction Curve

The corrected value of R′ is computed as 4.32 ft. The relative roughness :

$$R'/Ks = 4.32 \times 3.5/.24 = 5500$$

It is assumed that R′ remains nearly constant for all cases of sediment reduction of 25%, 50% 75% and 90%, and relative roughness will vary accord- to bed grade increment ratio.

The process of computation of velocity and slopes for all sediment reduction ratios is done in Table VII. The velocity is 4.05 ft/sec. with full charge but it reduces to 3.76, 3.67, 3.3 and 2.9 ft./sec; the corresponding slopes being S*= 0.15, 0.136, 0.132, 0.108, 0.086 respectively. The percentage decrease in slope is 9.6, 12, 38 and 43.5 and the corresponding increase in depth being 6.15, 7.7, 21.4 and 37% respectively. Thus it follows that up to 50% charge-reduction, the variation of slope and depth remains within 12%, and the tractive force γRS remains (.113 to .111) almost unchanged. For extreme case of 90% reduction of charge, the tractive force will be 0.087 showing a reduction of 23%

Engelund's[5] Friction Curve

Based on the concept of similarity of bed shape in respect of equal ratio of the ripple height to the length of ripple, it is assumed that similar shapes exhibit the same resistance. Engelund showed that a plot of $(D/d_{35})\ \sqrt{\psi'}$ against $S/(s-1)$ gives a definite relation.

$$\frac{1}{\psi'} = \theta' = R'S/(s-1) \cdot d_{35} \qquad \ldots\ldots\ldots(22)$$

where s is specific gravity of the material $= \frac{\rho_s}{\rho}$

The chop regime data has been plotted with Engelund's parameter in Fig. 8, on which Engelund's curve is superimposed. The curve shows a positive trend.

The practical application of the curve is that it reads slope directly.

Taking Upper Chenab Canal data with designed slope of 0.15‰ and $\psi' = 1.8$ for transporting 1-tons/cs/day sediment charge and using equation 22.

$$D/d_{35}\,(1.8)^{1/2} \propto \{S/(s-1)\}$$

5. Engelund F., Hydraulics of Alluvial Streams. *Journal, Hydraulic Division*, Am. Sec. C.E. March 66, 4739.

Using the curve in Fig. 8 the relative roughness is determined as D/d_{35} = 14,800.

This relative roughness is adopted and assumed to remain constant throughout computations of slope for Upper Chenab Canal as given in Table VIII.

TABLE VIII.—*Slope Computation*

Charge Reduction %	D/d_{35}	ψ'	$D/d_{35}\psi'^{1/2}$	$S/(s-1)$	S‰
0	14,800	1.8	20,000	.09	.15
25	14,800	2.06	20,300	.088	.148
50	14,800	2.54	23,500	.077	.13
75	14,800	3.33	27,300	.066	.111
90	14,800	4.70	32,000	.058	.097

Comparison with the slope of Einstein curve shows satisfactory agreement except the last case when sediment reduction is 90%.

Comparison of Results and Conclusions

The calculations made by different methods for estimating change in velocity, depth and slope as a result of reduction in the silt charge, are compared in Table IX. Ning Chien's relation connecting f_{VR} and f_{RS} to (q_s/q) and author's plotting of velocity $\propto (q_s . w)^{1/4}$ gives almost the same values for regime parameters after different sediment reductions. It will be realised that reduction of silt charge results in the scouring of sandy bed, and the calculated percentage-increase in depth will be 7%, 16.5%, 37.5% and 69% for the corresponding sediment reduction of 25%, 50%, 75% and 90%. With changes in velocity and depth, the changes in the Lacey's silt factor are very obvious. The Froude No. of flow for the new regime may decrease from its normal value of F_r = 0.2 to 0.1 for almost silt-free water. The percentage reduction in slope as worked out in Table IX is 3.7%, 10.9%, 24% and 36.5% for the corresponding sediment reductions. It is noted that the ultimate new slope may be about 60% of the initial slope.

In conclusion simple methods of estimating the ultimate degradation for different sediment reductions have been given. It is yet not so easy to estimate the rate of degradation involving all the variables. It is necessary

to study the mechanics of degradation more thoroughly and for that more detailed data of the bed material will be needed. If the bed contains coarse material that could act in such a way as to armour the bed for a given velocity, the process of degradation will stop earlier. But for the safety of the works, it is necessary to know what ultimate degradation is expected so that it could be provided for in the design. This is exactly what has been attempted in this paper.

TABLE IX.—*Change in velocity, depth and slope with percentage reduction in silt by different methods.*

Sediment Reduction Percentage		0	25	50	75	90
Change in Velocity & Depth						
1. Velocity						
(*i*) V : $(q_s . w)^{1/4}$		V	.94 V	.86 V	.74 V	.60 V
(*ii*) Ning Chien f_{VR} : q_s/q	..	V	.94 V	.88 V	.71 V	.57 V
Average	..	V	.94 V	.86 V	.725V	.585V
2. Depth $= q/V$						
(*i*) V : $(q_s . w)^{1/4}$	..	D	1.07 D	1.16 D	1.35 D	1.67 D
(*ii*) Ning Chien f_{VR} : q_s/q	..	D	1.07 D	1.17 D	1.40 D	1.75 D
Average	..	D	1.07 D	1.165D	1.375D	1.69 D
3. Lacey Silt Factor : f_0/f_1		1	.83	.64	.38	.2
Percentage Change in Slope by % Reduction in Silt Change						
4. Slope						
(*i*) $q^{2/3}$ S*/*w*: $(\bar{C})^{1/3}$	..	S_o	6.5	11.0	26.5	42.3
(*ii*) Ning Chien f_{RS} : q_s/q.	..	S_o	3.5	8.5	16.0	25.0
(*iii*) Brown Einstein (ϕ—ψ).		S_o	4.5	10.5	27	43
(*iv*) Engelund Curve	..	S_o	0.2	13.5	26.5	35.5
$D/d \quad \psi'^{1/2}\ s-1/S$						
Average slope %reduction		S_o	3.7	10.9	24	36.5

LIST OF SYMBOLS

A	Area
B	Channel Width
$\bar{C}$	Average Concentration of Sediment Transport in Grams Per Litre
$\frac{d\bar{c}}{dy}$	Concentration Gradient with depth
D	Depth of Flow
F_r	Froude Number
f_{RS}, f_{VR}	Lacey's Silt Factors
K_s	Protuberance Height
K	Constant
N	Manning's Roughness Coefficient
M	Unit Charge (1 Ton/CFt/Day)
M′	Fractional Charge
m	Mean Grain size in *mm*
Q	Fluid Discharge
q_s	Bed Material in Lbs/ft/Second
R	Hydraulic Radius
R_m	Modified Regime Hydraulic Radius with reduced charge
S	Energy Slope
S′, S″	Modified Slopes
s	Side Slope
V	Velocity of Flow
w	Fall Velocity of Particle
ρs	Density of Material
ρw	Density of Fluid
γ	Specific weight of Fluid
γs	Specific weight of Material
μ	Viscosity
σ	Standard Deviation
ϕ	Einstein's bed load function
ψ	Einstein's Entrainment Function

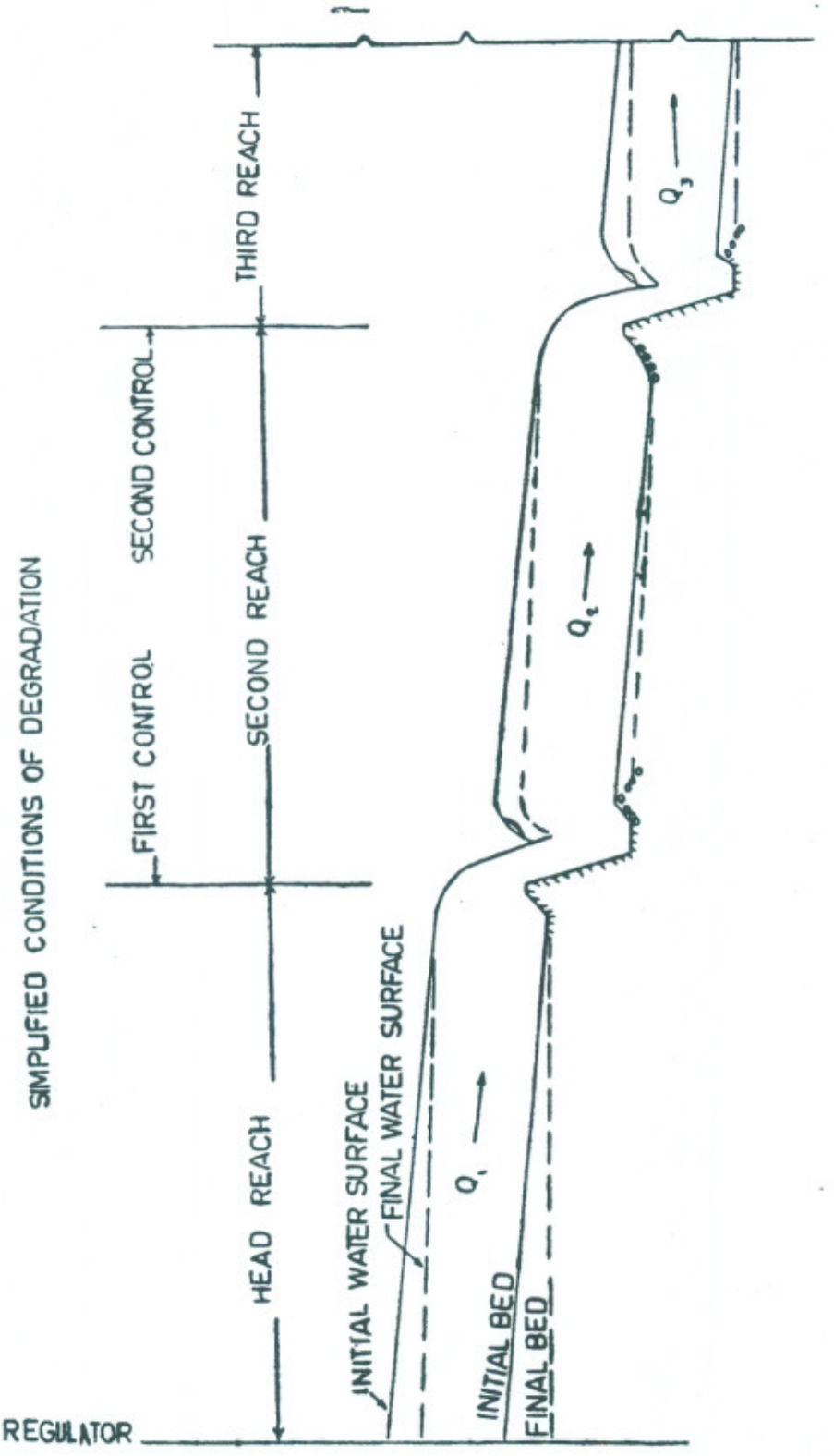

SIMPLIFIED CONDITIONS OF DEGRADATION
HEAD REACH
FIRST CONTROL
SECOND REACH
SECOND CONTROL
THIRD REACH
REGULATOR
INITIAL WATER SURFACE
FINAL WATER SURFACE
INITIAL BED
FINAL BED
Q1
Q2
Q3

FIG 1

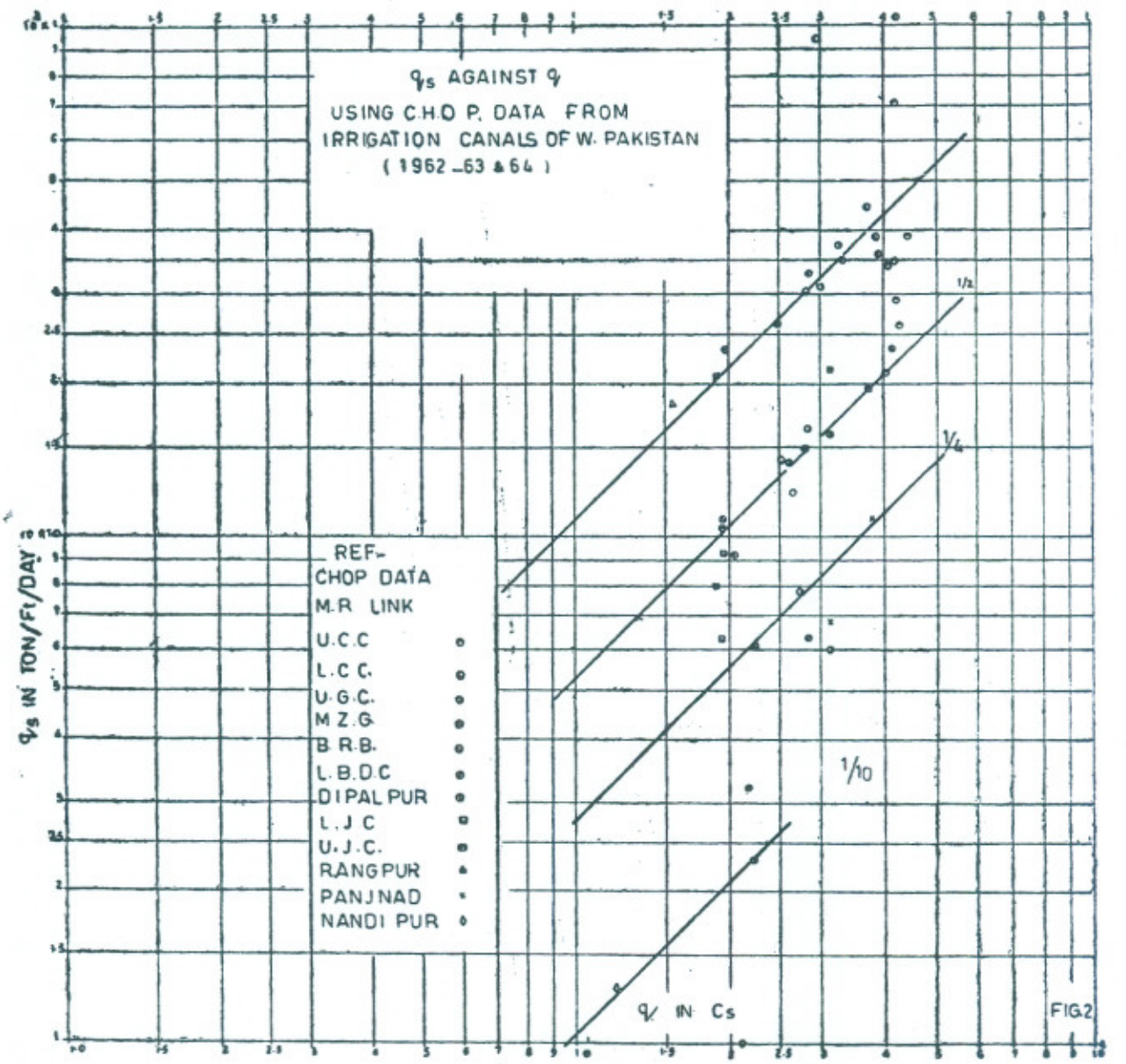
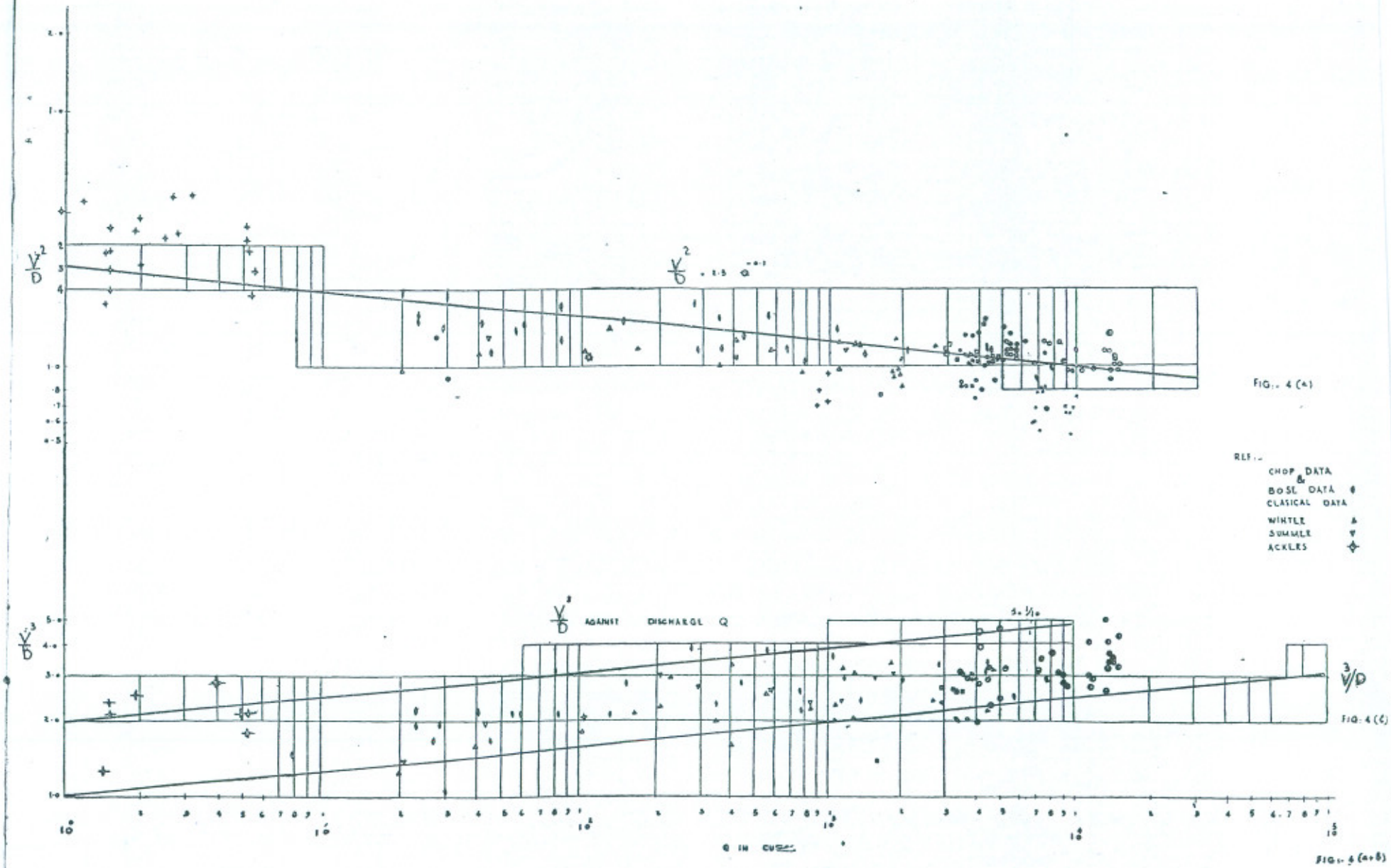

q_s AGAINST q
USING C.H.O P. DATA FROM
IRRIGATION CANALS OF W. PAKISTAN
(1962 -63 & 64)
REF-
CHOP DATA
M.R LINK
U.C.C
L.C.C.
U.G.C.
M.Z.G.
B.R.B.
L.B.D.C
DIPALPUR
L.J.C
U.J.C.
RANGPUR
PANJNAD
NANDI PUR
1/2
1/4
1/10
q_s IN TON/Ft/DAY
q IN Cs

FIG.2


$\frac{V^2}{D}$
$\frac{V^2}{D}$. 2.5 Q^-0.1
FIG:- 4 (A)
REF:-
CHOP & DATA
BOSE DATA
CLASICAL DATA
WHITE
SUMMER
ACKERS
$\frac{V^3}{D}$
$\frac{V^3}{D}$ AGAINST DISCHARGE Q
S = 1/10
$\frac{V^3}{D}$
FIG:- 4 (C)
Q IN CUSEC
FIG:- 4 (A+B)

LOWER CHENAB CANAL

R.D 149000

TOTAL CHARGE IN P.P.M		B&D GRADE m_{50}
DATE		
11.11.63	750	295
5.12.63	389	270
8.1.64	1310	350
6.3.64	640	355
5.4.64	774	365
7.5.64	689	310
7.6.64	673	280

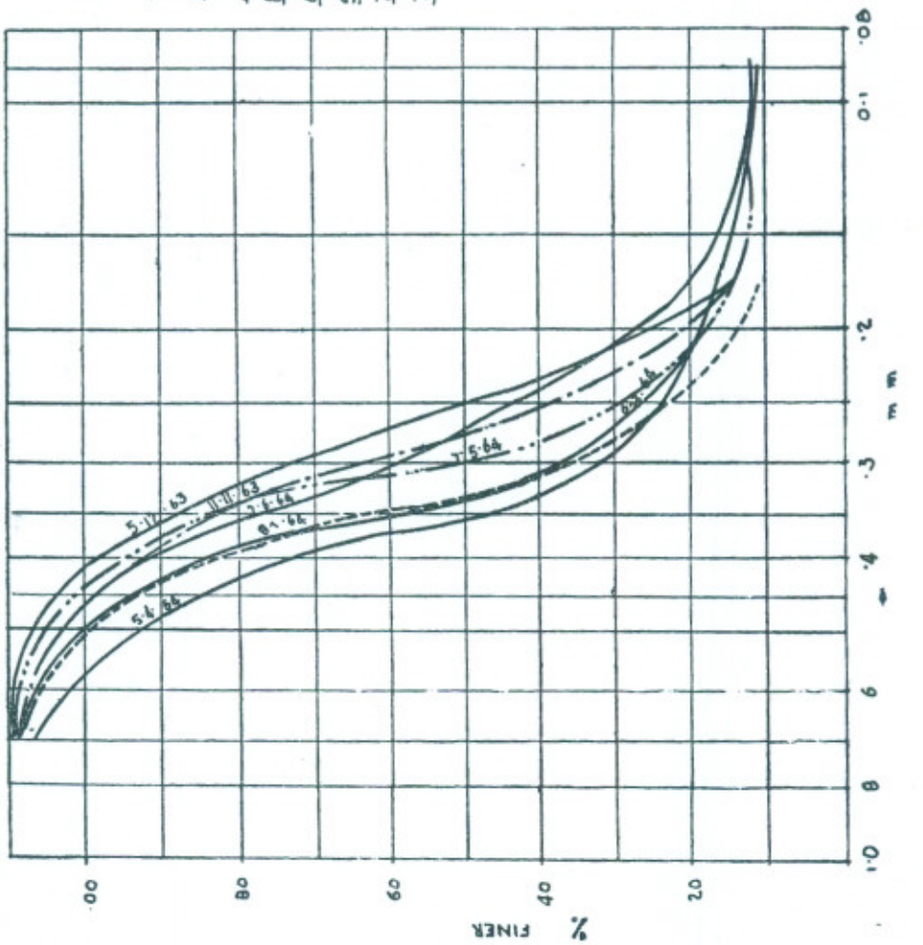
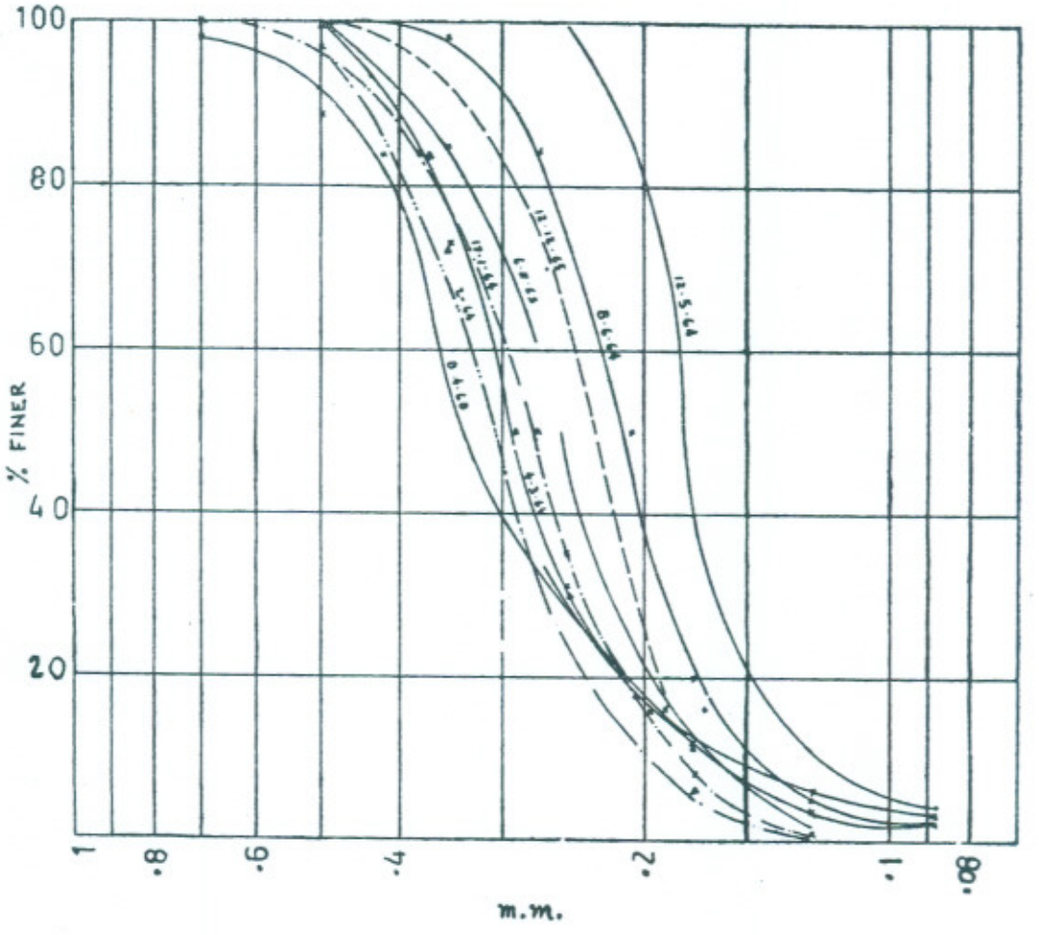


FIG: 5(a)

UPPER CHENAB CANAL
R.D. 29000

FIG-5 (b)

DATE	TOTAL CHARGE IN PPM	BED GRADE M_{50}
4-11-63	129	.255
12-12-63	222	.230
17-1-64	215	.272
28-2-64	196	.30
14-3-64	404	.290
8-4-64	230	.340
12-5-64	405	.180
8-6-64	352	.210



RIPPLE AND DUNE REGIME

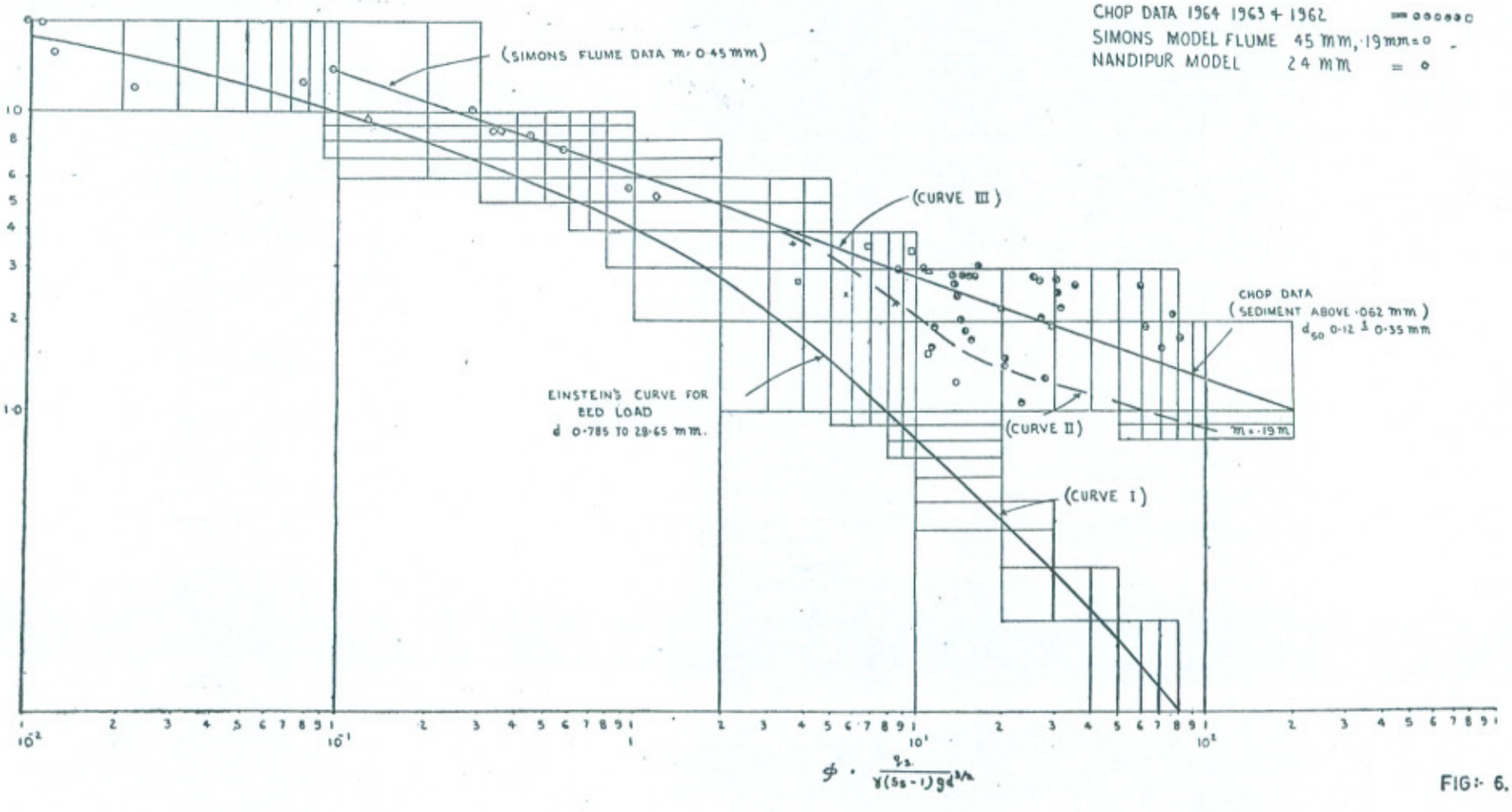


FIG:- 6.

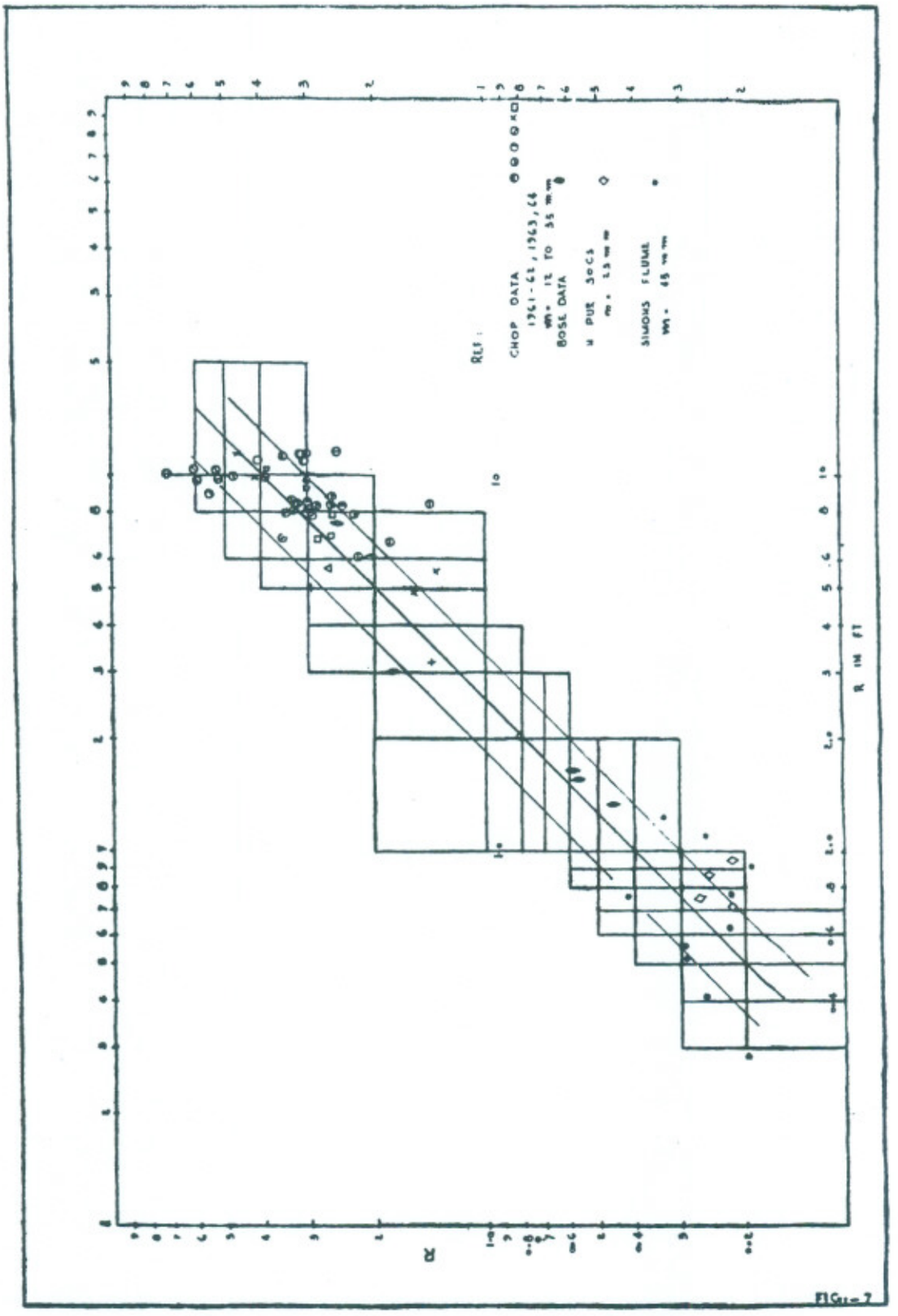
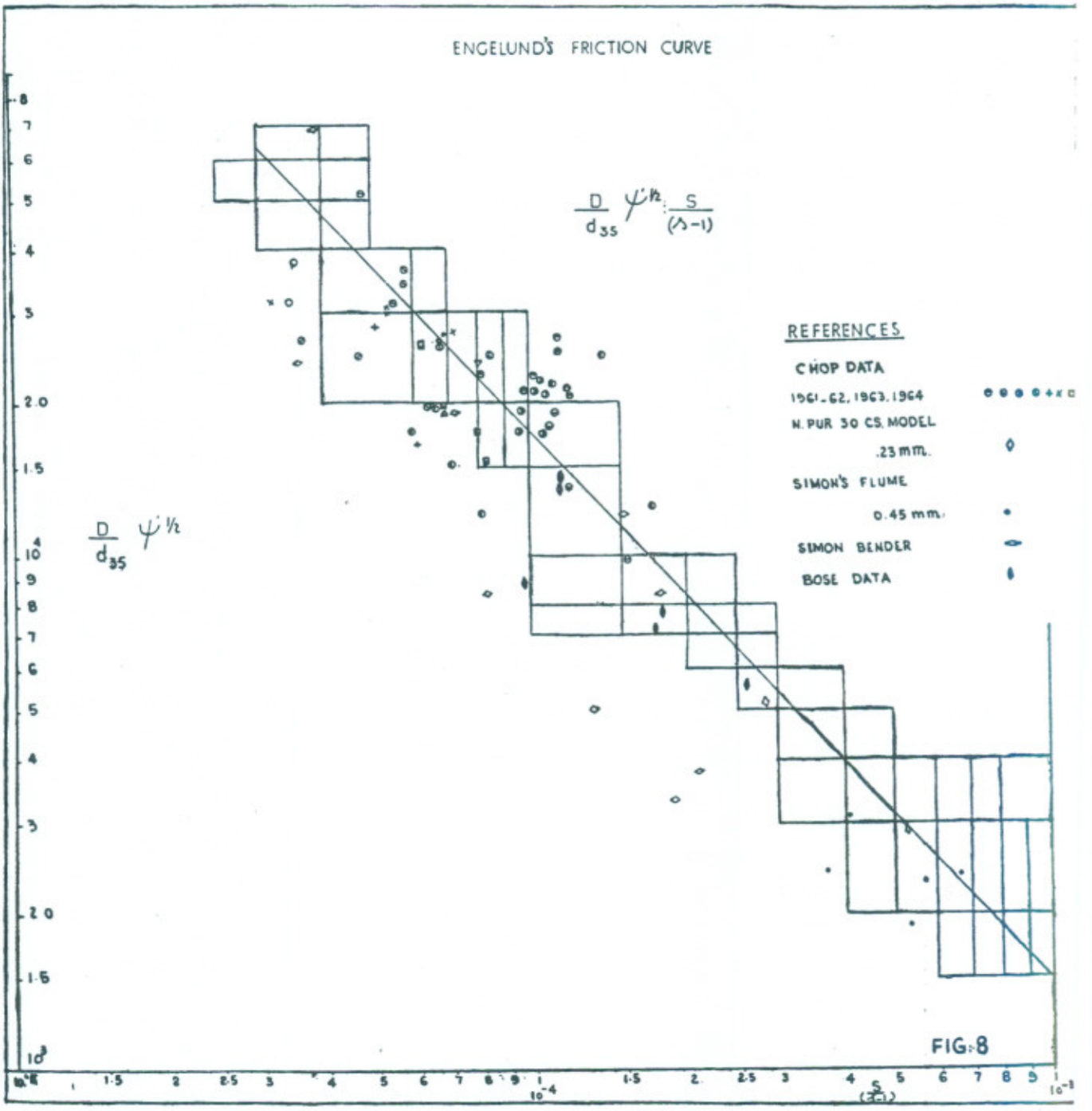


FIG. - 7


ENGELUND'S FRICTION CURVE
$\frac{D}{d_{35}}\psi^{1/2}:\frac{S}{(S-1)}$
$\frac{D}{d_{35}}\psi^{1/2}$
REFERENCES
CHOP DATA
1961-62, 1963, 1964
N. PUR 30 CS. MODEL
.23 mm.
SIMON'S FLUME
0.45 mm.
SIMON BENDER
BOSE DATA
FIG-8