$$\text{When } N_a = \cdot 018\, S_{10}{}^3 = \frac{Q}{38\cdot5\, R^{7/2}} = \frac{\dfrac{R^3}{\cdot 47^3}}{38\cdot5\, R^{7/2}} = \frac{1}{3\cdot99\, R^{\frac{1}{2}}}$$

$$N_a = \cdot 020\, S_{10}{}^3 = \frac{Q}{31\cdot25\, R^{7/2}} = \frac{1}{3\cdot24\, R^{\frac{1}{2}}}$$

$$N_a = \cdot 0225\, S_{20}{}^3 = \frac{Q}{24\cdot7\, R^{7/2}} = \frac{1}{2\cdot56\, R^{\frac{1}{2}}}$$

$$N_a = \cdot 025\, S_{10}{}^3 = \frac{Q}{20\, R^{7/2}} = \frac{1}{2\cdot08\, R^{\frac{1}{2}}}$$

$$N_a = \cdot 030\, S_{10}{}^3 = \frac{Q}{11\, R^{7/2}} = \frac{1}{1\cdot14\, R^{\frac{1}{2}}}$$

$$\text{III.—}S_{10}{}^3 = \frac{Q^{3/2}}{80\, R^5} = \frac{\dfrac{(R)^{9/2}}{(\cdot 47)}}{80\, R^5} = \frac{\dfrac{R^{9/2}}{(\cdot 47)^{9/2}}}{80\, R^5} = \frac{1}{2\cdot67\, R^{\frac{1}{2}}}$$

$$\text{IV.—}S_{10}{}^3 = \frac{Q^{3/2}}{75\ \ R^5} = \frac{1}{75 \times \cdot 03345\, R^{\frac{1}{2}}} = \frac{1}{2\cdot51\, R^{\frac{1}{2}}}$$

$$\text{V.—}S_{10}{}^3 = \frac{Q^{3/2}}{71\cdot21\ R^5} = \frac{1}{71\cdot2 \times \cdot 03345\, R^{\frac{1}{2}}} = \frac{1}{2\cdot38\, R^{\frac{1}{2}}}$$

$$\text{VI.—}S_{10}{}^3 = \frac{\cdot 340}{R^{\frac{1}{2}}} = \frac{1}{2\cdot97\, R^{\frac{1}{2}}}$$

Derivation of Formula for Slope from Lacey and Manning

I. Lacey's $V = 1{\cdot}16 \sqrt{f R}$ (1)

Manning's $V = \frac{1{\cdot}4858\ R^{\frac{2}{3}}}{N} S^{\frac{1}{2}}$ (2)

Equating (1) and (2) we get :

$$\sqrt{f} = \frac{1{\cdot}4858}{1{\cdot}16\ N} R^{1/6}\ S^{\frac{1}{2}}$$

Or $f = \frac{1{\cdot}6404}{N^2} R^{\frac{1}{3}}\ S$ (3)

Again

Lacey's $V = 1{\cdot}16 \sqrt{f R}$

,, $f^2 = 3{\cdot}8\ V^5$

Or $Q\ f^2 = 3{\cdot}8\ V^6$ (4)

Equating (1) and (4) we get :

$$Q\ f^2 = 3{\cdot}8 \times (1{\cdot}16)^6\ f^3\ R^3$$

$$Q = 3{\cdot}8 \times (1{\cdot}16)\ f\ R^3$$

$(Q = 9{\cdot}258\ f\ R^3)$ (5)

Now substitute for f (5) from (3)

$$Q = 3{\cdot}8 \times 1{\cdot}16^6 \times \frac{1{\cdot}6404}{N^2} R^{10/3}\ S$$

$$Q = \frac{9{\cdot}258 \times 1{\cdot}6406}{N^2} R^{10/3}\ S$$

$$= \frac{15{\cdot}189}{N^2} R^{10/3}\ S$$

$$\text{Or } S = \frac{N^2\ Q}{15{\cdot}189\ R^{10/3}}$$

$$S = \frac{N^2\ Q}{15{\cdot}189\ R^{10/3}}$$

$$\text{Or } S_{10^3} = \frac{65{\cdot}833\ N^2\ Q}{R^{10/3}}$$

This general formula for different values of Kutter's N works out as under :

When $N = 0{\cdot}018 \quad S_{10}{}^3 = \dfrac{{\cdot}0213\ Q}{R^{10/3}} = \dfrac{Q}{47\ R^{10/3}} = \dfrac{1}{3{\cdot}786\ Q^{1/9}}$

,, $N = 0{\cdot}020$,, $= \dfrac{{\cdot}0263\ Q}{R^{10/3}} = \dfrac{Q}{38\ R^{10/3}} = \dfrac{1}{3{\cdot}06\ Q^{1/9}}$

,, $N = 0{\cdot}0225$,, $= \dfrac{{\cdot}0333\ Q}{R^{10/2}} = \dfrac{Q}{R^{10/3}} = \dfrac{1}{2{\cdot}42\ Q^{1/9}}$

,, $N = 0{\cdot}025$,, $= \dfrac{{\cdot}411\ Q}{R^{10/3}} = \dfrac{Q}{24\ R^{10/3}} = \dfrac{1}{1{\cdot}93\ Q^{1/9}}$

,, $N = 0.030$,, $= \dfrac{{\cdot}0591\ Q}{R^{10/3}} = \dfrac{Q}{17\ R^{10/3}} = \dfrac{1}{1{\cdot}37\ Q^{1/9}}$

Substituting for R from $R = .47\ Q^{\frac{1}{3}}$ the relationship between S and Q is shown in the last column.

P. S.—For getting at the general slope formula, Dr. J. K. Malhotra of the Irrigation Research Institute has suggested a shorter derivation:

$$V = \frac{1{\cdot}4858}{N} R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \text{(Manning)}$$

$$\therefore\ S = \frac{V^2\ N^2}{R^{4/3}} \left(\frac{1}{1{\cdot}4858}\right)^2$$

$$= \frac{V.\ R.\ f^2\ N^2}{R^{10/3}} \left(\frac{1}{\ldots\ldots}\right)^2$$

$$\text{But } VR = \frac{Q}{P} = \tfrac{3}{8}\ Q^{\frac{1}{2}}$$

$$S = \frac{N^2\ Q}{R^{10/3}} \left(\tfrac{3}{8}\right)^2 \left(\frac{1}{1{\cdot}4858}\right)^2$$

$$\text{Hence } S = \frac{N^2\ Q}{15{\cdot}098\ R^{10/3}}$$

$$S_{10}{}^3 = \frac{63{\cdot}71\ N^2\ Q}{R^{10/3}}$$

II. Lacey's $V = 1{\cdot}16 \sqrt{f R}$ (1)

$$V = \frac{1{\cdot}3458}{N_a} R^{\frac{3}{4}} S \quad (2)$$

Equating (1) and (2) we get :

$$\sqrt{f} = \frac{1{\cdot}16}{N_a} R^{\frac{1}{4}} S^{\frac{1}{2}}$$

$$\text{Or } \sqrt{f} = \frac{1{\cdot}3458}{N_a^{\,2}} R^{\frac{1}{2}} S \quad (3)$$

Again $Q = 9{\cdot}258 \, f R^3$ (4)

Substituting (3) in (4) we get :—

$$Q = \frac{1{\cdot}3458}{N_a^{\,2}} \times 9{\cdot}258 \, S \, R^{7/2}$$

$$Q = 12{\cdot}46 \, S \, R^{7/2}$$

$$\text{Or } S = \frac{N_a^{\,2} \, Q}{12{\cdot}46 \, R^{7/2}}$$

$$(S_{10}{}^3 = \frac{80 \, N^2 \, Q}{R^{7/2}} \text{ Appc})$$

This general slope formula for different values of N_a works out as under :

$$N_a = {\cdot}018 \qquad S_{10}{}^3 = \frac{Q}{38{\cdot}58 \, R^{7/2}} \quad \frac{1}{2{\cdot}74 \, Q^{1/6}}$$

$$N_a = {\cdot}020 \qquad ,, = \frac{Q}{31{\cdot}25 \, R^{7/2}} \quad \frac{1}{2{\cdot}23 \, Q^{1/6}}$$

$$N_a = {\cdot}0225 \qquad ,, = \frac{Q}{24{\cdot}7 \, R^{7/2}} \quad \frac{1}{1{\cdot}75 \, Q^{1/6}}$$

$$N_a = {\cdot}025 \qquad ,, = \frac{Q}{20 \, R^{7/2}} \quad \frac{1}{1{\cdot}42 \, Q^{1/6}}$$

$$N_a = {\cdot}030 \qquad ,, = \frac{Q}{14 \, R^{7/2}} \quad \frac{1}{1{\cdot}0 \, Q^{1/6}}$$

Substitutiug $R = \cdot 47\ Q^{\frac{1}{3}}$ in the above formula the relationship between S and Q is shown in last column.

P. S.—Shorter derivation due to Dr. J. K. Malhotra :

$$V = \frac{1\cdot3458}{N_a} R^{3/4}\ S^{\frac{1}{2}}$$

$$S = \frac{(V\ R)^2\ N_a{}^2}{R^{7/2}}\ \frac{V^2\ N_a{}^2}{R^{3/2}}\ \frac{1}{(1\cdot3458)^2}$$

$$\left(\frac{1}{\cdot\cdot}\right)^2$$

$$S = \frac{N_a{}^2\ Q}{R^{7/2}}\ \left(\frac{3}{8} \times \frac{1}{1\cdot3458}\right)^2$$

III. Lacey's $S = \dfrac{f^{5/3}}{1844\cdot3\ Q^{1/6}}$ (1)

,, $R = \cdot47\ \left(\dfrac{Q}{f}\right)^{\frac{1}{3}}$ (2)

Or $f^{5/3} = (\cdot47)^5\ \dfrac{Q^{5/3}}{R^5}$ (3)

Substituting (3) in (1) we get :

$$S = \frac{(\cdot47)^5\ Q^{3/2}}{1844\cdot3\ R^5} = \frac{\cdot0229\ Q^{3/2}}{1844\cdot3\ R^5}$$

$$S \text{ in } 10^3 = \frac{\cdot01249\ Q^{3/2}}{R^5}$$

$$S \text{ in } 10^3 = \frac{Q^{3/2}}{80\ R^5}$$

Derivation of Slope Formula purely from Lacey

IV. Lacey's $V = \sqrt{4/5}\ \sqrt{fR}$ (1)

Lacey's $V = 16.0\ R^{\frac{2}{3}}\ S^{\frac{1}{3}}$ (2)

Equating (1) and (2) we get :

$$\sqrt{f} = \frac{16}{\sqrt{4/3}} R^{1/6} S^{\frac{1}{3}}$$

$$f = \frac{16 \times 16 \times 3}{4} R^{\frac{1}{3}} S^{\frac{2}{3}}$$

$$= 192\ R^{\frac{1}{3}}\ S \qquad (3)$$

We have $Q = 9.258\ f\ R^3$ (4)

Substituting (3) in (4) we get :

$$Q = 9.258 \times 192\ R^{10/3}\ S^{\frac{2}{3}}$$

$$= 1773.536\ R^{10/3}\ S^{\frac{2}{3}}$$

$$\text{Or } S^{\frac{2}{3}} = \frac{Q}{1777.536\ R^{10/3}}$$

$$\therefore S = \frac{Q^{3/2}}{74941.1177\ R^5}$$

$$S/_{10^3} = \frac{Q}{74.94\ R^5} \qquad \text{Say} \qquad \frac{Q^{3/2}}{75\ R^5}$$

V. Lacey's $V = 1.16 \sqrt{fR}$ (1)

$$V = 16.05 R^{\frac{2}{3}}\ S^{\frac{1}{3}} \qquad (2)$$

Equating (1) and (2) we get :

$$\sqrt{f} = \frac{16.05}{1.16} R^{1/6} S^{\frac{1}{3}}$$

$$F = \left(\frac{16.05}{1.16}\right)^2 R^{\frac{1}{3}}\ S^{\frac{2}{3}} \qquad (3)$$

We have also $Q = 9.258\ f\ R^3$ (4)

Substituting (3) in (4) we get :

$$Q = 9.258 \times \left(\frac{16.05}{1.16}\right)^2 R^{10/3}\ S^{\frac{2}{3}}$$

$$= 1719.7274\ R^{10/3}\ S^{\frac{2}{3}}$$

$$\text{Or } S^{\frac{2}{3}} = \frac{Q}{1719.7274\ R^{10/3}}$$

$$S = \frac{Q^{3/2}}{71210\ R^5}$$

$$S/_{10^3} = \frac{Q^{3/2}}{71.21\ R^5}$$

Derivation of Slope Formula (Lacey-*cum*-Bose)

VI. Punjab Research $V = 1.12 \sqrt{R}$ (1)

Lacey's $V = 16.05\ R^{\frac{2}{3}}\ 5^{\frac{1}{3}}$ (2)

Equating (1) and (2) we get:

$$1.12 \sqrt{R} = 1605\ R^{\frac{2}{3}}\ S^{\frac{1}{3}}$$

$$S \quad \frac{1.12\ R^{\frac{1}{2}}}{16.05\ R^{\frac{2}{3}}} = \frac{1.12}{16.05} = \frac{1}{R^{1/6}}$$

$$S = \frac{(1.12)^3}{16.05\ R^{\frac{1}{2}}} = \left(\frac{1.12}{16.05}\right)^3 = \frac{1}{(.47\ Q^{\frac{1}{3}})^{\frac{1}{2}}}$$

$$= \frac{(\ .0698\ )^3}{.68557\ Q^{1/6}}$$

$$S/_{10}{}^3 = \frac{.000340}{.6857\ Q^{1/6}} = \frac{1}{2.000\ Q^{1/6}}$$

Comments on the Derived Slope Formula

It must be stated in the first instance that the formulæ derived at are from relationships whose constants are not absolute but empirical, having been obtained by plotting or by correlations, and, therefore, absolute precision is not claimed.

With these derived slope formulæ slopes per thousand are worked out for discharges 10, 50, 150, 500, 1,000, 2,000, 5,000 and 10,000 cusecs both from the two sets of formulæ (*i*) having S in terms of R and the (*ii*) having S in terms of Q. These results are tabulated in two statements which give an interesting study individually as well as comparatively.

It will be noticed that Bose-*cum*-Lacey relationship for regime channels $S/_{10}{}^3 = \frac{1}{2\ Q^{\frac{1}{2}}}$ or purely Lacey's $S_{10}{}^3 = \frac{1}{1.83\ Q^{\frac{1}{2}}}$ will be found a good guide in practice whereas from flexibility with regard to Kutter's N Shanta's slope formula $S_{10}{}^3 = \frac{65.878N^2}{R^{10}/_3}\ Q$ which for value of N=.0225 works out Q. $S/_{10}{}^3 = \frac{Q}{30\ R^{10}/_3} = \frac{1}{2.42\ Q^{1}/_9}$ $= \frac{1}{3.1\ R^{\frac{1}{3}}}$ would be an equally good guide to those who look at the behaviour of channels in terms of Kutter's N.

These formulæ for slope can be grouped as under:

1. $S = \frac{f^{5/3}}{1.8443\ Q^{1/6}}$

2. $S\ 10^3 = \frac{65.838\ N^2}{R^{10/3}}$

This for Kutter's N=0.0225 works out $S_{10}{}^3 = \frac{Q}{30\ R^{10/3}}$

$= \frac{1}{2.42\ Q^{1/9}}$

(range of constant 1.37 to 3.78 for different values of R).

Or $S_{10}{}^3 = \frac{1}{3.1\ R^{\frac{1}{3}}}$ (range of constant 1.77 to 4.89 for different values of N).

3. $S_{10}{}^3 = \frac{80\ N^2\ Q}{\frac{a}{R^{7/2}}}$

This works out for $N_a = {\cdot}0225$ $S_{10}{}^3 = \frac{Q}{24.7\ R^{\frac{1}{2}}} = \frac{1}{1.75\ Q^{1/6}}$

(range 1 to 397 for different values of N).

4. Other group in which N or N_a don't appear.

$S10^3 = \frac{1}{1.8\ Q^{1/6}}$ (range of coefficient being 1.68 to 2.0).

Or $S10^3 = \frac{1}{2.63\ R^{\frac{1}{3}}}$ (range of coefficient being 2.38 to 2.97).

Taking these one by one the following comments are offered:

1. $S10^3 = \frac{f^{5/3}}{1.8443\ Q^{\frac{1}{6}}}$ Q and f determine slope then what about change in R ?

Or $Q = \frac{f^{10}}{1.8443\ S^{\frac{1}{6}}}$

For any particular discharge less the f then less the S.
More the f then more the S.
But f is unmeasurable and also it is a variable.
It is different for different discharges, hence the difficulty.

2. $S10^3 = \frac{65.838\ N^2 Q}{R^{10/3}}$

In this S depends not only on the discharge and section of the channel but also on N, the rugosity of the channel, which may comprise the roughness of its bed and sides and also the materials of its silt load.

The range of its effects is almost from 1 to 2.6 times in the value of slope for relationship of S and Q or S and R. In other words if S is written in terms of Q only such as in case I it means that for a particular discharge there is a particular slope and that slope varies under different conditions of N or if the relationship is written in terms of S and R, it means that the slope will still change under different conditions of N even though the discharge and R be kept constant.

3. Rewriting the formula $^{S}10^{3} = \dfrac{Q}{C\ R^{10/3}}$ of case (2)

or $^{S}10^{3} = \dfrac{Q}{24.7\ R^{10/3}}$ of case (3)

As $Q = C.S.R^{10/3}$ and $Q = C.R^{3/2}\ S^{\frac{2}{3}}$

it could be said in case of a particular discharge that for greater S you need less R—channel wide and shallow. For less S you need greater R—channel deep and narrow.

If more discharge is run and the slope remains constant, R will increase and the channel is likely to scour. This is how engineers wash down silt by running higher discharges.

If less discharge is run and slope remains constant, R will diminish ; that means silting the channel ; that is why small discharges are not run into the channels. Therefore, run your channels full or don't run.

4. $S_{10}{}^{3} = \dfrac{1}{3.1\ R^{\frac{1}{3}}}$ as in case II.

$S_{10}{}^{3} = \dfrac{1}{2{\cdot}6\ R^{\frac{1}{2}}}$ as in all others.

This shows that if R changes, S is bound to change.

As it is most desirable to maintain designed slopes to obtain designed W. S. levels at the sites of all the outlets the designed R must be maintained even though that may have to be done artificially by staking and bushing.

This conclusion can further be established by taking

(1) $V = 1.12\sqrt{R}$

(2) $S = \dfrac{1}{2.6\sqrt{R}}$

Relationship (1) shows that with the increase of R the velocity increases while the relationship (2) shows that with the increase of R, S flattens. Taking such an effect of change in value of R for the same discharge, desired slopes in the channel can be maintained by maintaining the designed values of R.

What happens when this is not done can be illustrated by taking examples of silting channels.

Some times a complaint is made that in spite of regular silt clearance, a channel keeps on silting again and again and silt trouble is always there.

On thorough investigation it will be found that the section is changed; probably it has become much wider and shallower. By silt clearance only the trouble will not end. The proper remedy is to define the section by staking and bushing and R being brought to its designed value.

Yet Another Way of Looking at it

Shanta's general slope formula $S = \frac{N^2 Q}{15.19\ Q^{10/3}}$ can be written

by substituting for Q from equation $P = \frac{8}{3} Q^{\frac{1}{2}}$ as S as

$$S = \frac{N^2 P^2}{108\ R^{10/3}}$$

When coarser particles of silt enter into a channel, the value of N increases. By falling of berms P also increases. Therefore, the water surface slope becomes steeper. In such cases, for maintaining certain designed slopes, the remedy is to arrest the undue increase of P or to increase R as well.

In case of silting in bed, the channel becomes wider and shallower. The entire hydraulic data change.

P increases. R decreases.

If product of $P \times R$ which is equal to A remains slightly more than the product of $P \times R$ in the original design to compensate for increased value of N, the designed slope can still be achieved. This should be the desideratum for maintaining the required water surface levels in the channels. But it may also be possible to re-design the channel with a bit higher slope to fit in with actual conditions at site but with above relationship of P and R in view of course.

The writer stated during last year's session of the Congress that it was in the economy of Nature that some lands had steep slopes and others had flat slopes. For the irrigation of these lands of varying slopes it may sometimes be unavoidable to adopt certain slopes other than those given by Lacey's or Irrigation Research Institute Slope Formulæ which, for a particular discharge and a particular grade of silt, give only one slope and no other. To meet such cases Shanta's slope formula is a better guide than any other formula yet known to the writer.

It may not, however, be construed that the writer denies the great worth of Lacey's or the Irrigation Research Institute's slope formulæ in their proper perspective. These are both good in their own way and have added much to our knowledge.

GENERAL

A peculiar feature of these derived slope formulæ is that the slope has been connected with Q, R, P and Kutter's N. Not only this but the slope has also been directly connected with Q as well as R.

For general regime conditions it is an advantage to know that :

$$S_{10^3} = \frac{Q}{30\ R^{10/3}}$$

$$\text{Or } S_{10^3} = \frac{1}{3.0\ R^{\frac{1}{3}}}$$

$$\text{Or } S_{10^4} = \frac{1}{2.0\ Q^{\frac{1}{6}}}$$

(The index of R varies but not appreciably.)

The range of change in the coefficient of the denominator of the right side of the equation in all the formulæ is known.

From the derived relationships value of S_{10^3} under different conditions are worked out in Statements 6 and 7. These will also be attached with the Improved Kennedy's Hydraulic Diagrams to form the basis for fixing slopes for different discharges under different conditions of rugosities.

Advantage has also been taken of the exponential form of the equations to make a discharge slide rule for design of earthen channels. This discharge slide rule has the advantage of being an ordinary slide rule as well.

The slide rule is described in the next chapter.

STATEMENT NO. 6 FOR DETERMINING SLOPE

$$S_{10^3} = \frac{65.838\ N^2\ Q}{R^{10/3}} \qquad S_{10^3} = \frac{80 N_a^2\ Q}{R^{7/2}}$$

R	$R^{\frac{1}{2}}$	$S_{10^3} = R^{\frac{1}{3}}$	N 018 / 1 / $4.89R^{\frac{1}{3}}$	020 / 1 / $3.95R^{\frac{1}{3}}$	0225 / 1 / $3.11R^{\frac{1}{3}}$	.025 / 1 / $2.49R^{\frac{1}{3}}$	.030 / 1 / $1.77R^{\frac{1}{3}}$	N_a .018 / 1 / $3.99R^{\frac{1}{2}}$	.020 / 1 / $3.24R^{\frac{1}{2}}$	.0225 / 1 / $2.56R^{\frac{1}{2}}$	.025 / 1 / $2.08R^{\frac{1}{2}}$	.030 / 1 / $1.14R^{\frac{1}{2}}$	1 / $2.67R^{\frac{1}{2}}$	1 / $2.51R^{\frac{1}{2}}$	1 / $2.38R^{\frac{1}{2}}$	1 / $2.97R^{\frac{1}{2}}$
1	1.0	1.0	0.205	0.253	.322	.402	0.565	0.251	.309	0.391	0.481	.877	.375	.389	0.420	0.377
2	1.4142	1.2599	0.162	0.201	0.255	.319	.448	.177	.218	.276	.340	.623	.265	.279	.297	.238
3	1.7321	1.4422	0.142	0.176	0.223	.279	.392	.145	.178	.226	.275	.506	.216	.230	.243	.194
4	2.0	1.5874	0.129	0.159	0.203	.253	.356	.125	.154	.195	.240	.439	.187	.199	.210	.168
5	2.2361	1.71	0.120	0.148	0.188	.235	.330	.112	.138	.175	.215	.392	.167	.178	.188	.156
6	2.4495	1.8171	0.113	0.139	0.177	.221	.311	.102	.126	.160	.196	.358	.153	.163	.172	.137
7	2.6458	1.9129	0.107	0.132	0.168	.210	.295	.095	.117	.148	.182	.332	.141	.151	.159	.127
8	2.8284	2.00	0.102	0.127	0.161	.201	.282	.0886	.109	.138	.170	.310	.132	.141	.149	.119
9	3.00	2.0801	0.098	0.122	0.155	.193	.272	.084	.103	.130	.160	.292	.125	.133	.140	.112
10	3.1623	2.1544	0.095	0.118	0.149	.186	.262	.079	.098	.124	.152	.277	.118	.126	.133	.106
11	3.3166	2.223	0.092	0.114	0.145	.181	.254	.076	.093	.118	.145	.264	.113	.120	.127	.102
12	3.4141	2.2891	0.89	0.111	0.140	.175	.247	.072	.089	.113	.139	.253	.108	.115	.121	.097
13	3.6050	2.3513	0.087	0.108	0.136	.171	.240	.070	.086	.108	.133	.243	.104	.111	.117	.093
14	3.7417	2.4101	0.085	0.105	0.133	.167	.234	.067	.082	.104	.126	.234	.1001	1.06	.112	.90
15	3.8720	2.466	0.083	0.103	0.131	.163	.229	.065	.080	.101	.124	.227	.097	1.03	.109	.087

STATEMENT NO. 7 FOR DETERMINING SLOPE

$$S_{10^3} = \frac{65.838\ N^2Q}{R^{10/3}} \qquad S_{10^3} = \frac{80\ N_a^2 Q}{R^{7/2}} \qquad S_{10^3}$$

Discharges S_{10^3} =	N .018	.020	.0225	.025	.030	.018	0.020	.0225	.025	.030				
	$\frac{1}{3.786Q^{1/9}}$	$\frac{1}{3.06Q^{1/9}}$	$\frac{1}{2.42Q^{1/9}}$	$\frac{1}{19.3Q^{1/9}}$	$\frac{1}{1.37Q^{1/9}}$	$\frac{1}{2.74Q^{1/6}}$	$\frac{1}{2.23Q^{1/6}}$	$\frac{1}{1.75Q^{1/6}}$	$\frac{1}{1.42Q^{1/6}}$	$\frac{1}{1.0Q^{1/6}}$	$\frac{1}{1.83Q^{1/6}}$	$\frac{1}{1.72Q^{1/6}}$	$\frac{1}{1.63Q^{1/6}}$	$\frac{1}{2.Q^{1/6}}$
10	0.205	0.253	0.320	0.401	0.565	0.249	0.305	0.385	0.480	0.681	0.372	0.396	0.418	0.341
50	0.171	0.212	0.270	0.358	0.474	0.190	0.233	0.298	0.367	0.521	0.285	0.303	0.319	0.260
150	0.151	0.187	0.237	0.297	0.418	0.158	0.194	0.247	0.306	0.433	0.237	0.252	0.266	0.217
500	0.132	0.164	0.207	0.260	0.366	0.130	0.159	0.203	0.250	0.355	0.194	0.206	0.218	0.178
1,000	0.123	0.152	0.192	0.241	0.339	0.115	0.142	0.181	0.223	0.316	0.173	0.184	0.194	0.158
2,000	0.114	0.140	0.178	0.223	0.320	0.103	0.126	0.161	0.198	0.281	0.154	0.164	0.173	0.141
5,000	0.103	0.127	0.160	0.202	0.283	0.088	0.108	0.138	0.170	0.242	0.132	0.141	0.148	0.121
10,000	0.095	0.118	0.149	0.186	0.263	0.079	0.097	0.123	0.142	0.216	0.118	0.125	0.132	0.108
15,000	0.091	0.112	0.142	0.178	0.251	0.073	0.090	0.115	0.142	0.201	0.110	0.117	0.124	0.101
20,000	0.088	0.109	0.138	0.172	0.243	0.070	0.086	0.110	0.135	0.190	0.105	0.112	0.118	0.096

CHAPTER XVII

DISCHARGE SLIDE RULE

The Discharge Slide Rule has two faces with a common slide. The two outer scales are joined up in position at ends with metal plates firmly riveted. The section of the slide rule and the elevation of its two faces and ends are given in the attached print. The length of the rule is 1.0 foot. One end is divided into eighths of inches and the other end divided into hundredths of a foot.

On one face are the three scales. The scale on the slide in the centre is that of $S_{10}{}^{3}$, *i.e.*, for a given Q and a given R, it gives slope per thousand. The outer scales are of R and Q.

For regime conditions the arrows on the slide should remain in line with the arrows on the scales of R and Q. The scales are made in this position.

For finding $S_{10}{}^{3}$ for any discharge or for any R put the cursor on the required R or on required discharge, $S_{13}{}^{3}$ may be read directly. For channels of greater rugosities the slide should be moved to the right side and for the lesser rugosities the slide should be moved to the left.

The common limits for movements are tentatively indicated by vertical lines in red on the scales of R and Q. These limits are for irrigation channels in the Punjab. The range of the scales is such that the slide rule can be used for river discharges as well.

It has been said in the text that rugosity comprises not only the roughness of the bed and sides of a channel but also the thickness of the materials of its silt. Therefore, in the head reaches of a system where there is generally coarse silt in the channels, rugosity will be greater and on the tails it would be less.

On the other face of the slide rule also there are three scales, those being of P, Q and R. The scale of Q is on the slide and outer scales are of P and R.

To make use of the scales to serve as an ordinary slide rule for multiplications and divisions another scale on the slide in its centre is made equal to the length of the scale of R. Portions 1 to 10 of both these scales are shown in a thick line in ink to make them direct.

The scales of P and R are put in a relative position to scale of Q with arrow marks on each scale in line with those of other scales.

Therefore, when such is the position of the scales, one can read directly opposite any Q its required P and R.

If greater constant than 2.67 is required in the Equation $P = 2.67 \sqrt{Q}$ then slide can be shifted to red lines on scale of P at 2.50 or 2.80. Even other values can easily be taken.

Similarly, for scale of R the values given are on the basis of $R = .47\ Q^{\frac{1}{3}}$ for Equation $P = 2.8\ Q^{\frac{1}{2}}$.

Or $R = .48\ Q^{\frac{1}{3}}$ for Equation $P = 2.67\ Q^{\frac{1}{2}}$.

Conveniently lower or higher values could be taken for other equations.

Use of ordinary Slide Rule

$$P \times R = A \text{ and } \frac{Q}{A} = V.$$

Having found P and R, multiplication and division can be done with the slide rule and A and V fixed.

With this some more difficult problems of designing sections for remodelling of channels can be solved.

From Hydraulic Surveys values of Q, R and S are generally available from relationship of existing data. Sections for remodelling can be proposed.

The discharges worked out in Table A with Chapter VI may be verified with the Slide Rule. Some slide rules have been made for purposes of demonstration only. The scales are on blue prints. The paper is liable to shrinkage, so a higher standard of accuracy in the scales is not claimed at present.

These will be shown in the session and their working illustrated with examples.

CHAPTER XVIII

CONCLUSION

From the discussion in the preceding chapters it is clear that the writer does not accept Lacey's "f" as a silt factor only. It is not exclusively an index of silt but it comprises so many other factors. I think Lacey himself has now come to admit this as it is clear from his writing in Publication No. 20 of the Central Board of Irrigation. In this he himself has suggested that "f" = C. M. where M represents silt and that may be truly silt index and C may represent rugosity, etc., but this is only a hint: the dissection has not gone far enough.

Just as it is, to take Lacey's "f" for purposes of design may be as much amiss from the mark as Kennedy's C. V. R. Both of them have been shown not to be independent of the data of the section of the channel nor of any proposed discharge.

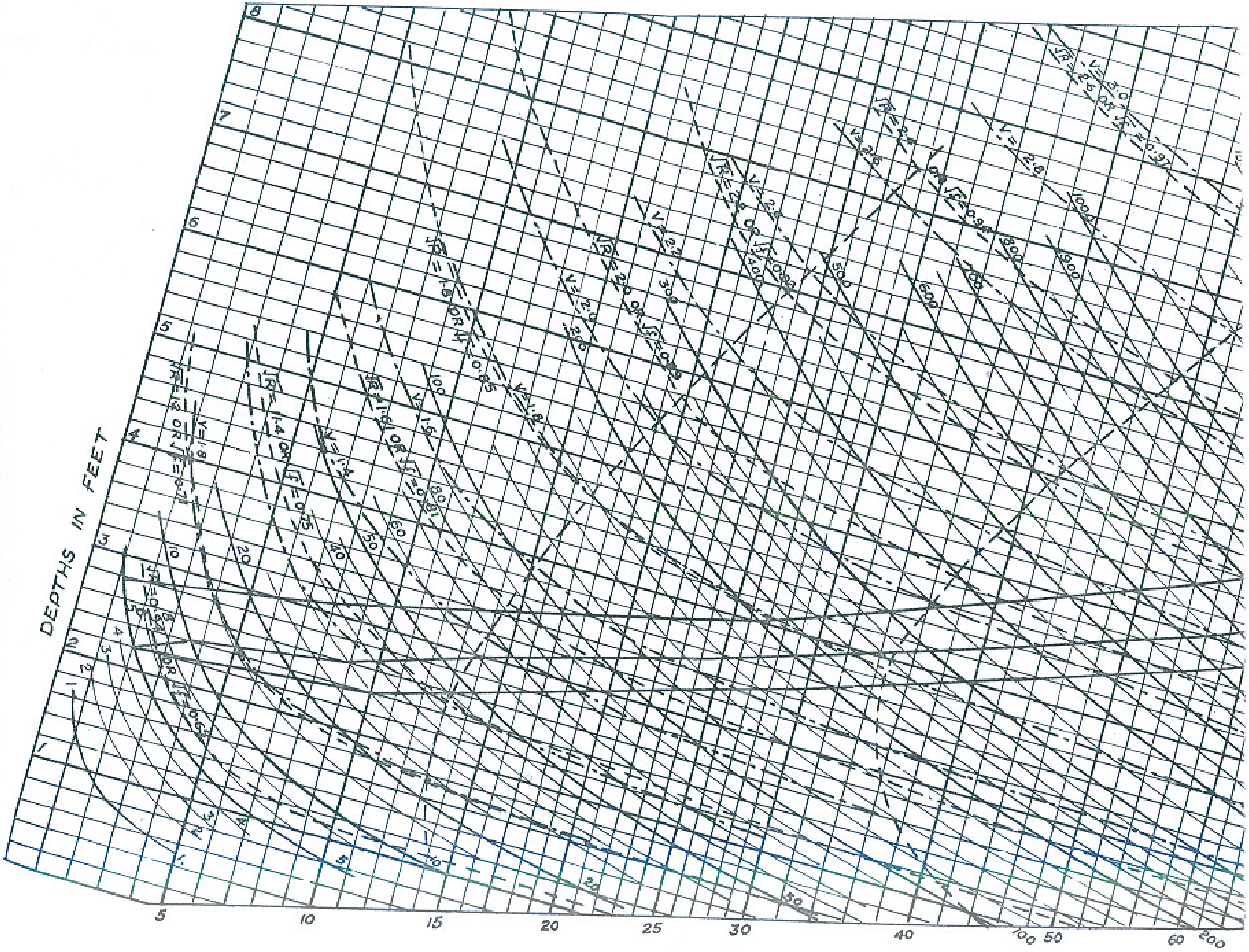
It is not suggested that the formulæ by Lacey are wrong; on the other hand, they are substantially correct. The introduction of "f" by Lacey in his first two formulæ $V = 1.17\sqrt{fR}$ and $A f^2 = 3.8V^5$ for the proper thrashing of the subject is highly commendable, the more so when he eliminates "f" and produces formula $P_W = 2.67\sqrt{Q}$, he has done an immense service to the Science of Hydraulics for which his fellow engineers are in permanent gratitude to him.

It has been shown vividly in Statements 2 and 3, Chapter XI, how Lacey's "f" and Kennedy's C. V. R. change with Q and S. It is not possible for any one to remember what particular value of $\sqrt{f}$ or $\frac{V}{V_o}$ should be adopted for a particular discharge and for a particular slope. It is, therefore, neither helpful nor accurate to lay emphasis on Lacey's Silt Factor or Kennedy's C. V. R., both being indefinite on account of their changing values under conditions too nemerous to need recounting Perimeter equations are the only safe guide.

For design in practice, the perimeter curve $P = 2.67\sqrt{Q}$ in the Improved Kennedy's Hydraulic Diagrams may be used. Fixation of slope can be decided with reference to Statements 6 and 7, copy of which forms an annexation of the Improved Kennedy's Hydraulic Diagrams.

The writer gratefully acknowledges the encouragement he has received from K. B. Mian Fakhar-ud-Din, Superintending Engineer, for writing this paper, and by going through the manuscript and making useful suggestions.

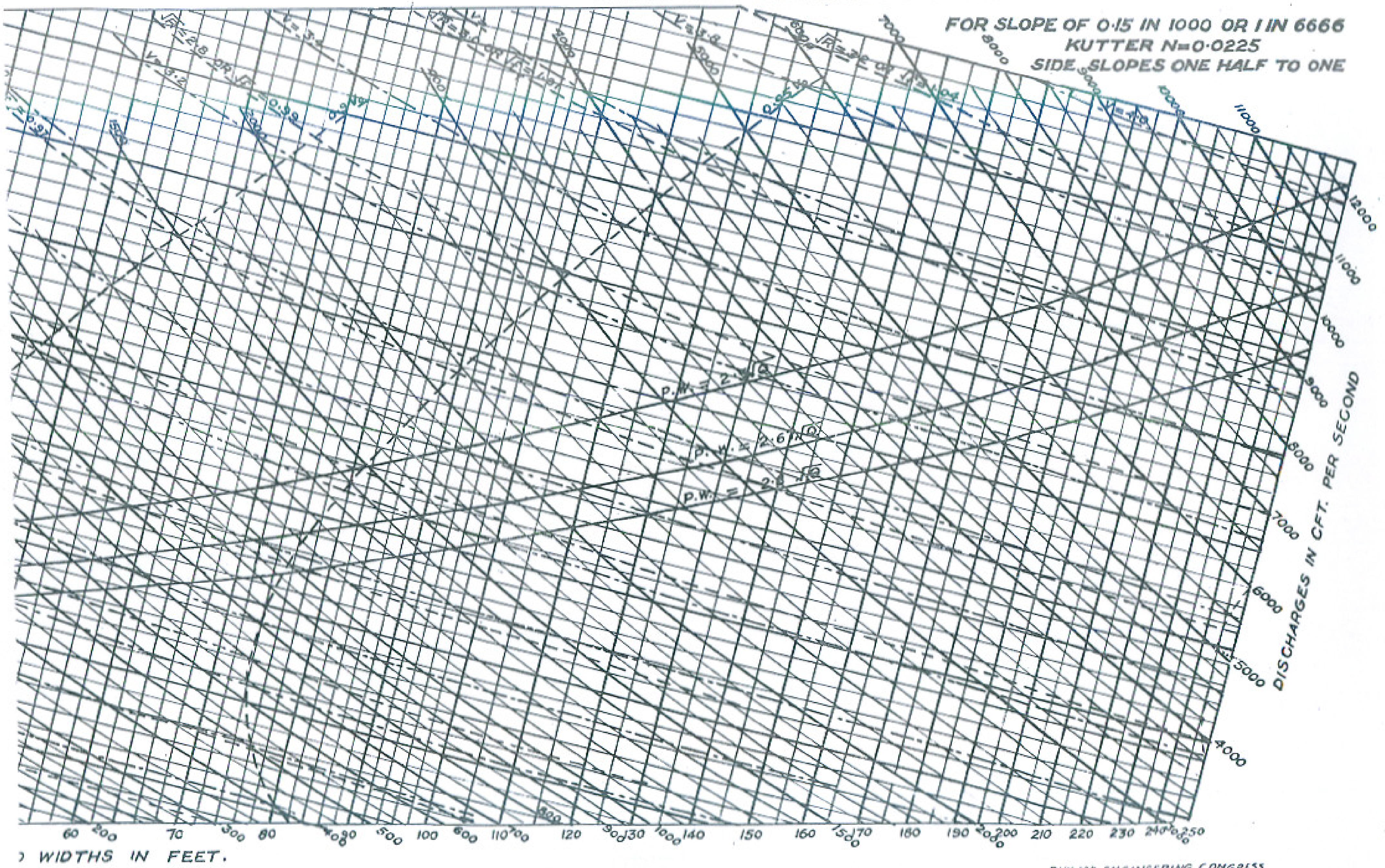
The writer also thankfully acknowledges help from valuable works of Mr. G. Lacey, I.S.E., Superintending Engineer, U.P., and Dr. N. K. Bose and Dr. J. K. Malhotra, but for whose researches this paper would not have been written.



DEPTHS IN FEET
BED WIDTHS
V = 2.8
V = 2.2
V = 2.0
V = 1.8
V = 1.5
V = 1.4
√R = 2.0 OR √f = 0.85
√R = 1.8 OR √f = 0.85
√R = 1.6 OR √f = 0.81
√R = 1.4 OR √f = 0.75

IMPROVED KENNEDY'S HYDRAULIC DIAGRAMS

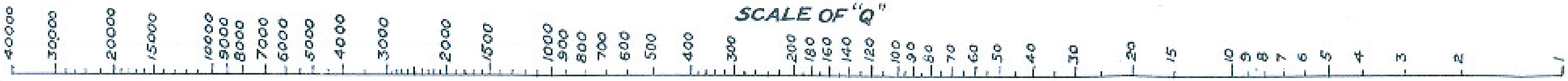
FOR SLOPE OF 0·15 IN 1000 OR 1 IN 6666
KUTTER N=0·0225
SIDE SLOPES ONE HALF TO ONE



PUNJAB ENGINEERING CONGRESS
1941.

NOMOGRAM
FOR
SHANTA'S SLOPE FORMULA
$S_{10^3} = Q/30R^{10/3}$ WHEN "N" = 0·0225

SCALE OF "Q"



NOTE:—FOR VALUES OF "N" OTHER THAN 0·0225 THE FOLLOWING MULTIPLES OF S_{10^3} SHOULD BE TAKEN.

FOR N	= 0·018	, MULTIPLY S_{10^3} BY	0·65
" "	0·020	" " "	0·80
" "	0·025	" " "	1·25
" "	0·030	" " "	1·76

SCALE OF SLOPE PER ‰

SCALE OF "R"

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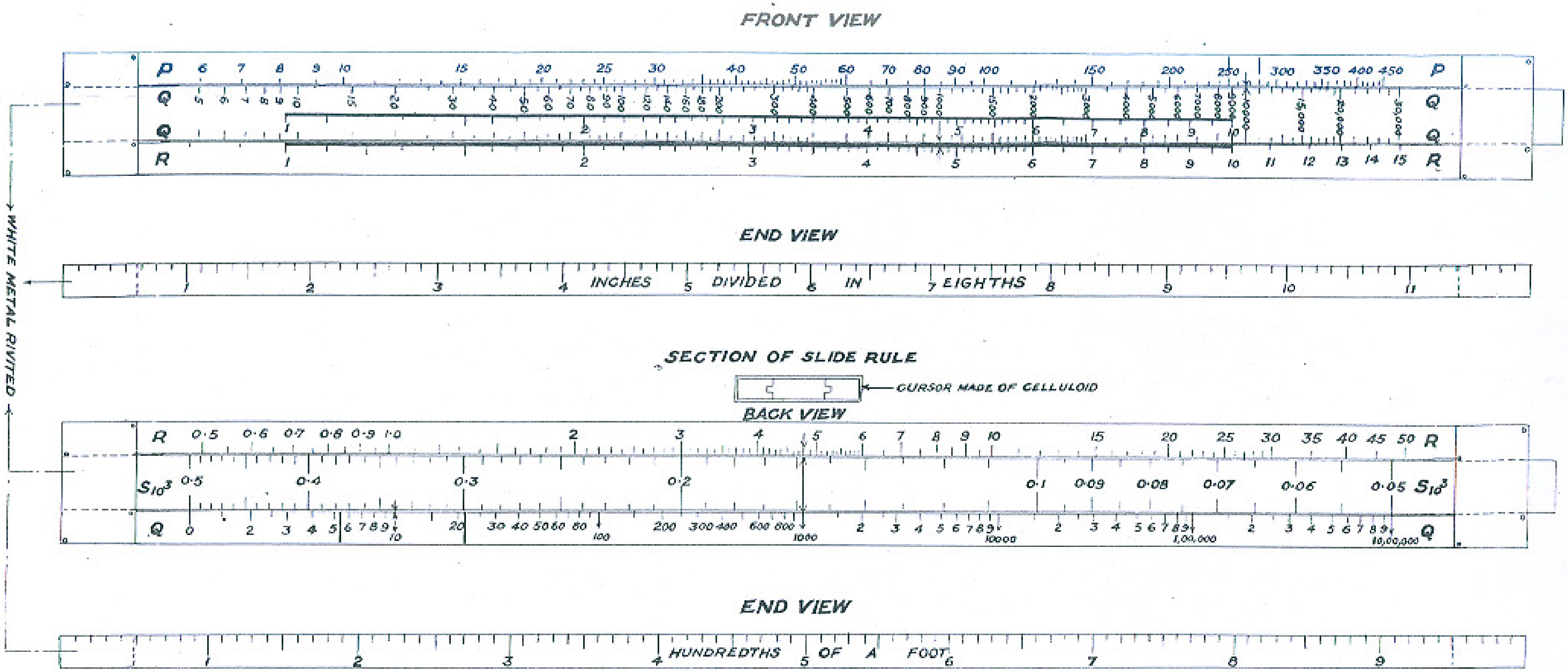
DISCHARGE SLIDE RULE



PUNJAB ENGINEERING CONGRESS
1941.

STATEMENT No. 5

Discharge	Formula	S = 1/10000 OR 0.10 PER ‰ B	D	V	√R	√f	S = 1/8000 OR 0.125 PER ‰ B	D	V	√R	√f	S = [illegible]6 OR 0.15 PER ‰ B	D	V	√R	√f	S = 1/5714 OR 0.175 PER ‰ B	D	V	√R	√f
10 CUSECS	G. LACEY											3.6	[illegible]	0.97	1.1	.755	3.8	2.0	1.04	1.077	0.794
	$P_W = 2.5\sqrt{Q}$	2.6	3.19	0.75	1.12		3.0	2.8	0.82	1.1		2.5	[illegible]35	0.89	1.04	.675	3.3	2.4	0.93	1.02	
	$P_W = 2.67\sqrt{Q}$	3.0	2.95	0.75	1.12		3.6	2.5	0.81	1.13		3.[illegible]	[illegible]4	0.87	1.08	.68	4.0	2.16	0.92	1.04	
	$P_W = 2.8\sqrt{Q}$	3.6	2.67	0.74	1.13		3.6	2.5	0.81	1.10		4.0	[illegible]	0.87	1.07	.678	4.5	2.0	0.90	1.04	
								$P_W = 2.8\sqrt{Q} = 8.85$						$R = 0.47\ Q^{1/3}$			= 1.01				
50 CUSECS	G. LACEY	12.2	2.95	1.24	1.463	0.728	12.6	2.70	1.33	1.421	0.815	13.[illegible]	[illegible]55	1.37	1.393	0.819	13.2	2.42	1.44	1.367	0.86
	$P_W = 2.5\sqrt{Q}$	9.6	3.7	1.18	1.54	0.637	10.5	3.3	1.25	1.48	0.70	10.[illegible]	[illegible]20	1.30	1.46	0.77	11.5	2.8	1.38	1.42	0.835
	$P_W = 2.67\sqrt{Q}$	11.3	3.39	1.14	1.54	0.634	12.0	3.05	1.21	1.46	0.70	12.[illegible]	[illegible]86	1.28	1.45	0.765	12.5	2.68	1.35	1.40	0.83
	$P_W = 2.8\sqrt{Q}$	13.0	3.08	1.11	1.50	0.63	13.4	2.8	1.20	1.45	0.694	14.[illegible]	[illegible]62	1.25	1.44	0.760	14.6	2.42	1.29	1.37	0822
								$P_W = 2.8\sqrt{Q} = 19.80$						$R = 0.47\ Q^{1/3}$			= 1.73				
150 CUSECS	G. LACEY	24.0	3.61	1.60	1.706	0.768	24.4	3.42	1.68	1.667	0.819	24.[illegible]	[illegible]30	1.74	1.646	0.866	25.5	3.15	1.76	1.619	0.911
	$P_W = 2.5\sqrt{Q}$	21.0	4.4	1.46	1.82	0.682	21.5	4.05	1.57	1.76	0.765	22.[illegible]	[illegible]80	1.65	1.73	0.835	22.5	3.55	1.74	1.69	0.895
	$P_W = 2.67\sqrt{Q}$	23.0	4.1	1.46	1.78	0.676	24.0	3.75	1.54	1.74	0.755	24.[illegible]	[illegible]55	1.62	1.68	0.827	25.4	3.35	1.85	1.66	0.89
	$P_W = 2.8\sqrt{Q}$	25.5	3.87	1.41	1.75	0.672	26.0	3.58	1.51	1.72	0.752	26.[illegible]	[illegible]35	1.59	1.65	0.824	27.0	3.2	1.64	1.64	0.885
								$P_W = 2.8\sqrt{Q} = 34.25$						$R = 0.47\ Q^{1/3}$			= 2.50				
500 CUSECS	G. LACEY	48.0	4.9	2.02	2.049	0.812	48.0	4.7	2.11	2.01	0.872	49.[illegible]	4.5	2.[illegible]7	1.975	0.922	50.0	4.3	2.23	1.939	0.964
	$P_W = 2.5\sqrt{Q}$	43.2	5.76	1.88	2.17	0.737	44.0	5.25	2.03	2.08	0.818	45.[illegible]	[illegible]	2.11	2.05	0.897	46.0	4.75	2.22	2.02	0.963
	$P_W = 2.67\sqrt{Q}$	47.6	5.46	1.83	2.14	0.73	49.0	4.95	1.996	2.06	0.816	49.[illegible]	[illegible]	2.07	2.02	0.892	50.0	4.42	2.17	1.96	0.953
	$P_W = 2.8\sqrt{Q}$	51.8	5.15	1.78	2.12	0.727	52.5	4.75	1.91	2.04	0.814	52.[illegible]	4.55	2.06	1.99	0.886	51.5	4.4	2.12	1.93	0.947
								$P_W = 2.8\sqrt{Q} = 62.61$						$R = 0.47\ Q^{1/3}$			= 3.73				
2000 CUSECS	G. LACEY	101	7.2	2.66	2.556	0.872	102	6.8	2.79	2.472	0.933	10[illegible]	[illegible]52	2.89	2.421	0.985	104	6.4	2.92	2.408	1.03
	$P_W = 2.5\sqrt{Q}$	94.2	8.12	2.51	2.66	0.796	95	7.6	2.66	2.57	0.877	96.[illegible]	[illegible]1	2.84	2.52	0.956	96.5	6.78	2.95	2.48	1.028
	$P_W = 2.67\sqrt{Q}$	103.0	7.7	2.43	2.62	0.792	104	7.15	2.6	2.54	0.871	10[illegible]	[illegible]7	2.76	2.45	0.948	106	6.4	2.86	2.45	1.023
	$P_W = 2.8\sqrt{Q}$	109	7.4	2.4	2.59	0.786	112	6.9	2.51	2.48	0.868	110	[illegible]5	2.71	2.43	0.944	110	6.22	2.84	2.40	1.019
								$P_W = 2.8\sqrt{Q} = 125.2$						$R = 0.47\ Q^{1/3}$			= 5.92				
5000 CUSECS	G. LACEY	167	9.2	3.17	2.90	0.917	168	8.75	3.32	2.835	0.975	16[illegible]	[illegible]5	3.4	2.798	1.034	170	8.25	3.48	2.76	1.053
	$P_W = 2.5\sqrt{Q}$	154	10.4	3.02	3.05	.845	155	9.75	3.2	2.96	0.926	15[illegible]	[illegible]5	3.38	2.88	0.998	157	8.8	3.52	2.83	1.073
	$P_W = 2.67\sqrt{Q}$	166	9.9	2.95	2.99	0.84	168	9.2	3.15	2.9	0.92	16[illegible]	[illegible]75	3.30	2.83	0.993	170	8.4	3.43	2.77	1.066
	$P_W = 2.8\sqrt{Q}$	177.5	9.5	2.88	2.94	0.832	178	8.96	3.05	2.86	0.916	17[illegible]	[illegible]4	3.26	2.79	0.968	179	8.1	3.37	2.73	1.063
								$P_W = 2.8\sqrt{Q} = 197.99$						$R = 0.47\ Q^{1/3}$			= 8.04				
10000 CUSECS	G. LACEY	240	11.3	3.60	3.236	0.949	241	10.7	3.79	3.154	1.015	24[illegible]	[illegible]4	3.89	3.113	1.068	243	10.0	4.03	3.056	1.118
	$P_W = 2.5\sqrt{Q}$						228	11.8	3.67			22[illegible]	[illegible]2	3.87			226	10.7	4.04	3.14	1.105
	$P_W = 2.67\sqrt{Q}$	240	12.0	3.38			242	11.25	3.6			24[illegible]	[illegible]62	3.79	3.14	3.032	245	10.18	3.93	3.08	1.098
	$P_W = 2.8\sqrt{Q}$																				
								$P_W = 2.8\sqrt{Q} = 280$						$R = 0.47\ Q^{1/3}$			= 10.13				

Discharge	Formula	S = 1/5000 OR 0.20 PER ‰ B	D	V	√R	√f	S = 1/4444 OR 0.225 PER ‰ B	D	V	√R	√f	S = 1/4000 OR 0.25 PER ‰ B	D	V	√R	√f	S = [illegible] B
10 CUSECS	G. LACEY	4.25	1.8	1.08	1.058	0.825	4.4	1.72	1.11	1.049	0.86	4.6	1.64	1.12	1.034	0.88	4.75
	$P_W = 2.5\sqrt{Q}$	4.0	2.0	1.0	1.04		3.8	2.0	1.04	1.03		4.2	1.9	1.08	1.04		4.3
	$P_W = 2.67\sqrt{Q}$	4.4	1.9	0.98	1.05		4.6	1.75	1.04	1.04		5.0	1.62	1.06	1.03		4.6
	$P_W = 2.8\sqrt{Q}$	4.5	1.9	0.97	1.05		5.0	1.70	1.0	1.04		5.0	1.66	1.05	1.03		5.0
		A = P×R = 8.94 ALSO A = Q/V = 8.85 Q = P×R×V = 10.0 BUT PROPOSED Q = 10.0										B = 5.6 D = 1.4					V =
50 CUSECS	G. LACEY	13.4	2.35	1.46	1.353	0.89	13.5	2.30	1.48	1.345	0.922	13.7	2.21	1.53	1.323	0.954	13.8
	$P_W = 2.5\sqrt{Q}$	12.0	2.60	1.45	1.38	0.889	12.2	2.5	1.46	1.36	0.93	12.4	2.4	1.53	1.36	0.93	12.8
	$P_W = 2.67\sqrt{Q}$	13.2	2.45	1.41	1.36	0.88	13.6	2.35	1.44	1.34	0.925	14.0	2.2	1.50	1.32	0.98	14.3
	$P_W = 2.8\sqrt{Q}$	14.5	2.30	1.39	1.34	0.87	15.0	2.22	1.40	1.32	0.915	15.0	2.10	1.48	1.30	0.915	15.0
		A = P×R = 34.25 ALSO A = Q/V = 34.01 Q = P×R×V = 50.0 BUT PROPOSED Q = 50										B = 14.9 D = 2.13					
150 CUSECS	G. LACEY	25.9	3.10	1.76	1.609	0.943	26.0	3.0	1.82	1.587	0.979	26.0	2.9	1.88	1.565	1.010	26.2
	$P_W = 2.5\sqrt{Q}$	27.6	3.4	1.82	1.64	0.947	23.8	3.15	1.87	1.61	1.003	24.0	3.08	1.91	1.59	1.038	24.[illegible]
	$P_W = 2.67\sqrt{Q}$	25.6	3.08	1.79	1.60	0.94	26.0	3.0	1.81	1.58	0.99	26.5	2.90	1.85	1.56	1.035	26.5
	$P_W = 2.8\sqrt{Q}$	27.2	3.00	1.74	1.58	0.935	28.5	2.85	1.76	1.55	0.989	28.5	2.75	1.83	1.53	1.025	28.[illegible]
		A = P×R = 85.73 ALSO A = Q/V = 84.75 Q = P×R×V = 152.0 BUT PROPOSED Q = 150										B = 27.36 D = 2.94					
500 CUSECS	G. LACEY	50	4.2	2.28	1.918	1.00	50.0	4.1	2.34	1.900	1.039	51.0	4.0	2.36	1.881	1.072	52.0
	$P_W = 2.5\sqrt{Q}$	45.5	4.5	2.32	1.95	1.05	46.0	4.30	2.41	1.93	1.05	46.5	4.15	2.45	1.89	1.11	46.[illegible]
	$P_W = 2.67\sqrt{Q}$	50.0	4.2	2.28	1.92	0.996	50.5	4.05	2.35	1.90	1.065	50.8	3.9	2.43	1.86	1.11	51.0
	$P_W = 2.8\sqrt{Q}$	53.0	4.05	2.24	1.90	0.992	54.5	3.90	2.27	1.87	1.057	53.5	3.75	2.4[illegible]	1.84	1.098	54.[illegible]
		A = P×R = 233.54 ALSO A = Q/V = 231.48 Q = P×R×V = 504.0 BUT PROPOSED Q = 500										B = 52.6 D = 4.23					
2000 CUSECS	G. LACEY	105	6.2	2.98	2.375	1.077	105	6.1	3.03	2.356	1.114	106	5.8	3.17	2.304	1.149	106
	$P_W = 2.5\sqrt{Q}$	98.0	6.5	3.04	2.43	1.083	98	6.3	3.14	2.38	1.143	98.5	6.06	3.25	2.33	1.20	
	$P_W = 2.67\sqrt{Q}$	106	6.2	2.96	2.37	1.075	107	6.0	3.03	2.34	1.134	108	5.7	3.17	2.29	1.155	
	$P_W = 2.8\sqrt{Q}$	112	6.00	2.90	2.34	1.073	113	5.75	3.02	2.31	1.13	112.5	5.56	3.12	2.26	1.19	
		A = P×R = 741.30 ALSO A = Q/V = 735.29 Q = P×R×V = 2016.0 BUT PROPOSED Q = 2000										B = 109.7 D = 6.57					
5000 CUSECS	G. LACEY	170	8.00	3.59	2.722	1.23	171	7.75	3.69	2.683	1.162	171	7.55	3.79	2.65	1.241	172
	$P_W = 2.5\sqrt{Q}$	158	8.4	3.67	2.78	1.137	159	8.06	3.80	2.73	1.187	160	7.8	3.9[illegible]	2.68	1.218	
	$P_W = 2.67\sqrt{Q}$	172	7.98	3.55	2.72	1.127	172.5	7.7	3.68	2.67	1.178	173	7.45	3.82	2.63	1.232	
	$P_W = 2.8\sqrt{Q}$	182	7.64	3.52	2.68	1.120	182	7.5	3.59	2.63	1.179	183	7.20	3.72	2.59	1.218	
		A = P×R = 1591.84 ALSO A = Q/V = 1572.33 Q = P×R×V = 5062.0 BUT PROPOSED Q = 5000										B = 176.0 D = 8.72					
10000 CUSECS	G. LACEY	244	9.57	4.20	2.995	1.162	245	9.5	4.21	2.985	1.204	246	9.39	4.29	2.956	1.249	
	$P_W = 2.5\sqrt{Q}$	227.5	10.2	4.21	3.07	1.167	228	9.92	4.33	3.03	1.223	229	9.54	4.45	2.96	1.276	
	$P_W = 2.67\sqrt{Q}$	246	9.75	4.09	3.02	1.162	247.5	9.48	4.18	2.98	1.218	248	9.20	4.30	2.93	1.270	
	$P_W = 2.8\sqrt{Q}$																
		A = P×R = 2836.4 ALSO A = Q/V = 2808.98 Q = P×R×V = 10098.0 BUT PROPOSED Q = 10000										B = 2.53 D = 10.87					

STATEMENT No. 5

S = 1/5000 OR 0·20 PER ‰				S = 1/4444 OR 0·225 PER ‰					S = 1/4000 OR 0·25 PER ‰					S = 1/3636 OR 0·275 PER ‰					S = 1/3333 OR 0·30 PER ‰					S = 1/2857 OR 0·35 FR ‰					S = 1/2500 OR 0·40 PER ‰					S = 1/2000 OR 0·50 PER ‰				
D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$	B	D	V	$\sqrt{R}$	$\sqrt{f}$
1·8	1·08	1·058	0·825	4·4	1·72	1·11	1·049	0·86	4·6	1·64	1·12	1·034	0·883	4·75	1·58	1·14	1·03	0·911	4·8	1·54	1·17	1·02	0·927	5·0	1·45	1·20	1·005	·975	5·4	1·36	1·21	0·99	1·02	5·4	1·3	1·27	0·915	1·086
2·0	1·0	1·04		3·8	2·0	1·04	1·03		4·2	1·9	1·08	1·04		4·3	1·8	1·1	1·02		4·0	1·75	1·16	1·01		5·0	1·5	1·20	1·0		5·0	1·45	1·24	0·9		5·0	1·4	1·25		
1·9	0·98	1·05		4·6	1·75	1·04	1·04		5·0	1·62	1·06	1·03		4·6	1·66	1·1	1·02		4·8	1·60	1·12	1·00		5·5	1·4	1·18	1·0		5·5	1·35	1·22			5·5	1·3	1·25		
1·9	0·97	1·05		5·0	1·70	1·0	1·04		5·0	1·66	1·05	1·03		5·0	1·60	1·09	1·02		5·2	1·50	1·11	1·00		5·6	1·38	1·18			6·0	1·28	1·20			6·3	1·2	1·22		
= 8·94 ALSO A = $\frac{Q}{V}$ = 8·85									B = 5·6	D = 1·4				V = 1·12 $\sqrt{R}$ = 1·13																								
V = 10·0 BUT PROPOSED Q = 10·0																																						
2·35	1·46	1·353	0·894	13·5	2·30	1·48	1·345	0·922	13·7	2·21	1·53	1·323	0·956	13·8	2·18	1·54	1·313	0·954	13·9	2·1	1·59	1·300	1·015	14·0	2·0	1·67	1·273	·063	14·2	1·95	1·69	1·261	1·100	14·5	1·85	1·75	1·237	1·175
2·60	1·45	1·38	0·885	12·2	2·5	1·48	1·36	0·93	12·4	2·4	1·53	1·36	0·93	12·8	2·3	1·56	1·34	1·033	12·8	2·2	1·63	1·30	1·09	13·0	2·1	1·70	1·27	·15	13·5	2·0	1·76	1·25	1·23	13·5	1·85	1·87	1·23	1·32
2·45	1·41	1·36	0·88	13·6	2·35	1·44	1·34	0·925	14·0	2·2	1·50	1·32	0·98	14·3	2·15	1·51	1·30	1·025	14·0	2·1	1·58	1·27	1·088	14·6	1·9	1·69	1·23	·145	14·5	1·9	1·70	1·22	1·23	15·0	1·7	1·85	1·15	1·28
2·30	1·39	1·34	0·87	15·0	2·22	1·40	1·32	0·915	15·0	2·10	1·48	1·30	0·975	15·0	2·07	1·49	1·28	1·02	15·2	2·0	1·54	1·26	1·083	15·6	1·85	1·63	1·22	·144	15·6	1·80	1·68	1·20	1·22	16·2	1·62	1·81	1·17	
= 34·25 ALSO A = $\frac{Q}{V}$ = 34·01									B = 14·9	D = 2·13				V = 1·12 $\sqrt{R}$ = 1·47																								
50·0 BUT PROPOSED Q = 50																																						
3·10	1·76	1·609	0·943	26·0	3·0	1·82	1·587	0·979	26·0	2·9	1·88	1·565	1·010	26·2	2·85	1·91	1·552	1·034	26·5	2·8	1·92	1·543	1·063	26·8	2·7	1·97	1·52	·118	26·9	2·6	2·04	1·497	1·162	27·0	2·45	2·17	1·459	1·241
3·4	1·82	1·64	0·947	23·8	3·15	1·87	1·61	1·003	24·0	3·08	1·91	1·59	1·038	24·0	3·00	1·96	1·57	1·092	24·2	2·85	2·05	1·53	1·138	24·5	2·70	2·15	1·50	·21	25·0	2·6	2·19	1·47	1·29					
3·08	1·79	1·60	0·94	26·0	3·0	1·81	1·58	0·99	26·5	2·90	1·85	1·56	1·032	26·5	2·80	1·92	1·54	1·09	26·8	2·70	1·97	1·50	1·134	27·5	2·55	2·04	1·48	·21										
3·00	1·74	1·58	0·935	28·5	2·85	1·76	1·55	0·989	28·5	2·75	1·83	1·53	1·025	28·0	2·70	1·89	1·52	1·08	28·0	2·60	1·97	1·48	1·128															
85·73 ALSO A = $\frac{Q}{V}$ = 84·75									B = 2736	D = 2·94				V = 1·12 $\sqrt{R}$ = 1·77																								
152·0 BUT PROPOSED Q = 150																																						
4·2	2·28	1·918	1·00	50·0	4·1	2·34	1·900	1·039	51·0	4·0	2·36	1·861	1·072	52·0	3·9	2·38	1·860	1·100	52·0	3·85	2·41	1·849	1·131	53·0	3·7	2·46	1·81	1·187	53·0	3·55	2·57	1·786	1·237					
4·5	2·32	1·95	1·05	46·0	4·30	2·41	1·93	1·05	46·5	4·15	2·48	1·89	1·11	46·0	4·1	2·54	1·88	1·181																				
4·2	2·28	1·92	0·996	50·5	4·05	2·35	1·90	1·065	50·8	3·9	2·43	1·86	1·11	51·0	3·8	2·48	1·85	1·172																				
4·45	2·24	1·90	0·992	54·5	3·90	2·27	1·87	1·057	53·5	3·75	2·41	1·84	1·098	54·5	3·68	2·41	1·83	1·168																				
233·54 ALSO A = $\frac{Q}{V}$ = 231·48									B = 52·6	D = 4·23				V = 1·12 $\sqrt{R}$ = 2·16																								
504·0 BUT PROPOSED Q = 500																																						
6·2	2·98	2·375	1·077	105	6·1	3·03	2·356	1·114	106	5·8	3·17	2·304	1·149	106	5·75	3·19	2·298	1·183	107	5·7	3·19	2·287	1·217															
5·5	3·04	2·43	1·083	98	6·3	3·14	2·38	1·143	98·5	6·06	3·25	2·33	1·20																									
5·2	2·96	2·37	1·075	107	6·0	3·03	2·34	1·134	108	5·7	3·17	2·29	1·195																									
5·00	2·90	2·34	1·073	113	5·75	3·02	2·31	1·13	112·5	5·56	3·12	2·26	1·19																									
741·30 ALSO A = $\frac{Q}{V}$ = 735·29									B = 109·7	D = 6·5				V = 1·12 $\sqrt{R}$ = 2·72																								
2016·0 BUT PROPOSED Q = 2000																																						
8·00	3·59	2·722	1·23	171	7·75	3·69	2·685	1·162	171	7·55	3·79	2·65	1·241	172	7·50	3·79	2·64	1·241																				
8·4	3·67	2·78	1·137	159	8·06	3·80	2·73	1·187	160	7·8	3·91	2·68	1·238																									
7·95	3·55	2·72	1·127	172·5	7·7	3·68	2·67	1·178	173	7·45	3·80	2·63	1·232																									
7·64	3·52	2·68	1·120	182	7·5	3·59	2·63	1·179	183	7·20	3·72	2·59	1·228																									
591·84 ALSO A = $\frac{Q}{V}$ = 1572·33									B = 176·0	D = 8·72				V = 1·12 $\sqrt{R}$ = 3·18																								
5062·0 BUT PROPOSED Q = 5000																																						
9·57	4·20	2·995	1·162	245	9·5	4·21	2·985	1·204	246	9·30	4·29	2·956	1·249																									
10·2	4·21	3·07	1·167	228	9·92	4·33	3·03	1·223	229	9·54	4·46	2·98	1·276																									
9·75	4·09	3·02	1·162	247·5	9·48	4·18	2·98	1·218	248	9·20	4·30	2·93	1·270																									
836·4 ALSO A = $\frac{Q}{V}$ = 2808·98									B = 2·53	D = 10·87				V = 1·12 $\sqrt{R}$ = 3·56																								
10098·0 BUT PROPOSED Q = 10000																																						

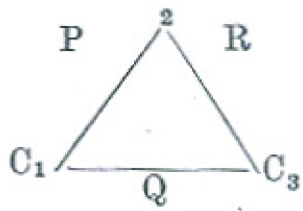
DISCUSSION

The AUTHOR, introducing the paper, craved the indulgence of the audience, according to him, consisting of eminent engineers, authors and research scholars, to forgive shortcomings in the expression of his ideas. He said that it was at Amritsar, the producer of religious leaders, that Kennedy formulated his silt theories, which were followed for years. Similarly, from the sacred land of Ganges and Jamna, Lacey formulated his own silt theories, which had in places replaced Kennedy's theory. He said that in Lahore, the seat of the Unionist Government, he had, like a true unionist, combined Kennedy with Lacey to get best out of the combination for common good.

Mr. Haigh had pointed out to the author that the great drawback in Kennedy's diagrams was the assumption of one rugosity factor, *viz.* N=0·0225, while actually we have to deal with all sorts of rugosities. The conception of rugosity expressed in the paper differs from Kennedy or Kutter's N, and the author accepted it good enough for calculating velocity and accepted the diagrams. It did not convey rugosity of the channel as a whole. Lacey's curve $P=2{\cdot}67\sqrt{Q}$ represents that average rugosity called N=·0225 and was a good average for Punjab channels. He suggested to use $P=2{\cdot}8\sqrt{Q}$ for greater rugosities and $P=2{\cdot}5\sqrt{Q}$ for less rugosities. On lower side of curve $P=2{\cdot}67\sqrt{Q}$ will be found dimensional designs for great rugosities or for coarse silt and on the upper side for finer silt or lower rugosities. The author explained that this point placed his diagrams on higher pedestal than those of Lacey. For one slope these diagrams give different designs to meet with different rugosities while Lacey's diagrams gave only one design for one slope. Producing Lacey's and his own diagrams the author, taking the example of slope 1/5,000 for a discharge of 1,000 cusecs gave dimensions for three different sites with different rugosities as in Statement 5.

The author said that the Research scholars of Lahore had given them elixir like "Amritdhara" for all diseases of the irrigation channels, in the form of their formulæ $P=2{\cdot}8\sqrt{Q}$ and $V=1{\cdot}12\sqrt{R}$. The data from which these relationships were derived was given on the blackboard and were taken from Table 1.4 of Research Publication, Vol. II, No. 23. The values of V on the board as obtained in $V=1{\cdot}12\sqrt{R}$ had varied from 1·0 to 1·3 and in $P=2{\cdot}8\sqrt{Q}$ from 2·0 to 3·2. These were good averages but the author did not advocate adopting such averages in actual practice.

According to the author arbitrarily fixing values of coefficients, C_1, C_2, C_3 in formulae, $V=C_1 \; R^{\frac{1}{2}}$, $P=C_2Q^{\frac{1}{2}}$ and $R=C_3Q^{\frac{1}{3}}$ is unsound. Inter-connection of C_1, C_2, C_3, P, Q and R can be represented like a frame in a structure such as triangle



in which P, Q and R are the sides and C_1, C_2, and C_3 are the apicies. Any force applied at R will create stresses in all members R, Q, P, C_1 and C_2 and change in one will create changes in others. But in these phenomenon of changes, the relationships put algebraically as below do not change :

$$P \times R = A \qquad V=C_1 \; R^{\frac{1}{2}}$$

$$P \times R \times V = Q \qquad P=C_2 \sqrt{Q}$$

$$R=C_3 \; Q^{\frac{1}{3}} \qquad R=C_3 \; Q^{\frac{1}{3}}$$

We get

$$\text{Taking } C_3 = \frac{R}{Q^{\frac{1}{2}}} \text{ and } P.V. = \frac{Q}{R}$$

$$P \, C_1 = \frac{Q}{R^{3}/_{2}} \qquad \text{or } C_3{}^{3}/_{2} = \frac{R^{3}/_{2}}{Q^{\frac{1}{2}}}$$

$$C_1 \, C_2 = \sqrt{\frac{Q}{R^{3}/_{2}}} \qquad C_3{}^{3}/_{2} = \frac{1}{C_1 \, C_2}$$

$$\text{or } C_3 = \frac{1}{(C_1 \, C_2)^{\frac{2}{3}}}.$$

The author said that fixation of values of C_1, C_2 and C_3 arbitrarily was fundamentally wrong.

The author continued that Mr. Garg, Superintending Engineer, Haveli Canals, had mentioned to him that in the Haveli Canal, the designed full-supply levels were attained only with 70 per cent. of the designed discharge. Mr. Garg had sent the designed data to the author, and with the information available he had worked out values of C_1, C_2 and C_3. He had also examined the data for Bikaner Canal, which he showed on the blackboard. The value of C_2 in $P=C_2 \; Q^{\frac{1}{2}}$ in the case of Gang Canal was 1·55 for a slope of ·13′ per % but in the Haveli Canal, the coefficient in the first reach was 1·96 and in the next reach came down to 1·5.

In Chapter X, the author had emphasized the importance of keeping berms straight and parallel. The author illustrated the effect of neglect in this respect by showing plan and long-section of Lahore Branch of U. B. D. C. In the reach 10,500 to 11,500 the existing waterway was 85′ to 90′ while hardly a mile above that the width was double that at R. D. 6,000, being 172′. The long-section naturally showed a huge quantity of silt in that reach. Only a haphazard effort had been made to restrict the waterway to 130′.

The author further showed the long-section of the M. B. L. of the U.B.D.C. for its 15 miles, showing huge quantities of silt deposited since 1874. The long-section, prepared by a predecessor of the author showed silt from 1874 to 1910 and the author completed it for 1941. The author said that the process of progressively raising banks due to silting of bed should end and he felt that he had rightly suggested construction of silt ejectors as a remedy.

Discussion :—

MR. MONTAGU prefaced his remarks by stating that he had read the paper by L. Ishar Das with mixed feelings. There was no question as to the importance of the subject nor the commendable zeal and keenness evinced by the author in his observations. But the speaker felt that many of the statements in the paper were wrong and the deductions were incorrect. Many of the mathematical processes though possibly arithmetically correct, were certainly false in their application and produced entirely useless results. The speaker sincerely hoped that those members of the Congress who desire to acquaint themselves with modern theory of silt transport would read Lacey in the original and not absorb their knowledge secondhand through mis-informed criticism by writers who clearly failed to understand the basis of the Lacey's theories. Indeed, for a thorough understanding of the Lacey theories, it is essential to read informed criticism on the subject and Lacey's replies thereto.

Before dealing with this side of the matter the speaker referred to Chapter I and the author's remarks on the silt contents of hill torrents and canals. The facts cannot be seriously disputed, but the author fails to draw one of the most important conclusions from his observations. The speaker suggested that in Nature there is no such thing as absolute and long continuing regime. Perhaps this "regime" requires definition. Regime has been defined by every one who has investigated the problem of silt transport. For the present purpose, the speaker defined regime as the state of flow in which the bed and sides remain constant in position and grade. This definition, of course, is only applicable to flow in alluvial channels. It may be said that a rigid trough is in constant regime. Of course, this is so, but it would be carrying the definition too far.

A stream issuing from the hills carries detritus of every size, shape and material up to a maximum, depending upon the volume, and velocity of flow and the extent and nature of the terrain. This stream ultimately must issue into the plains where the slopes are appreciably flatter than in the hills from which the stream emerges.

Consequently, detritus is thrown down in an endeavour to steepen the slope. Over the steeper slope so generated, the finer grades of silt may continue to be carried but heavier silt may continue to be deposited until the slope attains that sufficient to give a velocity which will carry all forms of detritus in the stream. From this it follows that the beds of all streams are steadily and continuously rising and the material passing any given point becomes steadily coarser.

The speaker did not wish to be understood as stating that scour never occurs in a natural stream. Of course, local silt and scour take place due to local conditions, but the above remarks refer to the general tendency of streams issuing from the hills in which they originate. The process is perpetual and nothing known to man can stop it.

If a headworks be built at any given point, the river bed at this point may be expected to rise steadily over a period of years and the material of which the bed is composed to become progressively coarser. Here again, the speaker did not refer to the purely local and temporary effect of the construction of the headworks but to the geological period of which the lives of the oldest headworks are only a fraction.

In passing, the speaker mentioned that while he had charge of the Marala Division, gravel arrived at the Marala weir for the first time on record. He would not be surprised to learn from officers who have been in charge of Marala Division since 1923, that there is appreciable gravel to be found there to-day.

Precisely the same phenomenon occurs in miniature in canals. As the material suspended in the river increased in coarseness, so does the coarseness of the silt introduced at the head of the canal, increase. The slopes in the upper reaches of the canal system consequently have a general tendency to increase together with the silt burden. This effect slowly travels down the canal and as the channels become smaller in size, the effect becomes more apparent, and the local officers report that their channels show a tendency to silt.

Broadly speaking, it is for these fundamental reasons that the speaker agreed with the views of the author, that silt excluding and ejecting devices are an essential on our canals. Indeed, he went further and stated that it was his conviction that the discharge necessary to operate these devices has a first claim on the discharge of the canal. It has been a constant endeavour in the past to pass down the maximum volume of water in response to the clamour of the irrigator. Water for silt excluding devices had only been utilized when surplus to irrigation requirements. This was a fundamental mistake for which the Punjab canals will suffer in the future.

Here again the general remarks referred to above do not cover errors in original design, made particularly in the older canals. Of these the Upper Bari Doab Canal is probably the finest example. The original designers designed the upper reaches of the canal with a rather steep slope, narrow bed width and high velocity to obtain a high discharging capacity. Consequently, all material below a certain grade was swept onwards. But the heaviest material was thrown down in the head of the canal and the slope steepened. The toe of this steeper slope advanced year by year until a "drop" in the water surface checked further advance. The heavy detritus then proceeded to increase the slope of the reach below, until in turn the second fall was reached. This process was carried on until the last fall in the Main Line of the Upper Bari Doab Canal was passed. The toe of the enhanced slope continued to advance until ultimately the last fall was completely obliterated. In the meantime, the heavier grades of silt were correspondingly deposited in the reaches above Tibri.

Lighter grades of silt were deposited above Aliwal and for many years the channels below carried only the finest silt without difficulty and without indication of the deterioration which was going on in the upper reaches of the canal.

To-day, there was bitter complaint that even the tail channel of the Upper Bari Doab Canal system are deteriorating as a result of silt influx. This is not in the least surprising. Indeed it was a matter for surprise that the causes have not been recognized and that remedies have not been applied many years earlier than was actually done.

The speaker had actually seen the report of one officer of the department who stated categorically that no silt was entering the canal at Madhopur.

On the other hand we have the observations of L. Ishar Das that the shrubs which were planted when the speaker was S. D. O Lahore, on the broad grassy berms of the Lahore branch, through Lahore itself, are on the point of falling into the channel due to erosion of the berms.

While S. D. O., Lahore, the speaker had occasion to berm cut the Niazbeg distributary. The channel at that time was extremely narrow and quite deep and the berms were formed of the very finest clay material. To-day the Niazbeg distributary is a stream of "normal" section broad and shallow.

The speaker emphasized that there is no such thing as permanent and long continuing regime in any silt-bearing channel, natural or artificial.

The question now arises as to how this effects theories of silt transport.

Mr. Kennedy whose work on the subject is dealt with in this paper, evolved an empiric formula and a theory to support it. The speaker was the last to depreciate the value of Kennedy's work. He evolved some sort of order out of chaos, but it does not alter the fact that his formula was empiric and his theory wrong. The fact that the Wood's normal data was required to round off Kennedy's theory and to admit of its reasonable application and to limit its eccentricities, is itself sufficient evidence that Kennedy's formula was but a rough though valuable guide. Indeed, the very channels which Kennedy declared to be in regime and on which his empiric formula was founded, are to-day appreciably wider and shallower than they were when he carried out his classic experiments.

The first real attempt to place silt transport on a proper theoretical basis was that of Mr. Gerald Lacey. It was not proposed here to discuss Lacey's theories any more than to expound the empiric formula of Kennedy, but it is essential to a proper understanding of his criticism of this paper, that the speaker should point out with maximum emphasis the fundamental basis of Lacey's theories.

Lacey's theories postulate a constant discharge flowing in an envelope made up of incoherent, self-borne alluvium and carrying a constant silt charge. These conditions never exist in practice in either artificial or natural channels, except as an accident and instantaneously.

Until this is understood, no progress can be made with the application of Lacey's theory to practice.

The practical engineer no doubt will cry, "then what is the use of a theory which does not take into account the absolute and practial conditions." To this the only reply was that unless the fundamental basis of a phenomenon is understood, it is impossible to apply any sort of theory to practical conditions. At this point a parallel might be useful. The pendulum or plumb-bob used by a mason to define a vertical, only attains the truly vertical in ideal conditions, *e.g.* absence of wind, absence of earth tremors, and absence of large masses in the near neighbourhood. If the pendulum swings, the mason is guided by the mean position or statistical average. Even if other causes of error cannot be wholly eliminated, no mason would assert that a true vertical did not exist. Similarly, although the constant discharge in incoherent self-borne alluvium is never met in nature, this should not prevent the engineer applying Lacey's theories, with due regard to the allowances which practical conditions compel.

In Chapter II the author makes a few remarks on meandering. Therein, he fails to mention the primary cause of meandering, *viz.* too steep a slope. If a canal be constructed with nice berms and smooth sides and bed to the proper section for the discharge and slope imposed, if that slope be steeper than nature desires, it is an accepted fact that scour will take place. The generation of a scoured section takes time. If the bed be hard, the time is increased but water is determined that it shall have the slope it desires. Attacks on the sides of the channel will become evident at the same time as attacks on the bed. Such attacks on the sides of the channels should not be confused with an endeavour to increase the bed width. Indeed, if the slope be too great, it is a matter of indifference as to the bed width afforded to the channel. The stream will adopt a sinuous progress and in so doing will attack the sides of its envelope in an endeavour :

(*a*) to lengthen its path and reduce its slope,

(*b*) to consume the surplus energy in superturbulence and erosion.

This is evidenced in the Western Jumna Canal. At least half the trouble on this canal is due to too steep a slope. In spite of tremendous bed widths, attacks on the sides continue and will continue, until the slope of the canal is flattened. In the meantime, valuable agricultural land is eroded to the detriment of the cultivator ; Government is put to vast expense in an endeavour to protect the banks and check the erosion ; driving banks have to be set back ; plantations fall into the stream. All this mess is due to too steep a slope. So far as records on the Western Jumna Canal can show, this fact was first specifically recognized by Mr. Haigh, but it was not until Government decided to increase the full supply discharge of the canal, that sanction was accorded to the necessary expenditure to flatten adequately the existing slope of the Main Lines.

In respect to Chapter III, the speaker selected one remark for comment. " This silt factor has not explicitly been defined but has loosely been said as an equivalent of Kennedy's V_o or CVR=1.' The speaker desired to know who had said anything so loose. Mr. Lacey himself in C. B. I. Publication No. 20 had stated that the *Lacey* critical velocity ratio was equal to the square root of the silt factor, and that the *Kennedy* critical velocity ratio—as rigidly defined by the Kennedy equation—was only approximately equal to the square root of the silt factor within the limited range of the Kennedy data. In Technical Paper U. P. No. 1, Mr. Lacey stated that the Lacey regime equation gave, *on canals*, substantially the same velocities as Kennedy's equation. Clearly, that statement postulated rational ratios of bed width to depths which were not in themselves inherent in the Kennedy formula. L. Ishar Das surely could see that computations of Kennedy's C. V. R. and Lacey's CVR from their respective theories must differ.

The sentence just quoted by the speaker is itself anything but explicit, but presumably is intended to draw attention to the fact that Lacey has made no attempt to define the precise meaning of his silt factor 'f'. The speaker offered his own understanding for consideration, of this factor 'f'. He suggested that it was a factor which takes into account the actual volume of the silt charge, its density, its shape and indeed any other attribute of silt. After all, every physical conception starts with a general definition. The number of planets in the solar system was increased by the discovery of Neptune, due to the measurement of fine variations between the observed and theoretical movements of the known planets. Newton's theory of gravity held the field for many years until refined by Einstein. The empiric formula of Kennedy was the last word in silt transport until Lacey arrived on the scene.

It is more than probable that the intelligent attack which is now being made on the Lacey's conception contained in the silt factor 'f', may lead to its further clarification and definition. But until this critical attack achieves definite results, the engineer may safely accept the Lacey's 'f' as an omnibus factor indicating the probable effect of silt burden on his channels.

It has been complained that the engineer must guess the value of 'f' before he can design his channels. This is true. The engineer must guess at the transmission constant of the soil before he designs tubewells. By "guess", the speaker does not mean an uninstructed "shot in the dark", but an intelligent and instructed estimate based on such data as is available—in other words, experience.

After all, the old designers of channels who used Kennedy in days gone by, must have made a similar instructed "guess" at the probable value of Kennedy's velocity ratio which would obtain in their channels.

L. Ishar Das has stated categorically in his Introduction that neither the Lacey's silt factor 'f' nor the Kennedy's CVR are "safe" as a basis of design. The speaker invited L. Ishar Das to inform the meeting what primary factors he would take into account if required to design irrigation channels. An examination of the diagrams appended to his paper has failed to disclose any new means of relating the shape of channel to the silt burden.

The author has further stated that the silt factor is unreliable as it varies with the discharge and slope. A statement of this nature proves conclusively that the author has no understanding of the Lacey's theories or he would not make a statement which is a complete inversion of the facts. The slope of the channel is determined along with all other dimensions, by the discharge and the silt factor. The speaker felt that it was truly amazing that here in India, the birthplace of the Lacey's theories, such ignorance of the fundamentals should still exist at a time when the Lacey's theories had attained a world-wide reputation.

In Chapter IV the author takes Lacey's silt velocity formula and equates it to Manning's flow formula. This astonishing process compelled the speaker to point out to the author that a silt-bearing formula and a velocity formula are two different—though possibly related—entities. A flow formula is not concerned with silt. A flow formula is expected to connect the velocity of a stream with other hydraulic factors such as slope, hydraulic mean radius, wetted perimeter, cross-sectional area, shape ratio, rugosity and discharge. Lacey's silt velocity formula connects the silt transported at a given velocity with the hydraulic mean depth.

Is it really necessary to point out that a velocity formula may be useful in computing flow in a rigid envelope? Lacey's silt velocity formula by definition, cannot. Provided that the velocity exceeds that required to transport all material carried in the stream, a flow formula will give the answer, independent of the silt burden. The silt velocity formula is primarily dependent upon the silt charge transported.

The author's ingenuous attempt to connect Lacey's silt transporting velocity with Manning's velocity of flow in a rigid envelope, is fundamentally wrong, misleading and useless. No matter how ingenious the arithmetic, the result is quite meaningless.

The author has devoted much attention to variation of the constant in the formula $Pw = kq^{\frac{1}{2}}$. Personally, the speaker said, he did not attach too much importance to the precise value of this constant. But if the formula itself has any fundamental value, then the value of the constant must be rigid. If in practice, channels are found whose actual dimensions do not precisely comply with the requirements of an accurate formula, it only follows that there are some local causes which compel divergence from the correct dimension. It is only too easy to make a list of such possible causes. A channel never runs consistently with a fixed discharge ; no stream ever carries continuously a fixed silt charge ; no silt is ever completely incoherent ; the regime is never absolute. A channel is always departing one side or the other from the mean regime, due to seasonal and other factors.

How can the author, or any one else, ever imagine that any particular channel shall, in practice, adhere strictly to the requirements of a theoretical process ? The speaker could not see how any other method than a statistical analysis can produce for us, an approximation to what is probably a real constant having a physical basis. The speaker expressed a hope that Lacey's theories will continue to receive the attention they deserve and that from persistent examination and re-examination of all factors, they would arrive closer and closer to the truth.

In the light of the above, it will be understood why no weight could be attached to the author's painstaking but useless analysis of formulæ based on a misconception of the theory.

In Chapter VI, the author quotes the formulæ produced by the Research Institute at Lahore. The speaker desired to focus attention on one aspect of these formulæ, *viz.* the entire absence in the first three, of any symbol representing silt. Velocity is a function only of the hydraulic mean depth. Pw and R, the wetted perimeter and hydraulic mean depth are functions only of the discharge Q. Hence the velocity is a function only of the discharge and bears no relation to the silt burden. Such a conclusion is repugnant to the entire experience of every officer who has ever served on silt-bearing channels and of every other research worker on the subject, and must be rejected. It is open to two explanations only. Either the Research Institute workers have carried out their observations only on channels carrying approximately the same grade of silt, or there is some other factor which vitiates their results.

In respect to Chapter VII, the speaker went on, he thought Kutter's formula had been despatched and buried by Mr. Lacey in his paper before the Institute of Civil Engineers, No. 4736. Indeed, he added, the only flow formula he used now, is Lacey's

$$V=\frac{1{\cdot}3458}{N_a}.\ R^{\frac{3}{4}}.\ S^{\frac{1}{2}}$$

It is simple, as accurate as anything can be and the coefficient of absolute rugosity is independent of other factors.

The speaker was perfectly well aware that Mr. Lacey was developing his shock theory and that it may lead to some modification of this flow formula. But it will not resuscitate Kutter.

In Chapter IX, the author appears to neglect the fact that the absolute coefficient of rugosity varies with the value of 'f'. The speaker fell into the same error in 1929 when he tried to plot the Lacey's formulæ on Kennedy's diagrams. His procedure was different to that advocated by the author in this paper. A given slope and discharge fix all the other variables. Now each of Kennedy's diagrams represent a given slope, for a wide range of discharges. He took a number of these discharges, on each diagram and calculated the remaining variables. He very soon found that the line of discharge selected on the Kennedy's diagram, did not pass accurately through the calculated bed width and depth. So he pricked off an approximation and wrote up the value of 'f' against it. He then joined up the points so secured on each diagram. The resulting line gave a rough approximation to a Lacey channel and indicated the value of 'f' corresponding to the rest of the factors. It should be added that he abandoned his rough guide with its obvious drawbacks, as soon as the Lacey's diagrams were published.

The speaker had said enough to show that the author has wasted a lot of time and effort. It is of no use, therefore, to follow him through Chapters X and XI which he confessed, he found very difficult to read.

Chapter XII reverts to the subject with which the author opened his paper, but the speaker was not clear as to the author's reason for so doing. He had already expressed his own agreement on the subject of silt-ejecting devices and he did not suppose any one would disagree with him, but what has Chapter XII got to do with the improved Kennedy's diagrams ? Does the author suggest that his diagrams would improve silt disposal ? If so, the speaker regretted his inability to agree with him. The heaviest silt found in the head reach of the canal will eventually find its way to the tail in course of time—perhaps centuries—unless

(*a*) it is dug out regularly, and
(*b*) it is ejected regularly.

If this is not done, irrigation will cease, unless banks are raised and raised again to accommodate the steepest slopes. But long before this stage is reached, the parent channel will have lost command from the river.

In Chapter XIV the speaker went on, the author had dealt with the slope required for irrigation channels. He had made the astounding statement "Hitherto the practice has been to fix the slope arbitrarily or through the exigencies of the levels available and then work out the dimensions of the required channel for the given discharge under that slope from some diagrams". If indeed this astounding process is really the author's habit, it is of itself clear and conclusive proof that the author does not understand the basis of silt-bearing hydraulics. The speaker suggested to the hydraulic engineers in the meeting that if the natural slope of the country exceeded that required for irrigation channels, nothing was easier than to insert surface drops. On the other hand if the slope available was insufficient for the discharge and the silt burden, two courses were open to the designer. He might either make special arrangements to reduce the silt burden in the channels irrigating the flat area—possibly by silt selective heads or local ejectors. Alternatively he could abandon any attempt to irrigate the high areas and confine himself to those areas which were irrigable by channels provided with a reasonable slope. Any attempt to irrigate high lands by means of unduly flat slopes was asking for trouble—a request invariably granted by nature.

As a particularly useful example of the process advocated by L. Ishar Das, the speaker invited the attention of the meeting to a channel which he believed was known as 1-L off-taking above Renala on the Lower Bari Doab Canal. The process advocated by the author was here followed. The diagrams employed to determine the shape of the channel were Kennedy's and the result was disaster. The channel would be silt-cleared once a year with regularity out invariably silted up within a few weeks of opening after silt-clearance.

The author's next mis-statement runs as follows: "But the difficulty is that the value of his 'f' is different for any different discharge and for different slopes." Once more the author was standing on his head and inverting nature's processes. The speaker emphasized that the silt factor 'f' represented the physical effects on the channel shape caused by the silt burden. Whether the designer could estimate the value of 'f' or not, the value thereof and the volume of the discharge uniquely determined the slope and all other hydraulic dimensions. If the speaker repeats himself in re-stating this proposition, it is because the author has repeated his fundamental mistake again and again in his lengthy paper.

The speaker did not disguise the difficulty of estimating accurately the value of 'f' which would obtain in a new channel after construction. But it had to be done and the measure of the designer's capacity and experience was his degree of success in this very process.

The speaker had already dealt with the futility of the process of equating Manning's formula with Lacey's. Once this fundamental and absurd error was appreciated, it did not appear necessary to follow the author through his algebraic exercises. Adequately to criticise these formulæ would take more time and space than the speaker had at his disposal. He hoped that the meeting would agree that the fundamental errors already pointed out rendered the rest of the author's labours quite futile.

The speaker proposed to skip to the concluding Chapter XVIII from which he culled the following gems :

"It is not suggested that the formulas by Lacey are wrong, on the other hand they are substantially correct."

"The introduction of 'f' by Lacey in his first two formulas is highly commendable."

"It is neither helpful nor accurate to lay emphasis on Lacey's silt factor being not definite on account of changing values."

"Just as it is to take Lacey's 'f' for purposes of design may be as much amiss from the mark as Kennedy's CVR. Both of them have been shown not to be independent of the data of the section of the channel nor of any proposed discharge."

The speaker concluded with a reference to his opening remarks and urged those interested in silt-bearing hydraulics to study Lacey in original and not to be misled by misinformed criticism such as was contained in the author's paper.

MR. RADHA KISHAN KHANNA offered his congratulations to the author for producing a paper which does not leave practically any aspect of Hydraulics untouched, but said that in presenting a set of diagrams for the design of earthen channels, the author's references to the theory of flow of water and behaviour of silt in flowing water were all irrelevant. The author had observed on page 254 that coefficient in Lacey wetted perimeter formula $P=2{\cdot}67\sqrt{Q}$ varied from 2·2 to 3·2 and on page 301 had stated that Lacey's formulæ are substantially correct, thus finding snags on the one hand and paying compliments on the other. The speaker quoted the four slope formulæ of the author and wanted to know if they were considered simple and direct even as compared to the two-line formula of Kutter.

DR. J. K. MALHOTRA congratulated Mr. Ishar Dass and his talented daughter Miss Shanta, B.A., on the results obtained in the paper. He said that the subject of silt and scour in relation to channel design is one on which there has been a lot of controversy. The main reason for the disagreement is that every author has started with a certain set of data which he has dealt with according to his own ideas, thus producing results of limited application. What is required is the analysis of accurate accumulated data on certain definite lines with a full appreciation of the limitations both of the data and the method used. The Irrigation Research has analysed by method of co-relation analysis, the averages of data, specially collected from stable sites, during the last few years but the Institute is not wedded to any particular formulae which have been developed so far and suggestions would be welcome.

He agreed with the author's contention that Lacey's $P=2{\cdot}67\ Q^{\frac{1}{2}}$ formula is a good average fit to data collected so far, though the constant has a certain range of variation, put at 2·5 to 2·8. These values have been obtained by Sind and Punjab respectively.

In deriving relation (6) on page 253, the author has combined Lacey and Manning. The elimination of variable quantities from such essentially different formulæ can be justified only by showing that the resulting formulæ fit the data better than those already existing. This the author should have done.

Turning to Chapter VI, the speaker explained that the constants in the Institute formulæ are based on a given set of data and are derived by the method of least squares. They are therefore neither absolute nor rigid.

The last column in Table A on page 263 is unnecessary. However, P, Q, R and V are calculated. Q must equal to P R V. The differences shown here are due to taking fewer decimal places than are necessary to get an accurate product.

In Chapter VI, it would have been invaluable if the author had published the data from which Kutter's N was derived and also given the values of N, so that the reader could judge if the opinion expressed by him in the last but one para was reasonably correct.

The objection raised by the author on page 281, regarding the Institute formulæ is correct, but it was found that it is not possible to improve the R—Q formula by introducing in this m. The speaker said that they were considering if m should not be introduced in this or in the P—Q formula irrespective of the improvement which results. The great difficulty which the speaker had encountered was that in the systems from which these formulæ were derived m changes with Q, so that there was no means of disentangling the effects of m and Q on R. The speaker shared the opinions of the author expressed on page 280 in regard to changes in f on a particular system.

Turning to Chapter XV the speaker said that if Lacey's two formulæ were taken, for channels in perfect regime, in which f does