Appraisal and Analysis of New Data from Alluvial Canals of West Pakistan in relation to Regime Concepts and Formulæ

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'CHOP' data has been analysed to determine Lacey's constants in his different regime relations. For the reasons explained in the text the ratio of actual to designed discharge has been used as a parameter. The values of constants specially in width discharge and slope discharge relations for the actual discharge/designed discharge equal to unity have been found to agree fairly well, with Lacey's values showing that computation for variable discharges should always be made for sustqined maximum discharge. The effect of silt charge on the reduction of friction factor 'n' is also studied. It has been found difficult to estimate the correct value of 'n' in relation to silt charge alone. The variation of Blench-King Number with n has also been studied. It appears to be quite significant. The reduction of friction factor with increase in the discharge is indicated. Capacity of regime channels to transport silt has been determined by authors in modified silt transport relation. The position of 'CHOP' data in the different regimes of flow has been shown to lie in the ripple and dune regime.

Appraisal of Previous Work

The history of evolution of regime concept and design of alluvial channels is closely associated with the development of Irrigation in the Indus Basin. The earlier engineers faced with the problem of constructing Irrigation canals had little information on the subject and used Chezy and Kutters formulae for the design of early channels such as Upper Bari Doab Canal, Sirhind and Lower Swat Canals.

Kennedy[1] in 1895, from 22 selected sites which he considered to be in regime on Upper Bari Doab Canal presented his first relation for non-silting, non-scouring channel connecting velocity and depth in the form

$V = C.D^m$

where the coefficient and power both C and m were fixed for U.B.D.C. as 0.84 and 0.64 respectively.

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Kennedy's work had become well known and his relations were adopted in India and Egypt. The most important channels designed on Kennedy's regime concept were Lower Jhelum, Upper Jhelum and Lower Bari Doab Canals. After 1910 the major system of canals *viz.* Upper Chenab Canal and Lower Bari Doab Canal were constructed and Lindley[2] in 1919 from 786 observations on Lower Chenab Canal System made a further contribution to the concept of regime of channels. Both bed width and depth were introduced as regime variables. He also pointed out that slope is an additional variable. He in fact clearly defined the regime phenomena and the variables entering into the problem, when he said:

> "When the artificial channel is used to convey silty water, both bed and banks, scour or fill, changing depth, gradient and width, until a state of balance is attained at which the channel is said to be in regime. These regime dimensions depend on discharge, quantity and nature of berm-silt, rugosity of silted section; rugosity is also affected by velocity, which determines the size of wavelets into which the silted bed is thrown."

Lindley even visualised that silt charge being carried by the channel is an influencing factor in the regime concept. While replying 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 supply loaded with a given silt charge were all fixed by nature."

He could, however, only correlate variables connecting width and depth with velocity. His equations were:

$$V=0.95\,D^{.57}$$

$$V=0.59\,B^{.355}$$

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

It is to be noted that neither Kennedy nor Lindley made direct volocity observations. Only bed width, depth and slopes were observed. Velocities were calculated by using Kutter's equation:

$$C=\frac{41.65+\frac{0.00281}{S}+\frac{1.811}{n}}{1+\frac{n}{\sqrt{R}}\left(41.65+\frac{.00281}{S}\right)}$$

n in this equation was assumed to be 0.0225.

Evidently Kutter's formula entered into the regime relations by implication.

The next major contribution to Regime Theory was made at the time when the engineers were confronted with other major projects in this part of the country *viz.* Sutlej Valley Project and Sukkur Barrage Project. Mr. Gerald Lacey of the United Provinces Government was specially deputed to study regime data and evolve working principles for the design of alluvial channels.

Lacey adopted Chezy's approach, that resistance is proportional to the square of velocity and that the force to counter-balance the resistance would vary with discharge and slope. He did not make any observation himself but analysed the existing regime data. Lacey[3] adopted R and P in place of D and B, and made fresh computations and derived a new set of relations *viz* :

$$V = 1.15\ [\ fR\ ]^{1/2}$$

$$Af^2 = 4V^5$$

equating Q = P.R.V. and by eliminating f, yielded

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

His complete set of equations is given below:

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

$$A = \frac{1.26Q^{5/6}}{f^{1/3}}$$

$$V = 0.7939\ Q^{1/6}.f^{1/3}$$

$$R = 0.4725\left(\frac{Q}{f}\right)^{1/3}$$

$$S = 0.000547\frac{f^{5/3}}{Q^{1/6}}$$

$$(SV) = 0.000434\ f^2$$

$$\frac{P}{R} = 5.65\ Q^{1/6}.f^{1/3}$$

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

$$VR = 0.375\ Q^{1/2}$$

In 1934, the Central Board of Irrigation (India) accepted Lacey's equations and curves as basis of design for alluvial channels.

Since Lacey had not collected any data himself; after publication of Lacey's theories and equations it was also decided by the Central Board of

Irrigation (India) that canal data should be collected from regime sites, by the Irrigation Research Organisations of various Provinces, to check Lacey's relations. The work of collecting data in the alluvial channels of Punjab was entrusted to Punjab Irrigation Research Institute. Dr. N. K. Bose selected 43 sites on different canals varying in discharge from 5 cusecs to 6000 cusecs.

Dr. Bose[4] and Malhotra carried out the analysis of new data and in 1939 produced the following set of equations :

$$V = 1.12\, D^{1/2}$$

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

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

$$S = 2.09\, m^{.86}/Q^{.21}$$

In fact this was the first systematic collection of data in which discharges were measured and silt samples were taken and analysed for each observation site. In the period 1942 to 1960 very little systematic collection of fresh data on stable alluvial channels was made in this part of the country.

However, as a result of further analysis of the old data and discussions of the older results, some modification in the coefficients or powers of the equations, some discrepancies and disagreements and some new concepts were brought to light. It was shown that Lacey's two values

f_{RS} and f_{VR}

do not agree. Attempts were made to make the equations non-dimensional and introduce sediment charge from theoretical considerations only.

Blench and King[5] introduced two new features *i.e.*, the bed and side factors utilising in their analysis the same data and proposed the following relations :

$$b = V^2/D$$

defined as the bed factor

$$s = V^3/B$$

defined as side factor; and

$$V^2/gDS = 3.63\ (VB/\nu)^{1/4}$$

as width to depth ratio in terms of Reynolds No. except that

VD/ν is replaced by VB/ν.

As a result of continuous researches by Lacey,[6] Inglis,[7] Bose,[8] Blench[9] and King—the main exponents of empirical and statistical approach on the regime theory concepts continued to develop. Outside the country, the theory though not receiving full recognition attracted attention of prominent Research Workers such as Lane,[10] Straub,[11] White,[12] Albertson,[13] Simons,[14] Maddock[15] and others.

Dr. N. K. Bose after publication of his relations in 1939 started further collection of data from Irrigation canals on the regime sites and included suspended sediment charge as an additional observation. The suspended silt data collected in 1940, 42 and 43 remained unused in the records of the Irrigation Research Institute till the authors[16] used it in 1961-62 and attempted to bring sediment charge as an additional factor in the analysis of the regime data and the design of alluvial channels.

Need for fresh Data on stable channels

Since Central Board of Irrigation of the Government of India accepted Lacey's design methods and his regime equations as basis of design of alluvial channels, large number of canals such as Haveli, Thal, B.R.B.D., Balloki Suleimanki Link, M.R. Link, and channels taking off from Kotri, Taunsa and Gudu have been designed, on this basis. Some of the channels that have been designed in the period 1947 onwards were very much bigger in capacity than those from which Lacey's data was obtained. As all these equations were statistical and empirical, and because some of the link canals were beyond the range of existing data, and were designed on extrapolated range, moreover some of the canals such as M. R. Link with excessive sediment charge suffered from chronic heavy silting, a need for collecting fresh data was very much realised by all.

Canal and Headworks Data Observation Programme 'CHOP'

After the Indus Basin Water Treaty between Pakistan and India, Pakistan was beset with the problem of constructing 7 new canals with a capacity varying from 6,500 to 21,700 cusces. The total length of the canals would be about 400 miles. The larger canals will be bigger than those constructed before and for conditions widely different from original Lacey's concept because some of the channels would now take off from reservoir with very much less sediment charge. It was thus considered necessary to review Lacey's regime concept in view of the most stringent design demands of new channels in alluvium. It was decided to collect fresh performance data of existing regime channels specially channels with higher discharges. This later known as 'Chop' (Canal and Headworks Observation Programme) was jointly set up by WAPDA and Irrigation Department in collaboration with 'Harza International' working as a Central Agency to coordinate and process the data obtained from regime sites. The canals selected with reaches and frequency of measurements of discharge, channel width, depth, velocity and silt charge are given in Tables I & II.

At each selected reach the discharge at a section was measured; sediment samples were collected by depth integrating samplers and bed material samples were also taken. Soundings were taken to determine bed configuration on three or more cross-sections in the reach. Water surface elevations at interval of 1000 ft. in the reach were observed. Water temperatures and velocity profiles were observed. This data was published by Wapda in April 1963. With such new valuable data from different channels becoming available, independent analysis has been made by Tipton & Kalmbach,[18] Harza and Mr. S. S. Kirmani.[19] Since the publication of the data the authors have been working to analyse and the results, in continuation of the work they produced and presented to the last two meetings of the West Pakistan Engineering Congress. are presented in this paper.

Special Features and Limitations of 'CHOP' DATA

The analysis of the Chop Data had to be made keeping the following limitations in view :

(1) The data pertains to one Summer Season only.

(2) The discharges in the canals have been varying considerably in the period of observation. The past history of the regime sites in relation to designed discharge and the dominant regime-forming discharges that have been running in the past and have been responsible for the formation of the Section have not been given for different sites.

(3) The nature of the site material at the regime sections has not been fully specified as to its qualities of resistance to change the Sections.

(4) In view of the fact that observations do not extend to 2 or 3 summer periods intervened by clear water periods. The over—all regime conditions over a long period in relation to the correlation of the ruling parameters such as discharge, silt charge and bed material size may not be significant.

(5) For the analysis of bed samples to determine the mean grain diameter. "Bottom Withdrawal Tube method" has been utilised whereas for Bose's analysis "Optical Lever Siltometer" was used. It is maintained that the former gives lower mean values as compared to the latter.

(6) These observations were made in limited reaches. some more observations on long reaches may be desirable.

(7) The observations in the reach near head-regulator of the canal are likely to show rapid fluctuations specially when the observations are confined to a short period of one Summer because the head reach is generally very sensitive to changes in silt charge. These sites are likely to give more dispersion in data,

But data from sites selected away from the head-regulator can throw more light on changes brought about by silt charge variation. These variations travel down the canal and affect its regime.

In spite of all these remarks it is really a valuable data in which independent observations on discharge, velocity profile, suspended load, bed diameter and accurate slope etc. have been taken from canals with wide range of discharge.

Appraisal of 'CHOP' DATA

The authors started the analysis after April this year when the data was made available in printed form. Tipton—Kalmbach and Harza's have presented their initial analysis of the data almost simultaneously with the presentation of the data. The main conclusions of the analysis by Tipton and Kalmbach were :

(1) The constant K in the Lacey's relation

$$P = K\ Q^{\frac{1}{2}}$$

is 3 instead of 2.67. The wetted perimeters should, therefore, be higher than Lacey's by 11 to 16%.

(2) The Sectional area should also be higher than that of Lacey. This would give lower velocities than those compared to Lacey's.

(3) The friction factor in terms of Manning's n for the canal is more than the Lacey's mean value of .0225.

(4) The bank slopes adopted to angle of repose should be 2 to 1 instead of half to one.

Harza Int. made their own analysis of data and later Mr. Kirmani made a thorough and painstaking examination of the data point by point and showed by making suitable assumptions that the wetted perimeter corresponding to dominant discharge agrees with the Lacey's values. However, it is not the purpose of this paper to discuss the results of the analysis in any detail but to present the analysis made by the Authors in their independent approach.

While appraising the data the authors also noted as was done by Mr. Kirmani that there is wide variation in discharge during the period of observations and that we have to keep in mind the fact that within a period of 6 months to which the observations relate, the changes in the Section cannot follow sympathetically the changes in discharge. Now if the discharge changes, without a change in cross-section, the depth and velocities would change with it somewhat according to the depth discharge relation. The change in depth, velocity and slope will also depend on the change in the rugosity due to silt charge variation and type of flow. At different stages it may be smooth bed. rippled bed or even duned bed. The depth, velocity and slope would, therefore, be affected due to simple variation of discharge and sometimes change in rugosity due to change in sediment charge without involving the regime concept of dependence of P on Q or depth on Q. In a stable channel of trapezoidal Section if discharge alone decreases, depth may vary as $Q^{3/5}$ and for a channel width compared to its depth, the change in Ws may be insignificant as compared to change in depth. Thus a correlation of mean depths and widths should not be done with mean values of actual discharges specially when the discharges lower than the maximum designed discharge have been running for periods not long enough to affect the regime dimension but can still influence the mean values of Q and by implication of D. For the analysis, therefore, it was necessary to assess the ruling maxium discharge which may have been responsible in forming the channel to its regime Section. For this purpose the maximum designed discharge of the channel was taken as a parameter. In the analysis that follows, Lacey's coefficients were studied as a ratio of the actual discharge to the designed discharge, thus in Lacey's relation,

$$P/Q^{\frac{1}{2}} = K_1$$

K_1 has been studied against the ratio of actual discharge to the design discharge to see if the value of K tends to agree with Lacey's value when actual discharge over design discharge tends to become equal to one. Similar studies have been made for Lacey's slope relations.

Analysis of 'CHOP' Data.

In the analysis of 'Chop' Data, an attempt has been made to test the following relationships :

1. Width-discharge relation $Ws : Q^{1/2}$
2. Slope discharge relation (*i*) $S : Q^{1/6}$
   (*ii*) $S : q^{1/3}$
3. $R^{1/2} : S$ relation.
4. Sediment charge and Manning's n.
5. Correlation between slope and the particle size.
6. (*a*) Correlation of Lacey's f and particle size.
   (*b*) Lacey's silt factor f, m and q.
7. Silt transport relation $\dfrac{q^{2/3}.S^*}{W^{1/2}} = A' + B' C^{2/3}$

8. Place of Chop Data in the Regimes of flow in Alluvial Channels.

9. (*a*) Blench-King No. $\frac{V^2}{gDS} \cdot / \frac{VB}{\nu}$ and Manning's n.

(*b*) Lacey's coefficient of S: Q relation and Mannings n.

10. Darcy-Weis-bach f_o and Reynold No. $\frac{4R.V}{\nu}$.

(1) Width-Discharge Relation

For the reasons given in the previous paras the actual mean values of Q have not been used for testing this relation but $W_s/Q^{1/2}$ has been plotted against the discharge ratio *i.e.*, actual discharge Q/Q_o, where Q_o is the designed discharge. For each value of discharge, W_s has been taken as the surface water width. The actual and design discharge Q and Q_o are taken from the Chop data Column 5 of the tables and the details given on the first page of each canal data respectively. The curve at Fig. 1 shows a falling trend as the ratio Q/Q_o approaches unity. The mean values for constant in the equation are given below :

Q/Q_o	$K_1 = W_s/Q^{1/2}$
0.4	3.9
0.6	3.45
0.8	3.02
1.0	2.6

It will be apparent that as Q/Q_o tends to unity the value of $K_1 = Ws/Q^{1/2}$ approaches very closely to the Lacey's value of 2.67. This shows that Lacey's relation holds good for the maximum designed discharge of the channel.

(2) Slope-Discharge Relation.

Lacey's slope discharge relation.

$$S^* = K_2 f^{5/3}/Q^{1/6}$$

can be written as

$$Q^{1/6} \cdot S^*/f^{5/3} = K_2$$

Taking f_{RS} from the Chop Data for this relation the constant has been calculated and a curve has been plotted between Q/Q_o (where Qo is the design discharge) and $K_2 = Q^{1/6} \cdot S^*/f^{5/3}$. The results are plotted in Fig. 2 which shows a scatter of $\pm$ 20% and the values of constant K_2 are as below :

Q/Q_o	$K_2 = S^*.Q^{1/6}/f^{5/3}$
0.4	0.64
0.6	0.605
0.8	0.57
0.9	0.555
1.0	0.54

The constant K_2 of the equation for Q/Q_o = unity agrees fairly well with the Lacey's relation: again showing that the relation holds good for the design discharge but the value of f in the relation is f_{RS}.

Lacey's slope discharge relation can also be written as

$S^* = K_3 f^{5/3}/q^{1/3}$, where K_3 is the constant

This can be written as $S^*.\ q^{1/3}/f^{5/3} = K_3$

This constant again has been calculated from Chop Data, again using the value of f_{RS} and has been plotted against Q/Q_o in Fig. 3. It shows a scatter of 10% only. The value of the constant K_3 has a range 0.35 to 0.4 for discharge ratio of 0.4 to 0.9. The mean value of K for discharge ratio of unity agrees closely with Lacey's value of 0.39.

(3) R—S Relation.

Lacey while defining a regime channel as a "stable channel transporting the minimum bed load consistent with a fully active bed" produced new equations

$$f_{(VS)} = 48\ \sqrt{VS}$$

and $VS = K\ (R^{1/2}S)^n$

and in terms of regime general equation this takes the form

$$SV = 16\ (R^{1/2}S)^{4/3}$$

In the present study, the constant in the equation

$$R^{1/2}S = \text{constant} \times f^{3/2}_{(RS)}$$

derived from $f_{RS} = 192R^{1/3}S^{2/3}$

has been studied.

The data plotted on Fig. 4 shows that the mean value of the constant occurring in the relation is 0.36 for $Q/Q_o = 1$. This again agrees with Lacey's figure.

(4) Sediment charge and Mannings 'n'.

Fig. 5 shows the change of Manning's n with silt charge: the upper figure is for coarse silt above .062 mm and the lower one for total suspended silt. The table shows range of n for different silt-charge ranges carried by the flowing water.

Range of C in p.p.m.	For coarse silt		For total silt	
	n	Average value.	n	Average value
10-20	.015 to .02	.017		
100-200	.02 to .03	.025		
200-300	.021 to .031	.026	.02 to .033	.026
300-500	.021 to .033	.027	.02 to .032	.026
500-1000	mean .025	.025	.02 to .03	.025
1000-2000	.022	.022	.018 to .028	.023

From this study, it appears that as silt charge increases, the value of 'n' decreases. It will be seen that Lacey's value of 'n' = .0225 falls in the range 100 to 200 parts per million of coarse silt above .062 mm. For silt charge greater than 500 parts per million; the average value of Manning's 'n' is .025 and from this data in Lacey's range 'n' comes out to be .026 instead of .0225 as proposed by Lacey.

(5) **Correlation between surface slope and the particle size**

Steeper slopes are symptomatic of higher velocities. therefore, large particle sizes are capable of being transported by water. It is considered desirable to determine the correlation between surface slope and the particle size. The Chop data for m and S* is plotted in Fig. 6, that shows a wide scatter. Some points from classical data of Punjab and Sind, Simon's and Laurson model data were chosen and introduced into the figure. This data pertains to particle size range from .02 to 0.4 m/m. The Fig. shows that there is a definite trend of higher slopes for larger particle sizes. The band of S* and m can be connected by a relation:

$$S \propto m^{5/6}$$

The data appears to be supporting Bose's adoption of particle size in his slope relation.

(6) (*a*) **Correlation of silt factor f_{VR} and m.**

A direct plot between f_{VR} and m shows a scatter. Another plot (Fig. 7) was made between $S^*/W^{1/2}$ and discharge intensity. The Chop data gives information for q above 12 cusecs only, therefore, classical data of Punjab, Sind and Simon's model data in the range of Fr=0.1 to 0.3 were introduced. The slope of the band is 1/4.

It yields a relation as:

$$q^{1/4} . S*/W^{1/2} = \text{constant} \times f$$

which is similar to Lacey's $q^{1/3}. S*/f^{5/3} = 0.39$.
and also compares favourably with Author's relation

$$q^{1/3}. S*/W^{1/2} = 1$$

A comparison of slope discharge and friction relations is given below:

Slope $S = \frac{0.39}{(VD)^{1/3}} .f^{5/3} \times 10^{-3}$ (Lacey)

Slope $S \propto \frac{W^{1/2}}{(VD)^{1/4}}.f$ (New relation)

Slope $S = fo.V^2/2gD$ (Darcy-weisbach)

friction factor $fo = \frac{K}{\left(\frac{VD}{\nu}\right)^{1/4}}$ (Blasius)

from Darcy-weisbach equation

$$\frac{S}{fo} \propto \frac{V^2}{gD} = \text{Froude No. or Lacey f}$$

Slope and friction factor fo appear to have similar forms and their ratio gives the Froude No. or Lacey f.

(6) (*b*) Correlating Lacey's f, m and q

Assuming silt charge in the Lacey channel to be proportional to discharge intensity, a plotting between q and $f/\sqrt{m}$ was made in fig. 8. This indicates that excepting a few points, the data can be considered to yield a simple relation.

$$f/\sqrt{m} = (0.5 + .05q) = K$$

The constant varies from 1.1 to 3.0 with an average value of 1.9. This indicates that the correct form of the relation is $f = K\sqrt{m}$
where K appears to depend upon discharge per foot run and by implication on silt charge.

(7) Silt transport relation.

Authors' silt transport function presented in the last session of the Engineering Congress can be written as :

$$q^{2/3} S*/W^{1/2} = A' + B'.C^{2/3}$$

where the constants A′ and B′ were
0.5 and 5 respectively,

Dr. Simons, while commenting on last year's paper suggested a change of the coefficient A′ from 0.5 to 1.0 to fit the data of Simons and Bender Canals. The present data has been plotted over the same curve in Fig. 9 (*a*). The conclusions are that the average suspended silt data appears to follow the mean curve, but the silt above .06 m.m. is less than that predicted by the curve (Fig. 9 (*b*), therefore, the constant B′ of the equation is changed to 7 and the equation is written as

$$q^{2/3} \cdot \frac{S^*}{W^{1/2}} = 1 + 7[\bar{C}]^{2/3}$$

The above relation is employed to calculate the average capacity of a channel to carry sediment load above .06 mm.

When the equation is written in the slope form as

$$S^* = \frac{(1+7C)^{2/3}(W)^{1/2}}{q^{2/3}}$$

and comparing with Lacey's slope relation

$$S^* = \frac{0.39}{q} \cdot \frac{f^{5/3}}{1/3}$$

substituting $f = 1.9\sqrt{m}$ and $m^{5/6} = W^{1/2}$

$$.39f^{5/3} = 1.13W^{1/2}$$

$$1.13q^{1/3} = (1+7C^{2/3})$$

$\bar{C}$ above ·06 mm. in gr/litre

$$= \left\{ \frac{1.13q^{1/3} - 1}{7} \right\}^{3/2}$$

The values have been calculated in Table III and the curve is shown in Fig. 10. The Chop data is plotted in Fig. 11 as $\bar{C}$: q. The previous data as well as the data of average silt intensity above .06 mm observed at the boil has also been included (in the same figure). The mean of the CHOP data is represented by the curve drawn. The previous Punjab data falls to the right half only. The reason probably may be that the present silt charge observation is made by depth integrating sampler whereas the previous data was by a point sampling in a boil. This point is being further investigated. The calculation for average silt indicates that roughly the permissible silt $\bar{C}$ is very nearly proportional to the discharge intensity. Simple relation comes out to be as :

q=2 to 30 Cs. $\bar{C}=7.\ q$
in p. p. m.

q=40 to 60Cs. $\bar{C} = 6.\ q$
in p.p.m.

8 The position of CHOP data in the regimes of flow.

Lacey's regime lies in the stream flow range having

$$F_r=\frac{V}{\sqrt{gd}}= \text{between } 0.15 \text{ to } 0.23$$

=averge 0.19 say 0.2

In this range, the bed has ripples, and dunes and the channel silts and scours to form in the end a stable channel.

Research work in Western Laboratories has shown that sand bed can take different forms depending upon the velocity depth ratio or Froude No., silt charge and the slope. The types of regimes have been suggested as :

(1) Plane bed (without motion of sediment particles).
(2) Ripples and dunes.
(3) Transition (including bars and flat bed).
(4) Standing waves and antidunes.

Data plotted by Garde[20] and Albertson at Fig. 11 indicates the various regimes. The ordinate is showing the tractive force divided by the submerged weight of the particle and the abscissa as the Froude No. The bold line divides the ripples and dunes zone from transition zone and dotted line further divides antidunes zone. Our Chop data falls at the ripple and dune position for

Fr=.15 to .23

and $\frac{\tau}{(\gamma_1-\gamma)d}=.45$ to 3.8

On the left is the plane bed; where the data of Mississippi river near Arkansas City m =0.2 mm falls. The data of river Ganges at Hardinge Bridge in the East Pakistan falls in this zone too.

Q→	10^5Cs.	10^6Cs.
Fr. No.$=\frac{V}{\sqrt{gD}}$	0.085	0.12
$\tau^*=\frac{\gamma DS}{(\gamma_1-\gamma)d}$	2.2	5.0

and its position is along the line of Mississippi river.

9 (*a*) Relation between Manning n and Nk-the King No. in Blench equation for actual discharges.

The Blench relation gives

$$V^2/gDS=3.63\left(\frac{VB}{\nu}\right)^{1/4} \text{ for low silt charge}$$

$$=3.63\left(\frac{VB}{\nu}\right)^{1/4}(1+\alpha C) \text{ for high silt charge.}$$

The silt charge factor due to the bed load is quite small and it is not likely to affect the relation as a whole, for higher concentrations of suspended silt, the variation of King No.

$$N_k=3.63\ (1+\alpha\ C)$$

has been plotted in Fig. 12 against Mannings 'n' observed for the same flow. As the plotting indicates there is a wide variation of King No. changing from 1.25 to 9.4 for the corresponding bed roughness

$$n=.035 \text{ to } .016$$

It is apparent that the King No. varies inversely as the Mannings 'n'. The mean value of King No. 3.63 occurs for one value of n=.022—the Lacey channel rugosity coefficient.

(9) (*b*) **Manning's 'n' and Lacey's coefficient of slope-discharge relation for actual discharges.**

Lacey Slope discharge coefficient $K_2=S^*Q^{1/6}/f^{5/3}$ and Mannings 'n' for actual discharges have been plotted in Fig. 13.

The figure shows that the Lacey S—Q coefficient varies inversely as Mannings 'n'. The relationship can be expressed as,

$$n=.06-\frac{K_2}{15}$$

For $K_2=0.54$, the value of n=0.024 for F. S. conditions.

(10) **Friction Factor Diagram.**

Weis-bach friction factor f_o for the data calculated from the formula

$$f_o=2\ gDS/V^2$$

is plotted against Reynolds No. $4\,RV/\nu$ in the range 5×10^6 to 1.18×10^7 in Fig. 14. It gives different phases of turbulent flow over the universal friction factor curve. The Blasius line

$$f_o=.316/R_e^{1/4}$$

terminating at $R_e=10^5$, has been extended to higher range of Reynold numbers.

Data of Sidhnai, Panjnad, Abbasia and Rangpur having flat slopes and low values of friction factor, shows a better fit for the Blasius line and data of L.C.C. and M.R. Link with slopes 1/5,000 to 1/7,000 falls between the smooth pipe and complete rough turbulent region. A few points fall beyond the complete turbulent zone. It follows that the boundary conditions formed by the water sediment complex is determined by the channel slope and the value of its friction factor. Conversely a channel with a flatter slope will have smooth boundary conditions while a steep one has smooth-rough boundary formed of ripples and dunes. Thus regime channels can belong to both types of smooth and smooth-rough boundary conditions.

SUMMARY AND CONCLUSIONS

Discharges have been considerably varying in the period of observation; the variation being between limits of 40 to 102% of the designed channel capacity. A check up of the Lacey relations and the range of their coefficients was made by adopting the ratio Q/Q_o *i.e.*, actual discharge/designed discharge as a parameter. The study was made for following relations :

(1) Ws: Q width-discharge relation.

(2) a. S/Q slope discharge relation.

b. S/q slope discharge intensity relation.

(3) R.S Depth-Slope relation

(4) $f/\sqrt{m}$ Silt factor-diameter relation.

The data indicates that :

1. $K_1 = W_s/Q^{1/2}$ has a maximum value of 3.9 for the discharge ratio of Q/Q_o equal to 0.4 but this value approaches Lacey K=2.67 as the ratio Q/Q_o is nearly unity. T & K's evaluation of $K_1=3$ corresponds to Q/Q_o equal to 0.8.

2. $K_2 = S^*.Q^{1/6}/f^{5/3}$ gives a band with some variation—its range being 0.45 to 0.7. The average value of K_2 for Q/Qo=1 is 0.54 which fairly agrees with Lacey value.

(b) $K_3 = S^*.q^{1/3}/f^{5/3}$ gives lesser scatter and its value ranges between 0.42 and 0.35; the mean value of 0.39 for $Q/Q_o=1$ again agrees with Lacey's value.

3. $R^{1/2}S^*/f^{3/2}$ behaves similar to item (2b). Its range varies from 0.3 to 0.4 while its average value for $Q/Q_o=1$ is about 0.36.

(4) $f/\sqrt{m}$ shows a variation of 1.1 to 3.0 with an average of 1.9 against Lacey's value of 1.76.

(b) S: m indicates that there is a slope band occurring as $S^*: m^{.86}$, thus the 'CHOP' data, in a way supports Bose slope relation

$$S. \propto m^{.86}/Q^{.21}$$

whereas $m^{.86} = w^{1/2}$ was shown by authors previously.

(5) For the effect of silt concentration on Mannings 'n', the data shows a variation between the range

$$n = .018 \text{ to } .033$$

therefore the correct value is very difficult to predict.

The change in rugosity coefficient n is large when the bed changes, such that ripple and dunes disappear and a flat bed forms when n=.012 can be attained.

(b) Lacey K_2 in slope-discharge relation is very much connected to the Mannings' 'n'. The data shows that K_2 varies inversely as Mannings' 'n'. A relation found from thê plotting is :

$$n = .06 - K_2/15$$

The value of K_2 for F. S. conditions is 0.54 which gives the bed roughness n=.024 against Lacey's assumed value of .0225.

(6) **Universal friction factor curve**

$$f_0 = 2\ gDS/V^2$$

from pipe flow is adopted to indicate the change in the value of friction as the Reynolds No. or the discharge intensity increases. The curve and the data indicate that the average slope of the friction factor corresponds to Blasius line extension and the curve for smooth pipe for higher Reynolds number.

(7) **Blench King No. vs Rugosity.**

$$N_k = \frac{V^2}{gDS} \Big/ \left[\frac{VB}{\nu}\right]^{1/4} = 3.63\ (1 + \alpha c)$$

shows a wide variation of King No. It changes from 1.25 to 9.4 for the corresponding bed roughness n = .035 to .012

For the value of n=.022 the corresponding value of $N_k = 3.63$

It follows if the friction factor of a channel remains between n=.022 to .024 the N_k is likely to remain fairly constant.

(8) **Silt transport relation:**

$q^{2/3} S^{*}/W^{1/2} = A' + B'(C)^{2/3}$ the value of constant $A = 1$, has been previously suggested by Simons. With the present data the constants in the relation take the values as :

(*i*) for total silt charge in suspension C_T.

$$A' = 1, B' = 5.$$

(*ii*) for silt charge above .06 mm $\bar{C} = A' = 1; B' = 7$.

(9) **Channel's capacity for silt transport.**

For Froude Number of flow $V/\sqrt{gD}$ equal to 0.2 silt capacity appears to be proportional to discharge intensity. Roughly each cusec contributes 6 p.p.m.

TABLE 1—WEST PAKISTAN CANALS DATA 1962

Station		R. D.	Q. in Cs.	q in Cs.	V Ft./sec	Width Surface ft.	Average Depth ft.	l/S
1	2	3	4	5	6	7	8	9
Sidhnai		13000-23000	3330-3980	20.1-26.5	2.52-3.10	178-182	6.7-8.5	7980-14300
Panjnad	(1)	68000-77000	9860-8960	35.4-38.3	2.81-3.00	268-272	11.8-12.3	9700-11570
,,	(2)	137000-141000	6850-7320	29.6-31.6	2.65-2.89	248-252	10.0-10.40	8970-11200
Abbasia		9000-14000	878-972	12.8-13.5	2.26-1.84	77-79	5.5-6.3	9250-13400
Haveli		20000-28000	3900-4880	..	3.77-4.08	104-110	9.3-12.3	8680-13100
Rangpur		11000-15000	1790-1960	14.4-15.5	2.30-2.49	132-136	5.8-6.4	8210-10400
L. C. C.		147000-151000	4860-5640	25.7-30.6	2.96-3.17	201-205	8.1-9.0	3000-5510
U. J. C.	(1)	42000-46000	4590-6200	24.2-30.01	2.85-3.30	212-216	7.5-8.8	6220-6700
,,	(2)	106100-108900	4330-5250	26.7-34.04	3.03-3.43	166-172	8.4-9.4	5630-6910
M.R. Link	(1)	20000-26000	12800-15500	34.9-36.71	3.38-4.51	388-395	8.8-10.5	3410-6200
,,	(2)	154000-160000	12400-15000	35.0-41.9	4.84-5.24	367-373	6.9-7.8	8450-9200
U. C. C.	(1)	23000-29000	5350-14400	22.0-43.2	2.67-3.50	340-360	5.90-11.80	4620-6100
,,	(2)	100000-105000	6790-14200	23.2-44.9	2.78-4.27	324-334	7.60-10.80	4050-6170
L. J. C.	(1)	160000-166000	3030- 3870	15.2-19.8	2.59-2.74	210-212	5.60-6.80	6000-7600

TABLE 1—*continued*

Station		n	f_{VR}	f_{RS}	$\bar{C}$ in ppm above .062 mm	C_T in p.p.m.	Bed sediment	
							Diamater in mm.	Std. deviation
1	2	10	11	12	13	14	15	16
Sidhnai		.016-.021	.57-1.03	.63-.92	25-800	124-8530	.05-.07	..
Panjnad	(1)	.024-.028	.50-.58	.85-.96	26-252	425-3650	.175-.197	1.25-1.272
,,	(2)	.022-.028	.52-.63	.83-.96	82-370	411-4180	.139-.163	1.22-1.23
Abbasia		.018-.027	.45-.75	.61-.79	26-195	142-4840	.167-.20	1.217-1.23
Haveli		.014-.019	1.09-1.39	.71-.95	..	77- 830	..	..
Rangpur		.020-.022	.61-.82	.73-.85	67-440	251-3770	.16 -.23	1.295-1.330
L. C. C.		.027-.036	.83-.89	1.25-1.88	104-466	615-2620	.20 -.34	1.35 -1.43
U. J. C.	(1)	.023-.025	.81-.97	1.07-1.15	174-1203	524-4150	.14 -.35	1.30 -1.80
,,	(2)	.024-.027	.85-1.04	1.81-1.77	146-473	419-1560	.17 -.208	1.335-1.520
M.R. Link	(1)	.024-.030	.87-1.76	1.21-1.73	117-530	806-1680	.12 -.20	1.38 -1.54
,,	(2)	.011-.012	2.60-3.93	.85-.92	530-1220	987-1000	.126-.17	1.27 -1.28
U. C. C.	(1)	.025-.033	.73-.91	1.16-1.47	79-587	141-2260	.23 -.36	1.35 -1.48
,,	(2)	.024-.027	.77-1.47	1.11-1.59	320-850	181-2310	.168-.25	1.21 -1.49
L. J. C.	(1)	.021-.025	.82-.93	.92-1.10	220-250	225-3820	.23 -.29	..

TABLE 2.—CHOP DATA SHOWING AVERAGE OF OBSERVED READINGS THROUGH 1962

S. No.	Station	R. D.	Discharge in cusecs		q-cs.	V-ft/sec.	Width surface ft.	Average depth ft.
			Designed	Q-actual				
1	Sidhnai	13000- 23000	4005	3690	22.1	2.75	179.8	7.78
2	Panjnad	68000- 77000	9120	9412	36.9	2.88	27.0	12.1
	,,	137000-144000	6980	7090	30.9	2.79	26.9	10.1
3	Haveli	26000- 28000	5200	4248	45	3.93	106.4	10.4
4	Abbasia	9000- 14000	1064	926	13.1	2.05	78.0	5.8
5	Rangpur	11000- 15000	2700	1887	15.0	2.37	134.3	6.0
6	L. C. C.	147000-151000	4750	5400	28.7	3.09	203.0	8.57
7	Upper Gogera	42000- 46000	4950	5400	27.6	3.03	215.0	8.3
	,,	106000-109000	4174	4940	31.7	3.22	170.0	8.9
8	M. R. Link	20000- 26000	23000	11025	35.3	3.77	390.0	9.8
	,,	154000-160000	21000	13725	38.3	5.08	370.0	7.3
9	U. C. C.	23000- 29000	16500	10660	30.8	3.27	350.0	9.5
	,,	100000-105000	16500	12000	38.7	3.75	330.0	9.7
10	L. J. C.	160000-166000	3890	3600	18.2	2.68	211.0	6.4

TABLE 2.—CHOP DATA SHOWING AVERAGE OF OBSERVED READINGS THROUGH 1962—*Continued*

S. No.	Station	m_{50}	1/S	n	f_{VR}	f_{RS}	$\bar{C}$ above .062 mm ppm	C_T in ppm.
1	Sidhnai	. 06	11450	.019	.79	.75	255	3470
2	Panjnad	0.187	11208	.026	.53	.90	147	1572
	,,	0.151	9800	.025	.58	.91	207	3441
3	Haveli	..	10328	.017	1.23	.87	..	..
4	Abbasia	0.188	10990	.022	.59	.69	125	2220
5	Rangpur	0.187	9400	.021	.73	.79	226	1370
6	L. C. C.	0.285	4670	.030	.86	1.44	330	1528
7	Upper Gogera	0.253	6470	.024	.87	1.11	700	1865
	,,	0.253	6050	.025	.89	1.28	290	906
8	M. R. Link	0.160	4423	.026	1.17	1.47	469	1242
	,,	0.144	8623	.012	2.93	.88	831	1492
9	U. C. C.	0. 19	5200	.029	.80	1.35	340	945
	,,	0. 19	5200	.025	1.12	1.40	557	1366
10	L. J. C.	0. 26	6880	.023	.87	.92	162	1514

TABLE No. 3

Sediment Carrying Capacity of Stable Channels; $Fr=\frac{V}{\sqrt{gD}}=$ *about* 0.2

$$\bar{C}=\left(\frac{1.13\,q^{\frac{1}{3}}-1}{7}\right)^{3/2}$$

in gr./lit.

Discharge intensity in cusecs q	$\bar{C}$—Silt charge above .062 mm.	
	in gr./litre	in P.P.M.
1	.003	3
2	.014	14
5	.046	46
10	.089	89
15	.125	125
20	.156	156
25	.179	179
30	.216	216
35	.24	240
40	.262	262
45	.28	280
50	.30	300
55	.32	320
60	.343	343
80	.41	410

NOTATIONS AND SYMBOLS USED

A =Area of water section.
B =Bed width.
b =Bed factor in Blench relation.
$\overline{C}$ =Silt Concentration in gms/litre or P.P.M. above .06 mm as explained in the text.
C_T =Total Silt Concentration.
D =Depth.
F =Froude No.
f =Lacey Silt factor.
f_{VR}, f_{RS} =Lacey Silt factors from V—R, R—S relations.
f_o =Weisbach friction factor.
g =Gravitation
K =Constant.
m, m_{50} =Mean grain diameter of bed material in mm.
d, d_{50} =Mean grain diameter in ft.
n =Manning's rugosity coefficient
P =Wetted perimeter.
Q =Discharge.
Q_o =Designed discharge.
q =Discharge per foot run
R =Hydraulic mean depth.
R_e =Reynolds Number
S =Slope of water surface
S* =Slope per thousand
s =Side factor in Blench relation.
U_* =Shear velocity.
V =Mean velocity.
W =Fall velocity of particles in still water.
W_s =Water surface width.

A′, B′, C, K_1, K_2, K_3, m, have been used as constants and explained in the text.
ν =Kinematic Viscosity.
τ =Tractive force.
γ_1 =Specific weight of sand.
γ =Specific weight of water.

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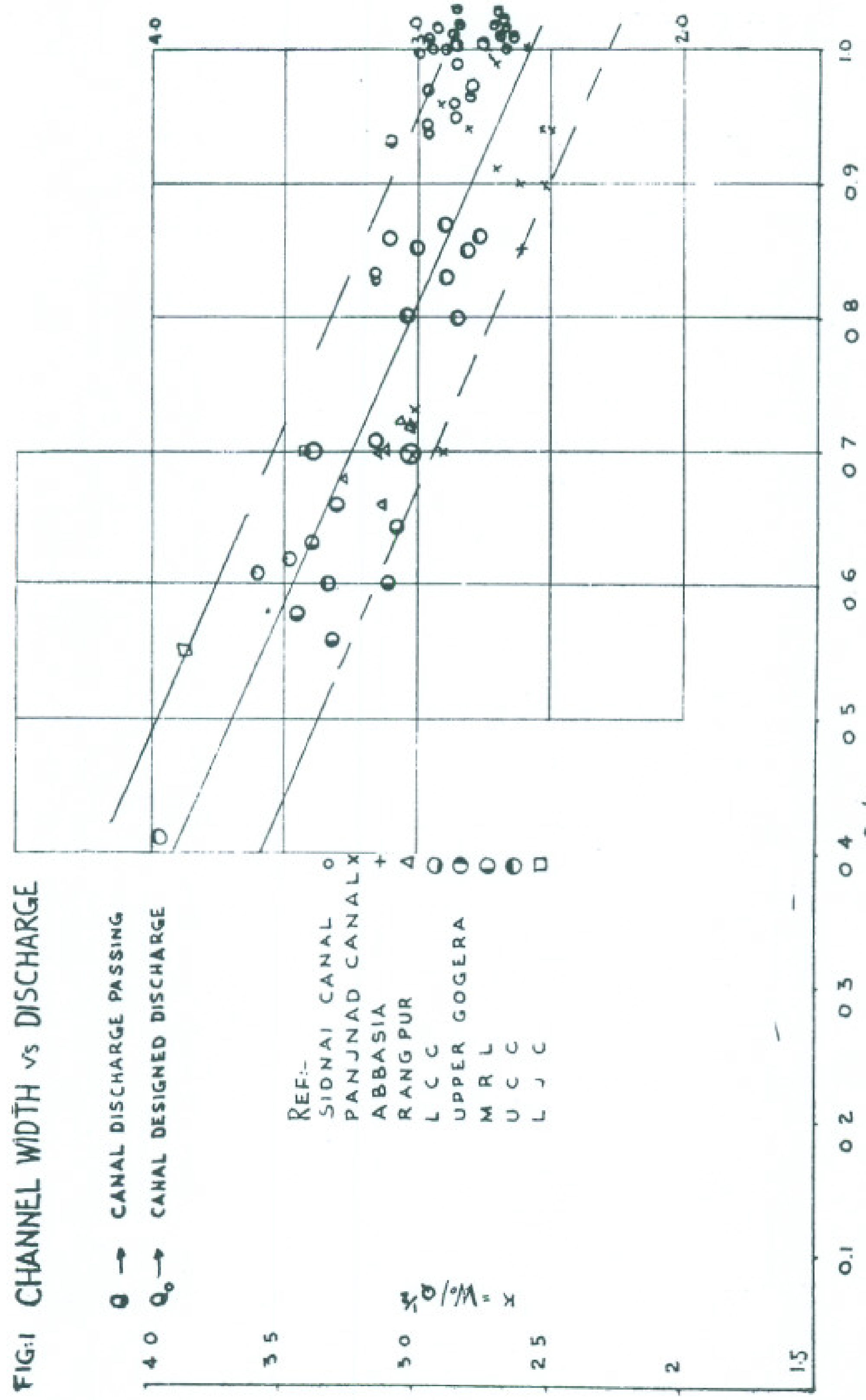


FIG:1 CHANNEL WIDTH vs DISCHARGE
Q → CANAL DISCHARGE PASSING
Q0 → CANAL DESIGNED DISCHARGE
x = W/Q0½
REF:-
SIDNAI CANAL
PANJNAD CANAL
ABBASIA
RANGPUR
L C C
UPPER GOGERA
M R L
U C C
L J C
Q/Q0
4.0
3.5
3.0
2.5
2
1.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2.0

FIG:-2

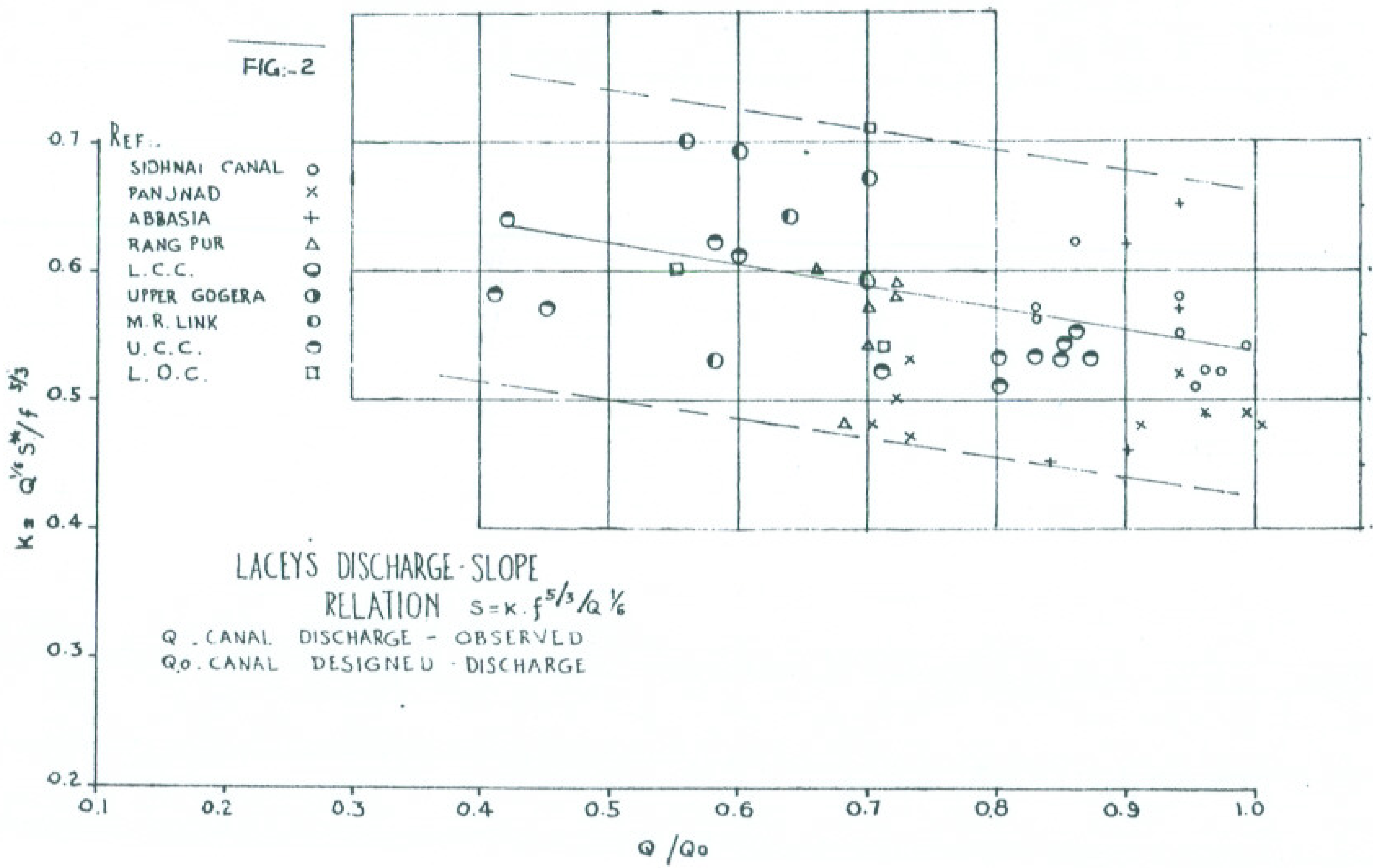

REF:
SIDHNAI CANAL ○
PANJNAD ×
ABBASIA +
RANG PUR △
L.C.C.
UPPER GOGERA
M.R. LINK
U.C.C.
L.O.C. □
LACEYS DISCHARGE-SLOPE RELATION S=K.f^5/3/Q^1/6
Q. CANAL DISCHARGE - OBSERVED
Qo. CANAL DESIGNED - DISCHARGE
K = Q^1/6 S^* / f^5/3
Q/Qo
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.2 0.3 0.4 0.5 0.6 0.7
·4 ·5 ·6 ·7

FIG.-3

LACEYS SLOPE-DISCHARGE RELATION

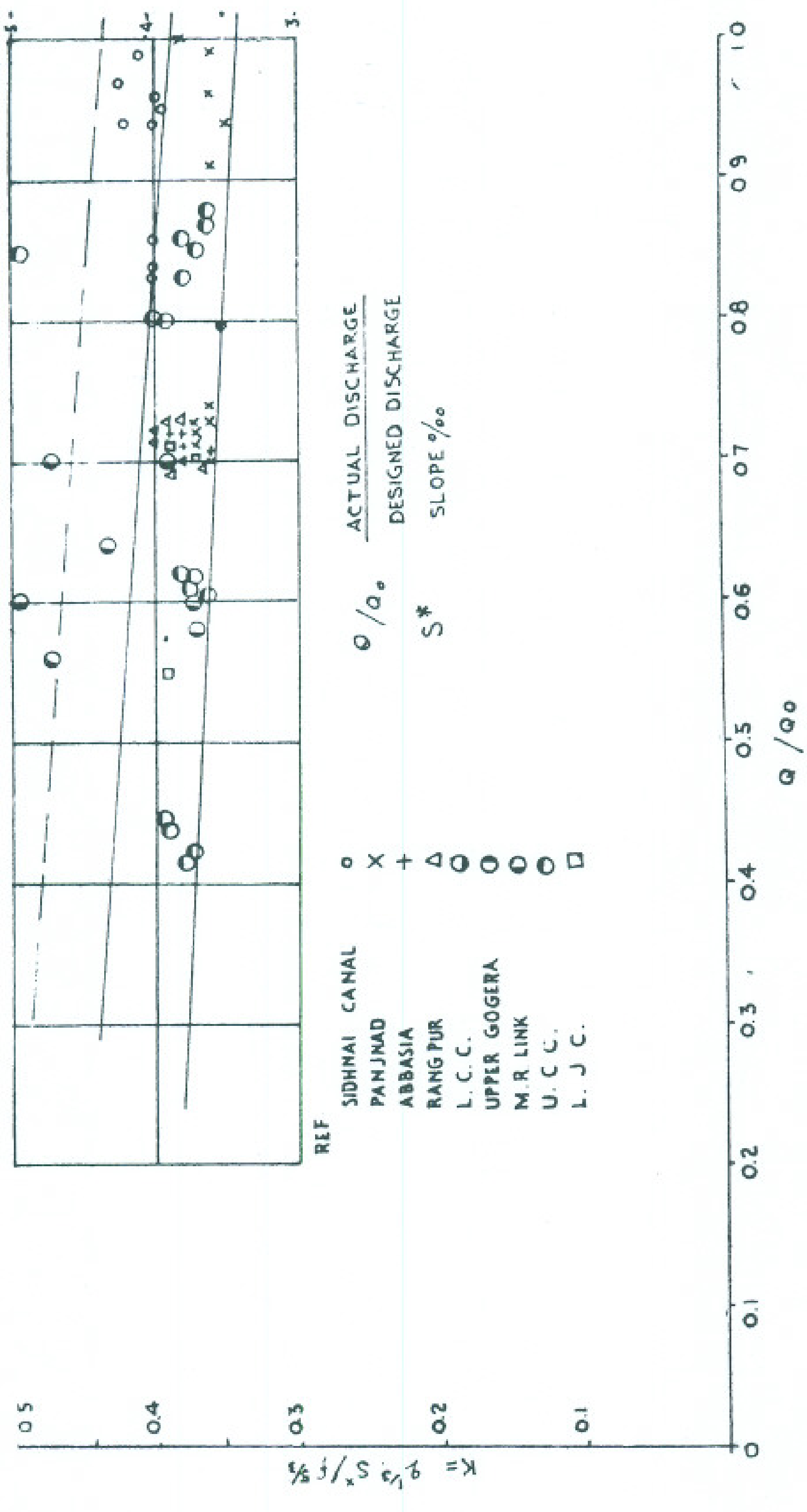
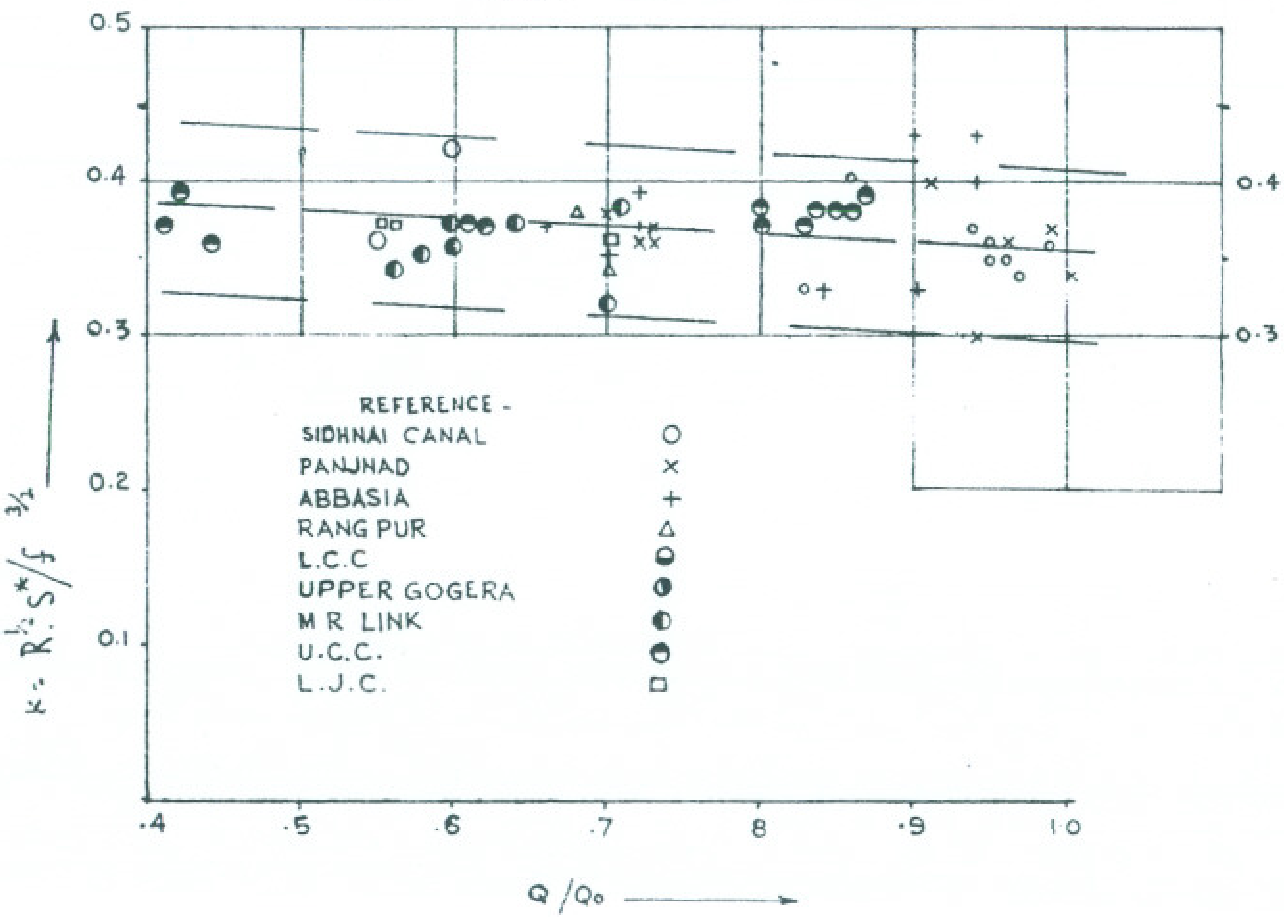
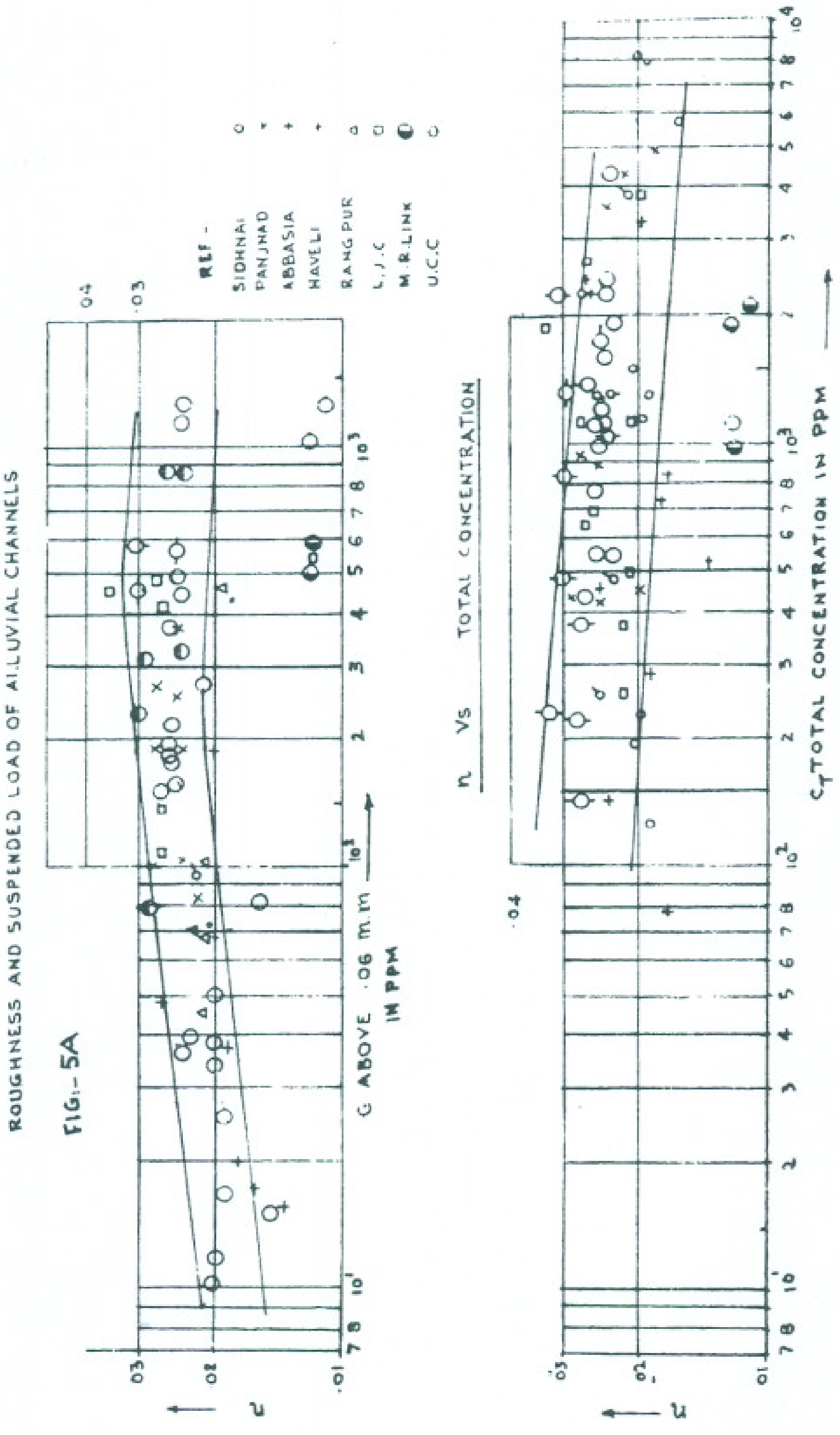


FIG:-4 LACEY'S SLOPE - DEPTH RELATION vs DISCHARGE

Q - CANAL DISCHARGE - OBSERVED

Qo - CANAL DESIGNED - DISCHARGE




ROUGHNESS AND SUSPENDED LOAD OF ALLUVIAL CHANNELS
FIG.- 5A
C ABOVE .06 m.m IN PPM
n VS TOTAL CONCENTRATION
C_T TOTAL CONCENTRATION IN PPM
REF -
SIDHNAI
PANJNAD
ABBASIA
HAVELI
RANGPUR
L.J.C
M.R.LINK
U.C.C

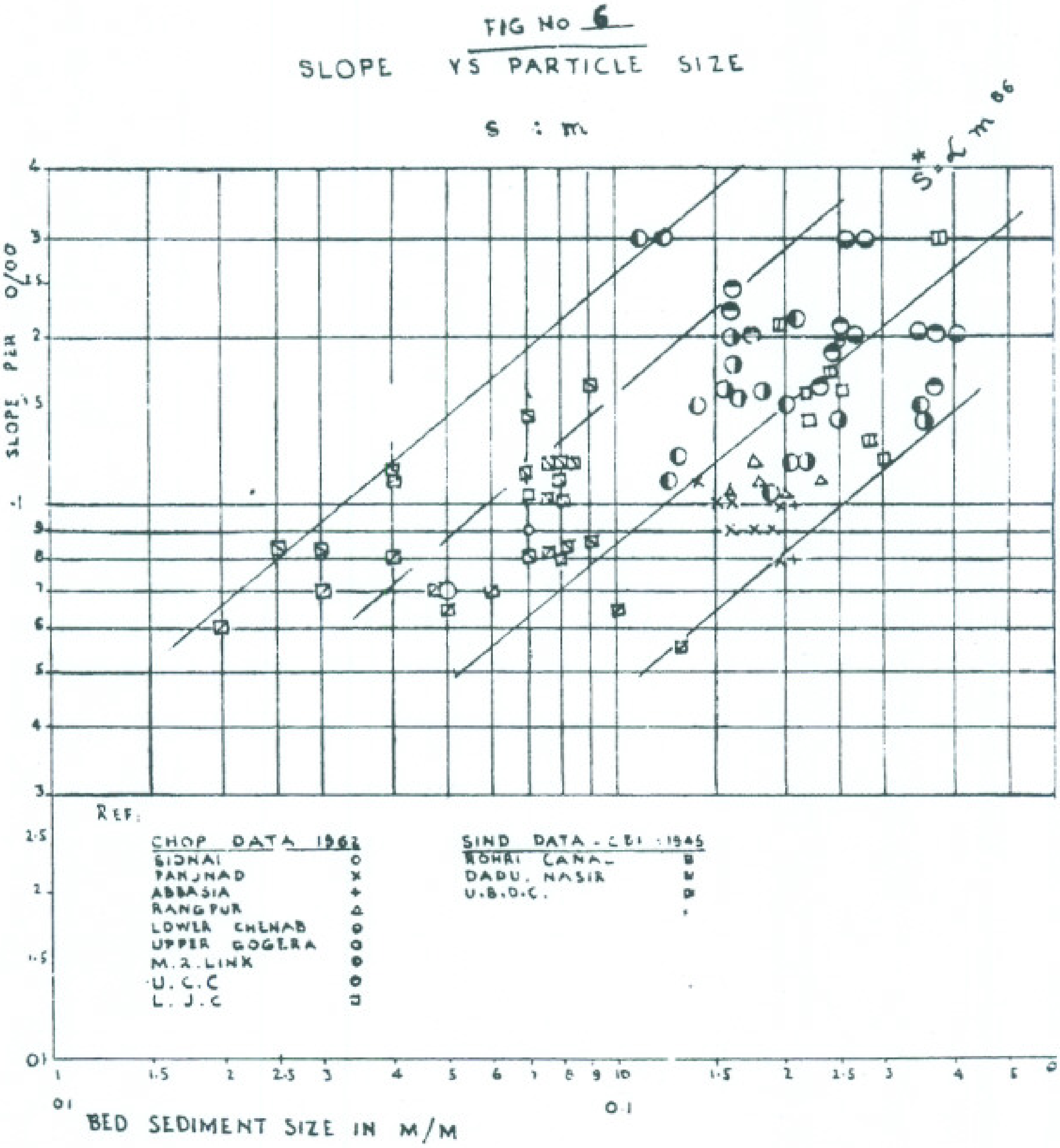
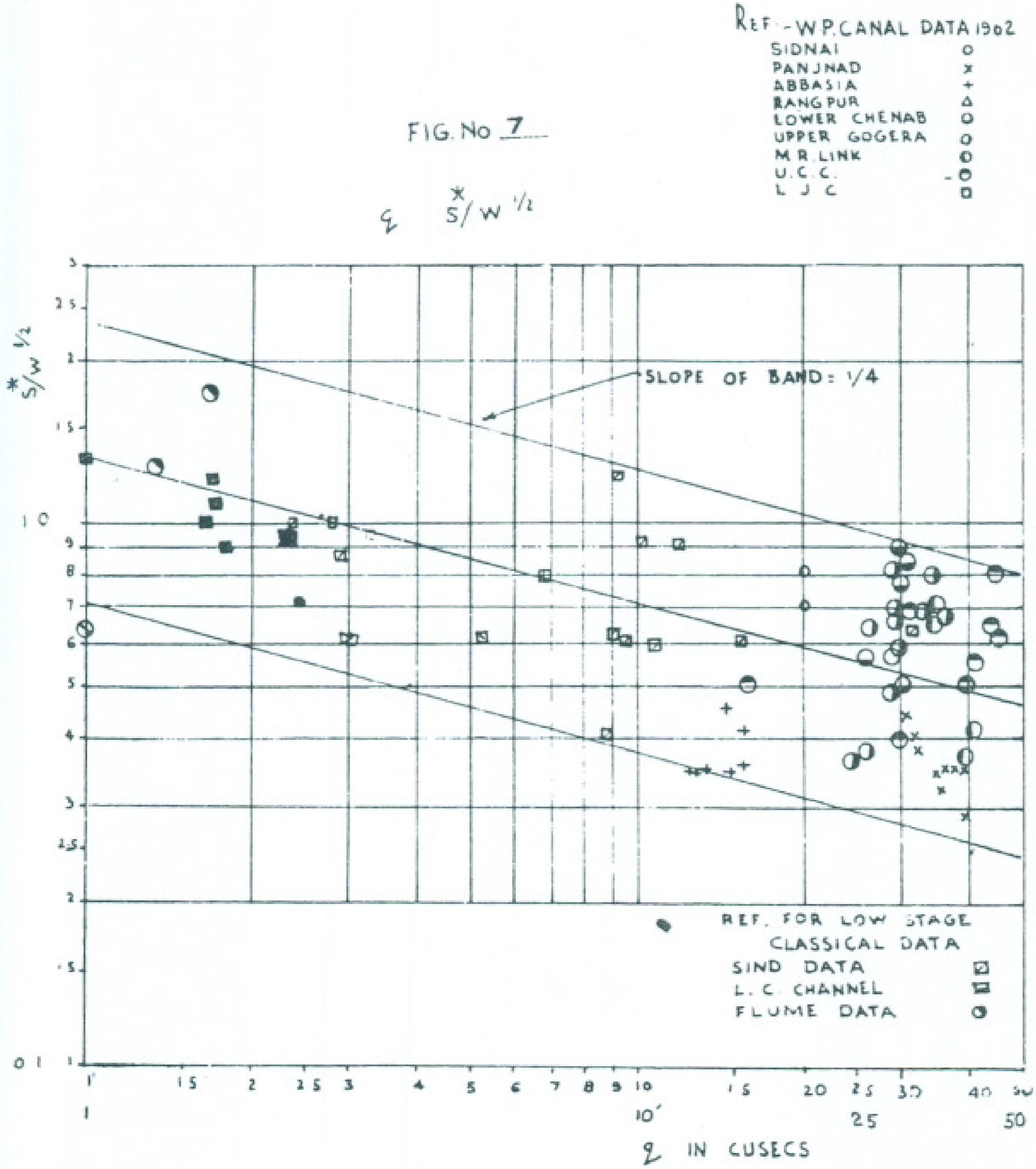


FIG NO 6
SLOPE VS PARTICLE SIZE
S : m
SLOPE PER 0/00
BED SEDIMENT SIZE IN M/M
REF:
CHOP DATA 1962
SIDNAI
PANJNAD
ABBASIA
RANGPUR
LOWER CHENAB
UPPER GOGERA
M.R.LINK
U.C.C
L.J.C
SIND DATA - CBI - 1945
ROHRI CANAL
DADU, NASIR
U.B.D.C.

FIG. No 7



REF - W.P. CANAL DATA 1902
SIDNAI
PANJNAD
ABBASIA
RANGPUR
LOWER CHENAB
UPPER GOGERA
M.R. LINK
U.C.C.
L J C
SLOPE OF BAND: 1/4
REF. FOR LOW STAGE
CLASSICAL DATA
SIND DATA
L. C. CHANNEL
FLUME DATA
q IN CUSECS

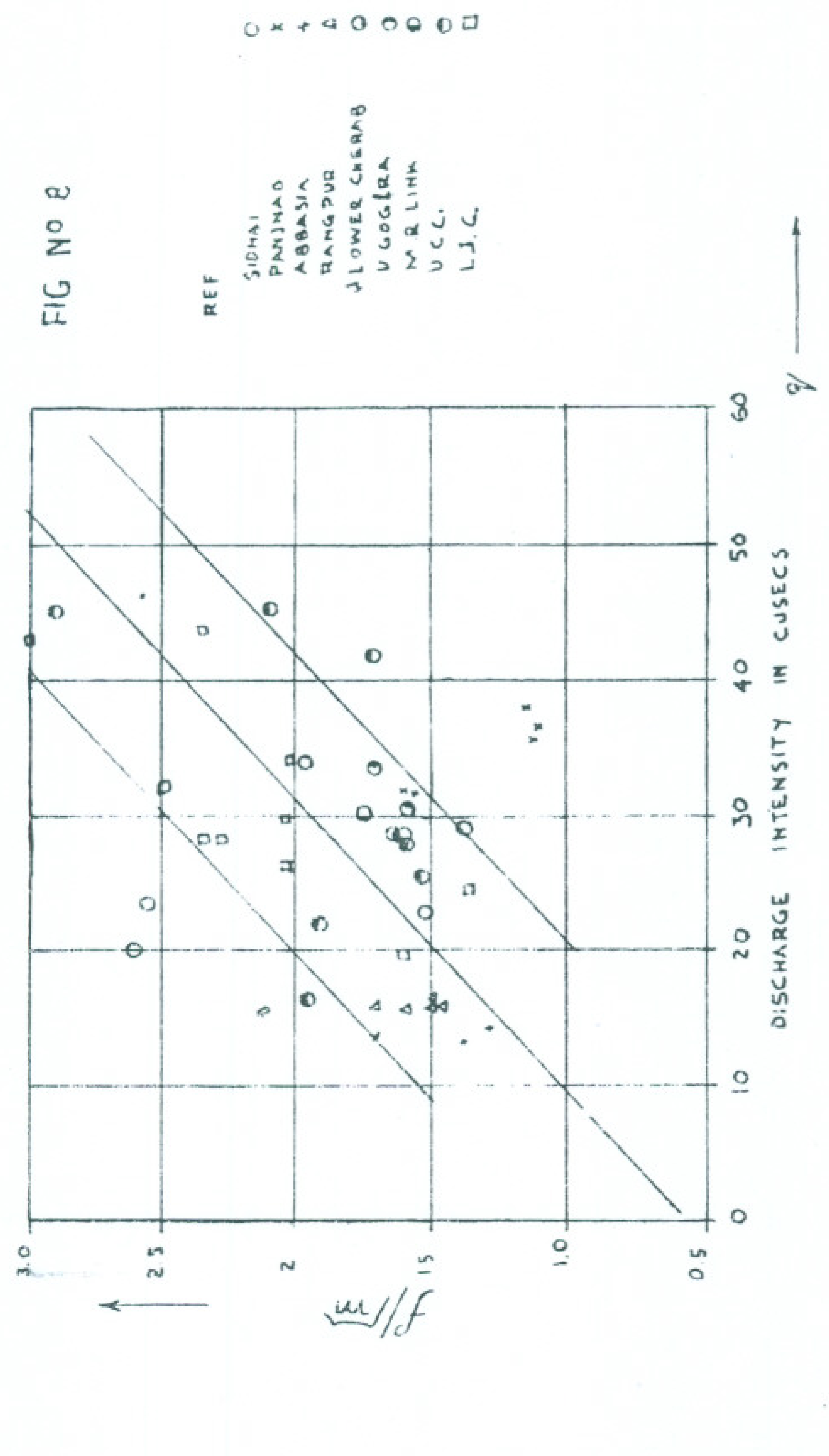

REF
SIDHAI
PANJNAD
ABBASIA
RANGPUR
J LOWER CHENAB
U GOGERA
M.R LINK
U C C.
L.J.C.
DISCHARGE INTENSITY IN CUSECS
q
f/m
0
10
20
30
40
50
60
0.5
1.0
1.5
2
2.5
3.0

FIG No 8

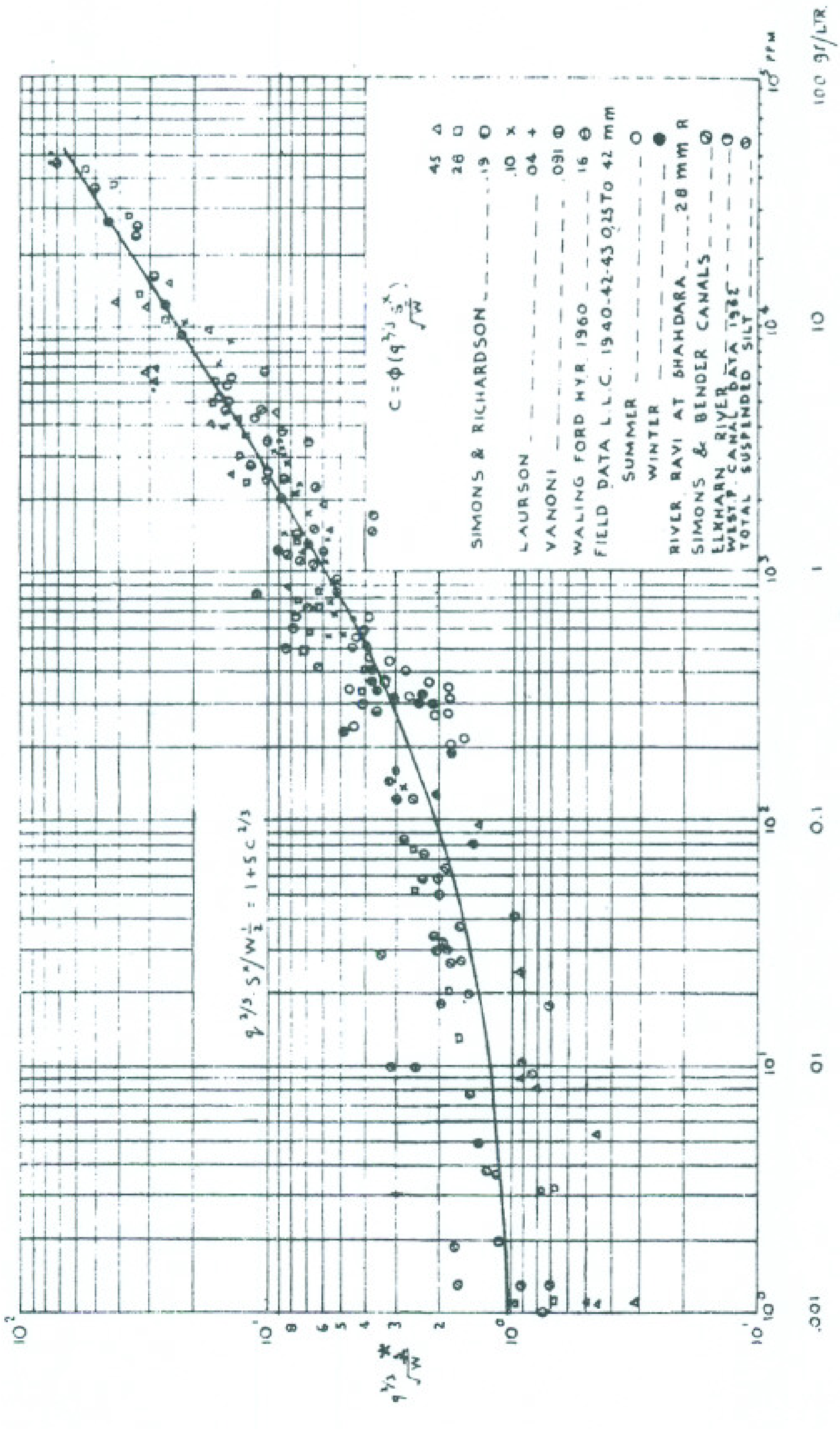


FIGURE-9A RELATION OF $q^{2/3} \frac{S^x}{\sqrt{W}}$ TO SILT INTENSITY $\bar{C}$

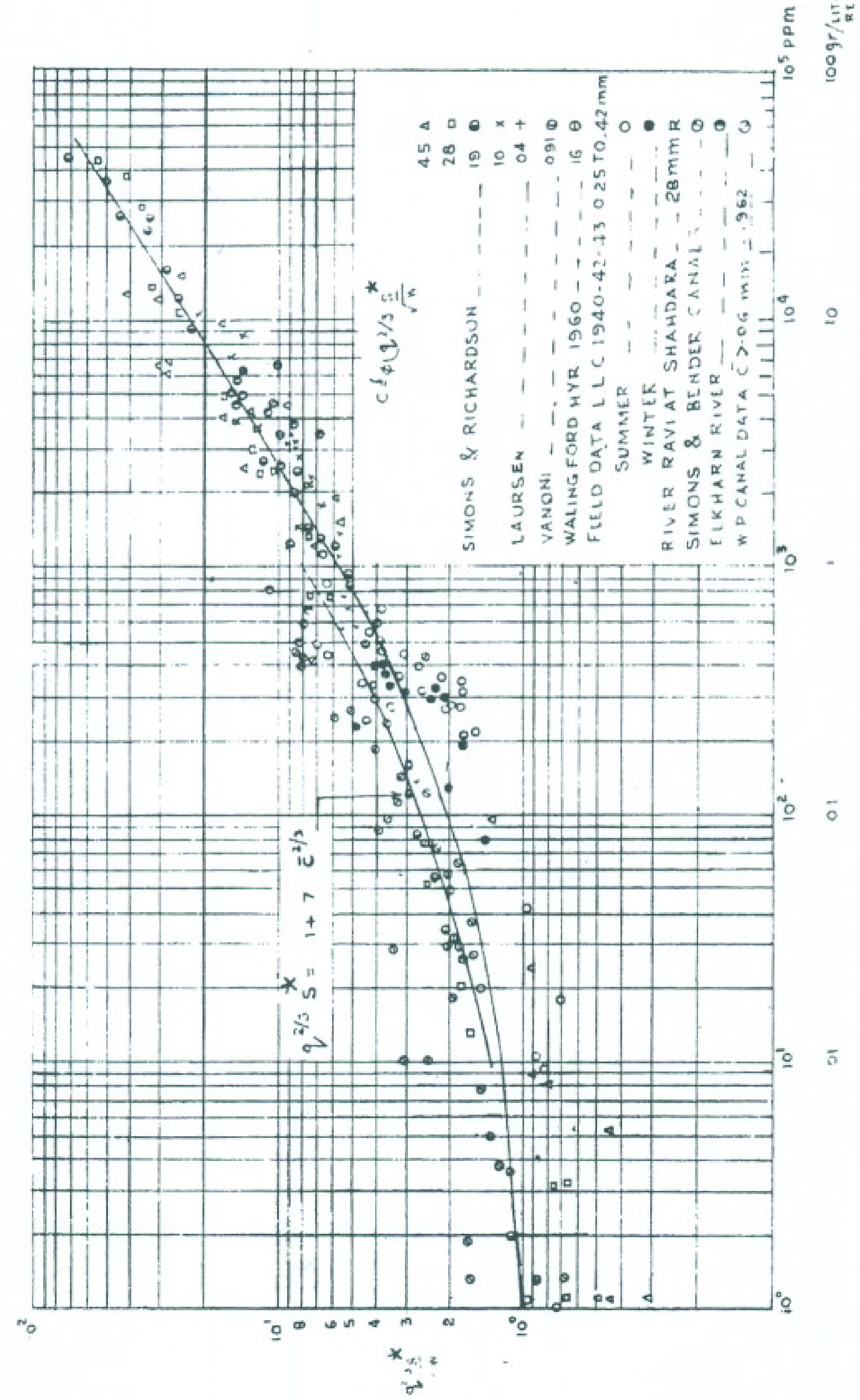


FIGURE-9B. RELATION OF $q^{2/3} \frac{S}{\sqrt{\kappa}}$ ✱ TO SILT INTENSITY $\bar{C}$

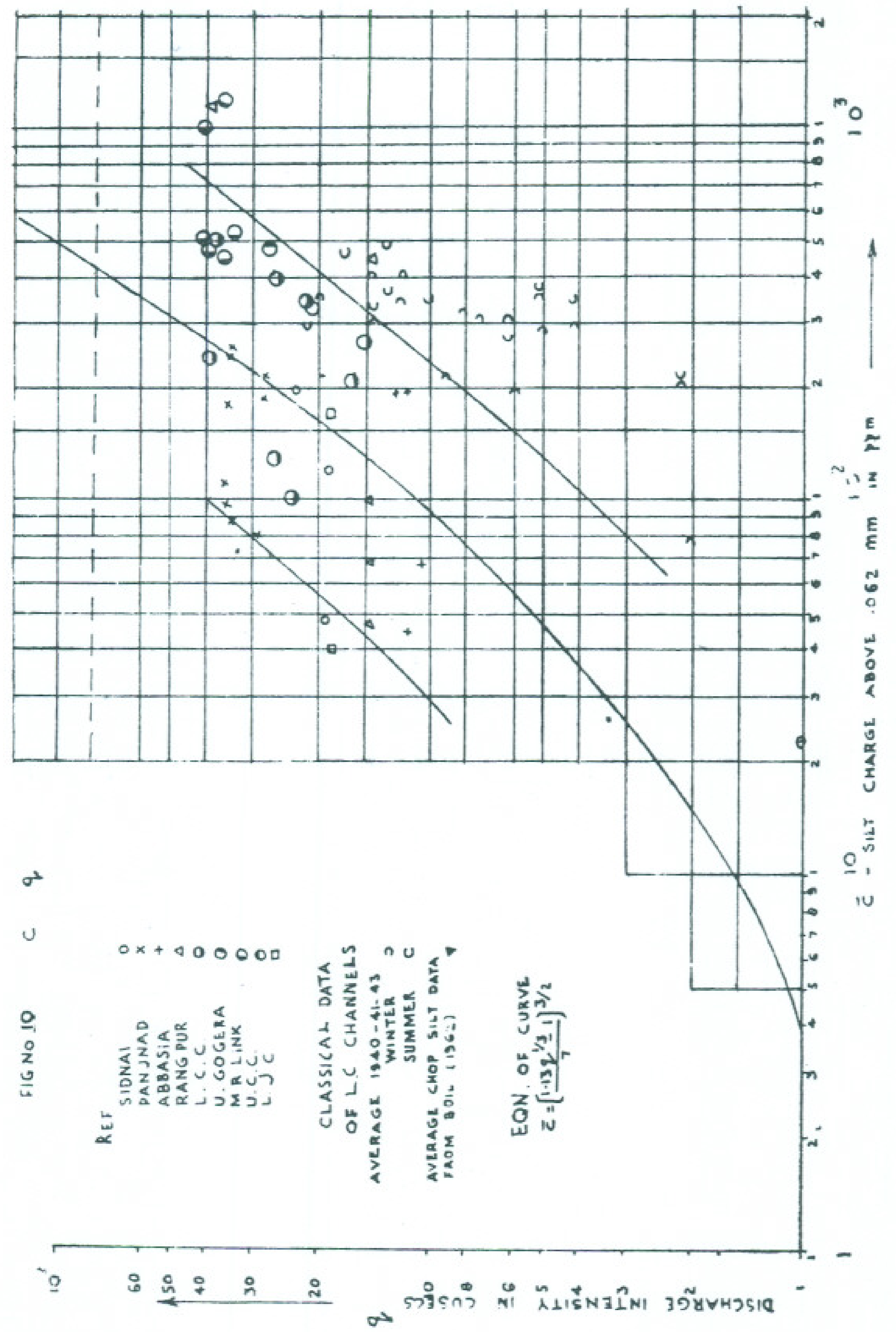
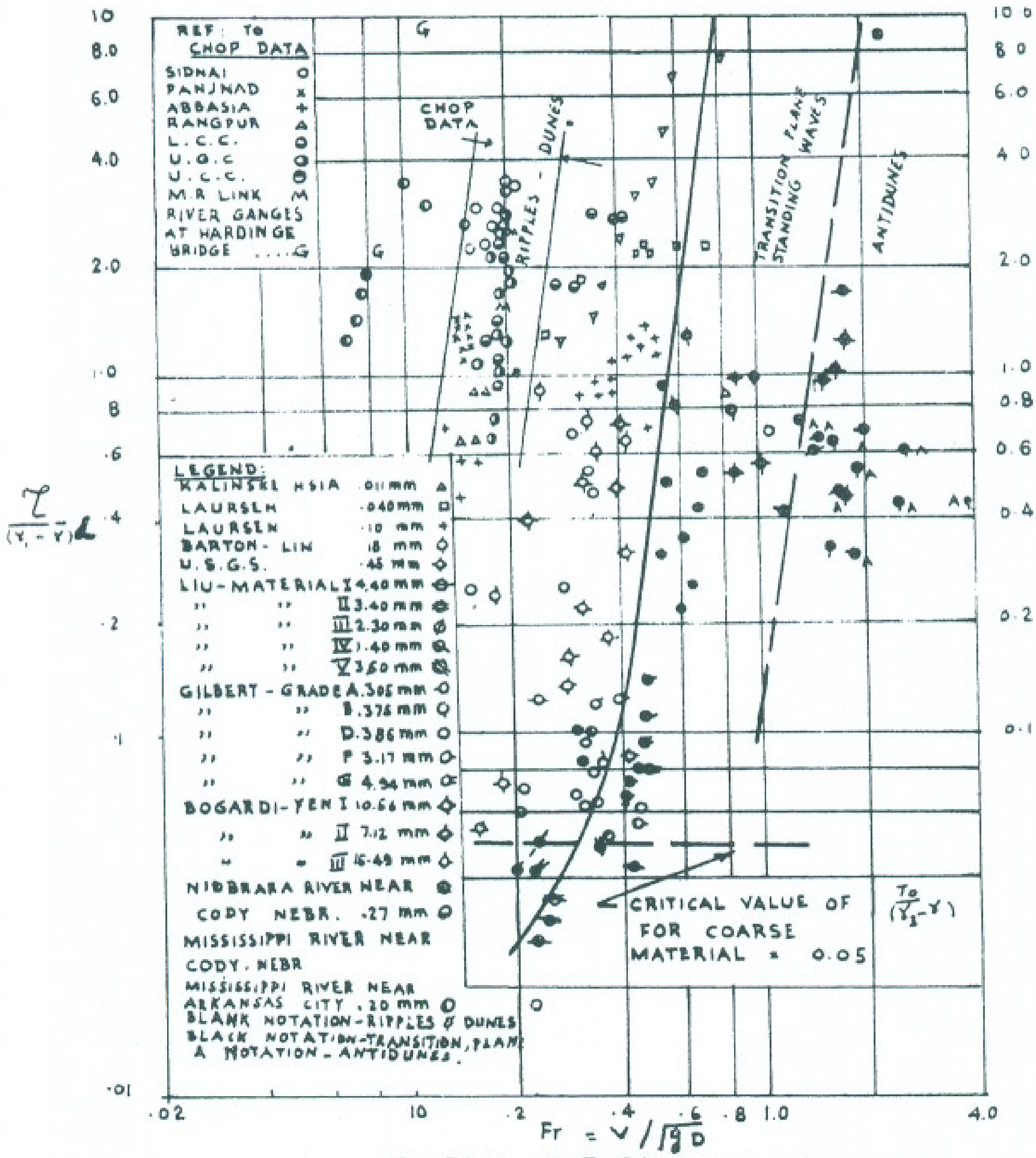


FIG No 10
REF
SIDNAI
PANJNAD
ABBASIA
RANG PUR
L.C.C.
U. GOGERA
M R LINK
U.C.C.
L.J.C
CLASSICAL DATA
OF L.C CHANNELS
AVERAGE 1940-41-43
WINTER
SUMMER
AVERAGE CHOP SILT DATA
FROM BOIL (1962)
EQN. OF CURVE
DISCHARGE INTENSITY IN CUSECS
SILT CHARGE ABOVE .062 mm IN PPm

FIG. No 11



CRITERIA FOR REGIMES OF FLOW

FIG. 12

KING BLENCH NO VS MANNING'S 'n'

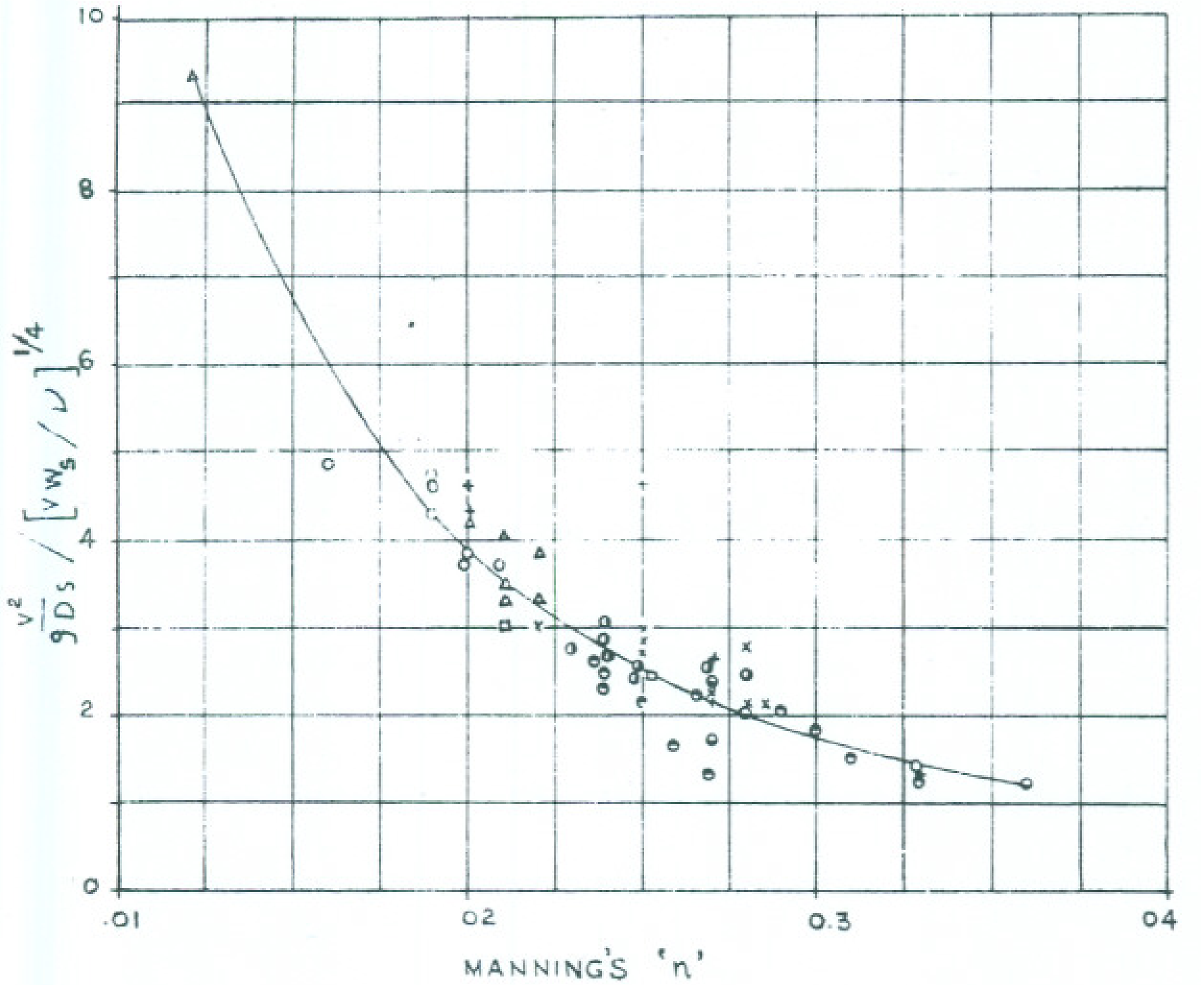
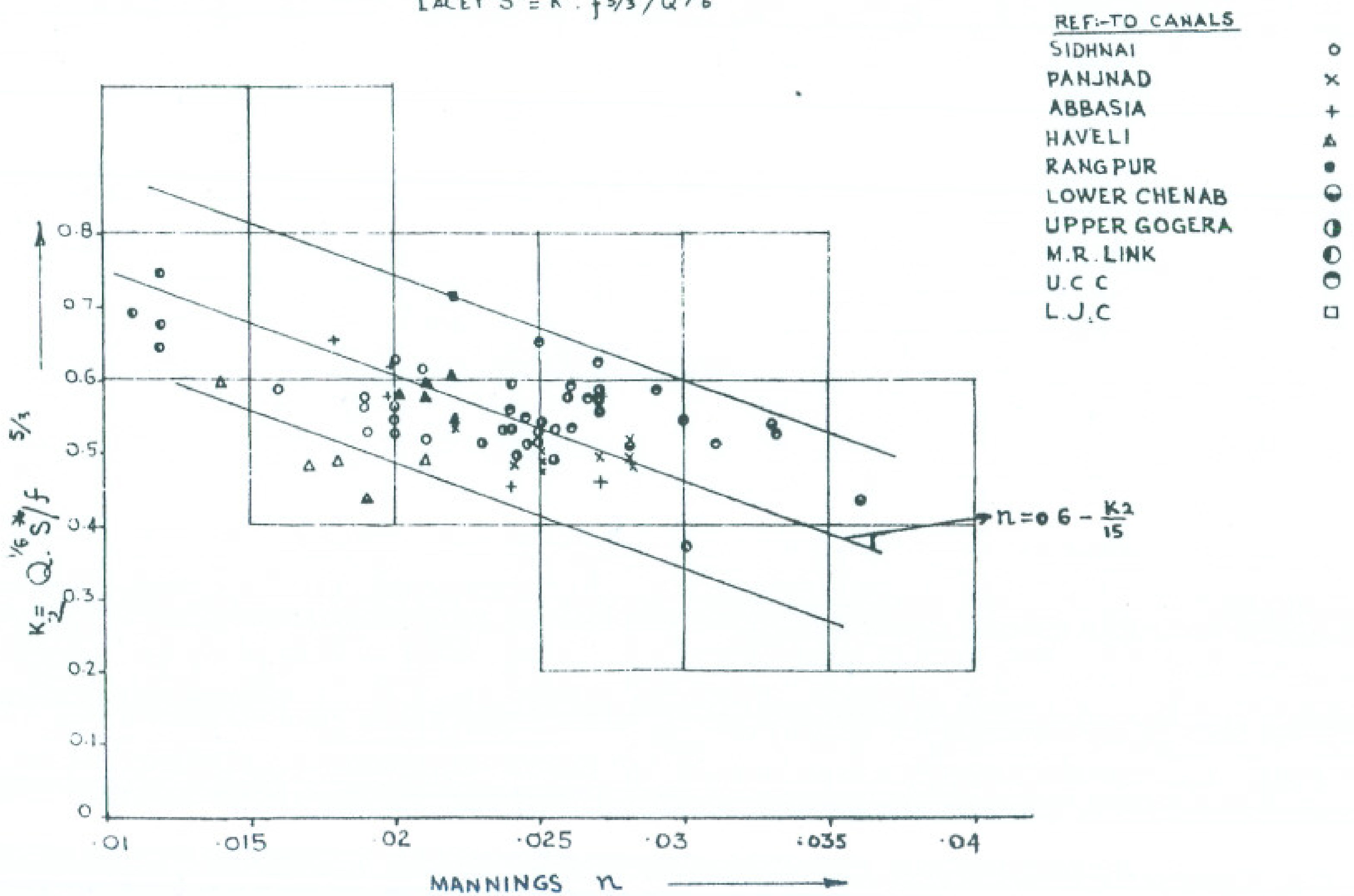


FIG:-13

CONSTANT OF LACEY'S SLOPE RELATION VS. MANNINGS 'n'

LACEY $S^* = K \cdot f^{5/3} / Q^{1/6}$



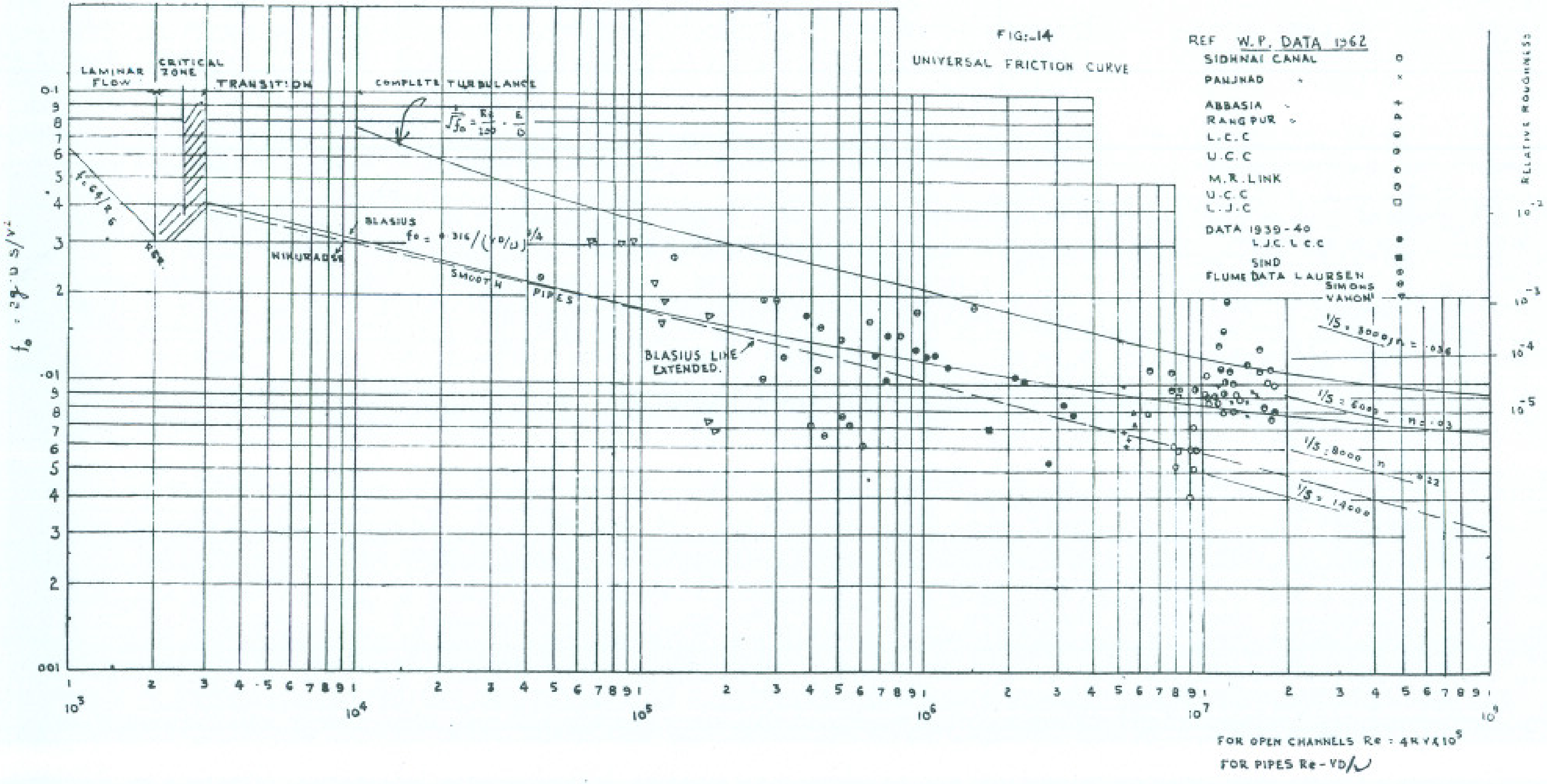


FIG:-14
UNIVERSAL FRICTION CURVE
REF W.P. DATA 1962
SIDHNAI CANAL
PANJNAD
ABBASIA
RANGPUR
L.C.C
U.C.C
M.R. LINK
U.C.C
L.J.C
DATA 1939-40
L.J.C. L.C.C
SIND
FLUME DATA LAURSEN
SIMONS
VANONI
LAMINAR FLOW
CRITICAL ZONE
TRANSITION
COMPLETE TURBULANCE
BLASIUS
NIKURADSE
SMOOTH PIPES
BLASIUS LINE EXTENDED.
RELATIVE ROUGHNESS
FOR OPEN CHANNELS Re = 4RV×10⁵
FOR PIPES Re = VD/ν