PAPER No. 252.

DESIGN OF CHANNELS IN ALLUVIUM

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Some years back in a paper before the Punjab Engineering Congress one of the present authors discussed the problem of "Silt Movement and Design of Channels" (Paper No: 192 P. E. C. 1936). In this paper it was shown:

1. That the annual frequency distribution of the types of the size distribution curves for the bed silt of any channel is a very reliable indication of the stage of equilibrium of that canal.

2. That silt plays a very important part in controlling the regime of a channel.

Since then much work has been done in the field and the laboratory on "Silt Movement" and it is hoped to write a paper on the subject on some future date. In the present paper attempts have been made to summarize the results obtained from observation and analysis of data on "Design of Channels in Alluvium."

In the above mentioned paper on "Silt Movement and Design of Channels" a few relationships were worked out for the purpose of design. Of these the one involving average bed silt diameter in the slope discharge relationship *viz.*

$$S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}} \quad \cdot\cdot \qquad (1)$$

still holds good though it is admitted that it is not a perfect one. Attempts have been made to introduce the quantity of bed silt in this equation but no success has been possible. But for the purpose of practical design wherever the diameter of the bed silt is known the slope can be calculated with a fair degree of precision. In many cases complaints had been received from the Canal Officers about silting of channels and on analysis of the bed silt obtained from site it had been found that the channel had assumed a slope which Eq. (1) should give for the bed silt obtained. Recently a survey of the main line and branches of the Lower Chenab Canal system has given one of the authors the opportunity of studying this problem more carefully. It has been found that in those channels where the bed did not show any sign of silt movement either due to silting or scouring, the actual water-surface slope agreed to a great degree with the calculated slope from Eq. (1). While in other cases such as the Lower Gugera Branch or the Burala Branch which show unmistakable signs of bed silt movement downstream of certain R. D.s the slope is very much in excess of that required by Eq. (1). This equation will give the designer the slope or the full supply level.

In the above mentioned paper two other relations were given for determining the size and shape of the channel. One of these was Lacey's P – Q relationship with a slightly altered constant, *viz:*

$$P_W = 2.8\, Q^{\frac{1}{2}} = C_1\, Q^{\frac{1}{2}} \qquad (A).$$

Though the relation between P and Q has been found to be almost perfect from the statistical point of view yet great difficulties have been experienced in fixing the constant 2·8. It varies considerably from channel to channel and also on the same channel itself. Various attempts have been made by Mr. Lacey himself to explain and calculate this constant. Explanations have been sometimes plausible but the calculations have invariably led to very divergent values. The designer had been baffled. Ultimately Mr. Lacey in his last note on the subject to the Research Officers' Meeting of the Central Board of Irrigation (July 1941) has been forced to fall back upon the water-surface width W instead of the wetted perimeter P in the following form :—

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

where $E = \frac{P}{W}$ reducing the above to

$$W = K\, Q^{\frac{1}{2}}$$

—the old Schocklitsch relation for rivers. Calculations of the Punjab regime site data have shown that this does not offer any improvement.

After the above paper was read before the Punjab Engineering Congress Dr. Malhotra of the Research Institute showed statistically from the regime site data that

$$R = {\cdot}47\, Q^{\frac{1}{3}} = C_2\, Q^{\frac{1}{3}} \qquad (B)$$

Mr. Lacey pointed out that this could be derived from the equation (1) and (3) given in his paper " Stable Channels in Alluvium ",

$$V = 1{\cdot}15 \sqrt{fR}$$

$$Qf^2 = 3{\cdot}8\, V_o^6$$

and had been actually used by him on pp. 279 of his paper to determine the depth of scour at the bridge across the river Ravi at Dera Baba Nanak.

This relation however suffers from the same defect as the other relation between P and Q. The variation in the constant is almost of the same order as that in Eq. (A).

This has led us to examine the data of the Punjab regime sites from a different point of view. The values of P and R have been

$$\sqrt{Q} \qquad Q^{\frac{1}{3}}$$

calculated for all the sites and their percentage variations from the constants given in Equation (A) and (B) have been tabulated in Table 1. A careful study of the table shows that in almost all cases where the variation of the constant in Eq. (A) has been on the positive side that in Eq. (B) has been on the negative side. This means that where the channel has become wider than is required by Eq. (A) the depth has become shallower than required by Eq. (B). This observation is very significant. There are some exceptions to this but if we omit a few cases even these exceptions are not very significant.

A survey of all these regime sites were undertaken during the Winter closure of 1940-41 in connection with Lacey's "Theory of Shock." The following observations were carried out at all the regime sites :

(*i*) Cross Section of the channel at the observation site and at every 100 ft. upstream and downstream of the site to a distance of 1000 ft. on either side—R. L.s of the natural surface were taken at the same time.

(*ii*) Soil samples from both the berms at every one of these Cross Sections.

(*iii*) Photographs of the berms and the bed at representative points of the canal over the site.

While carrying out this survey it was noticed that the width of the canal depended perceptibly on the nature of the soil in the berm. In consequence the variation of the constant in Eq. (A) was mainly determined by the character of the berm soil. If it was full of kalar, the berm could not stand any action of flowing water and naturally fell in and widened the channel. When the channel thus widened, the discharge being constant it tended to silt up keeping the waterway constant. If the waterway was altered it could be presumed that the water-surface slope would adjust itself to accommodate the altered waterway. As has been pointed out before, a reference to Table 1 will confirm this. When the percentage variation of C_1 is positive that of C_2 is negative that is when the wetted perimeter P is increased the depth is reduced and *vice versa*. This occurs in almost all the cases excepting for cases No. 4, 15, 25, 31, 34, 38, 39 and 41. In consequence it was to be expected that the waterway $A = P R$ will be highly correlated with the discharge Q. This is in fact the case. The correlation between A and Q is 99·94% and the variation in the constant C_3 in

$$\frac{A}{Q^{\cdot 85}} = C_3 \quad .. \quad (2)$$

is comparatively very limited. Only in those cases where C_1 and C_2 deviate the same way from the mean value, the values of C_3 are also appreciably different from the average. It is easy to understand that when P and R both increase, A will also increase but it is difficult to explain how the channel passing the same discharge through increased waterway will maintain equilibrium unless the slope changes. Of the cases quoted above only the cases of Nasrana Distributary, Southern Branch Lower Jhelum Canal, Main Line R. D. 93,400 and 115,000 of Lower Bari Doab Canal and Dhuniwala Distributary require special consideration. Even in these cases the actual water-surface slopes are not very much different from the slopes calculated from Eq. (1). As a matter of fact when the slope is introduced in equation (2) the correlation is not improved at all and the slope comes in with a very low power of S, ($1/s^{\cdot 02}$). So that the effect of slope can be considered as negligible. Thus we have for the Punjab regime site

$$A = 1{\cdot}145\, Q^{\cdot 85} \quad .. \quad (2)$$

This will replace Eq. (A) and (B). In this case the correlation is as high if not higher than in Eqs. (A) and (B) and the variation of the constant 1·145 is very much reduced.

This equation though fundamentally correct does not lead us very far in designing channels. A study of the existing literature on canal engineering will show that there are two different schools of thought regarding the calculation of bed width and depth. The older school of thought represented by Kennedy, Lindley, Woods and others preferred to calculate bed width and depth directly, whereas Lacey and others thought P and R as fundamental hydraulic constants and calculated bed width and depth on the assumption of trapezoidal or Elliptical Section. In the Punjab Engineering Congress paper No. 192 quoted above, one of the authors followed Lacey and worked out B and D from P and R. This had the disadvantage as pointed out above that due to the considerable divergence of the calculated values of P and R from the actual values, the derived values of B and D were never satisfactory for the purpose of design. The present Eq. No. (2) will, however, give the total waterway necessary for passing the required discharge. But for the purpose of design this is not enough, we must know some linear dimensions of the section, either the depth or the water-surface width. The width has the same disadvantages as the wetted Perimeter P and consequently the depth was chosen for the purpose of analysis.

A practical difficulty was encountered at the very outset of this investigation. Depth in any Cross Section of a channel is not uniform. To get over this difficulty depth D was defined as the mean central depth neglecting the slope segment. It must be admitted that this definition of depth D is purely arbitrary and cannot be expected to have any fundamental significance. It has the advantage of convenience and the high correlation obtained indicates that it has the sanction of nature.

This depth has been correlated with the discharges from the regime channels of the Punjab and gives a very high order of correlation which is further improved by the introduction of slope that comes in with a high power. The final equation assumes the following form :—

$$D = 0{\cdot}39 \frac{Q^{\cdot 29}}{S^{0\cdot 37}} \quad .. \quad (3)$$

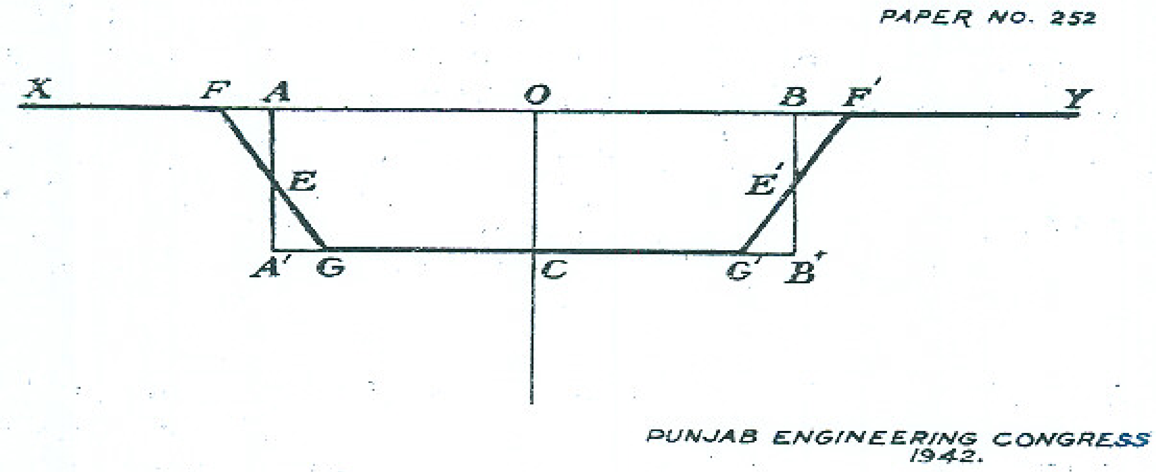
where D = Depth

S = Slope per 1000 ft.

and has a correlation coefficient of 99·95%. In Table II the calculated value of D and the divergence of the calculated values from the actual values have been tabulated. This shows that the maximum divergence is of the order of 13%.

Having then obtained D from Eq. (3) and the waterway from Eq. (2) it is possible now to design the channel. Eq. (1) gives the water-surface slope or the full supply level shown by line XY in Fig. 1

Fig. I.



Let OC be the centre line of the canal section, OC being the depth D obtained from Eq. (3); and AB a length which with D as the other arm forms a rectangle whose area is equal to the area A obtained from Eq. (2).

The engineer is now provided with all the information that our equation Nos. 1, 2 and 3 can supply. He shall have to apply his local knowledge to design the exact section. This he can do in the following way. Suppose he knows that the soil through which the canal is to be taken consists of very hard clay and the berm can stand at an angle even steeper than $\frac{1}{2}$: 1. Through the middle points E and E′ of the verticals AA′ and BB′ of the rectangle he will draw the lines FEG and F′E′G′ at an angle to which the berms can stand. If the berm soils are of kalar he shall have to make these lines slope at a much flatter angle. If it is desired to have berms formed from fine silt obtained from the flowing water the engineers will excavate the channel to a wider section and bush up so that the finally formed berms take the slope which is natural to such formation. The final canal section is given by FEG G′E′F′ which has got the same full supply level FF′ as required by Eq. (1), the same depth OC as required by Eq. (3) and the same waterway as required by Eq. (2). The water-surface width will be determined by the local conditions which the engineer will be able to fix knowing the nature of the soil through which he is going to excavate the channel or through which the channel is ultimately going to flow.

Advantages of this method are that though the designer is given all the information required by him for the purpose of his design, his hands are not tied down. He can apply his discretion and local knowledge to fix the exact water-surface width and the slope of the berm.

One word of caution must be uttered before we close. These equations (1), (2) and (3) are empirical equations and derived from observation confined to regime channels in the Punjab. As they are derived by statistical analysis they cannot stand extrapolation and as they are not mathematically derived equations they cannot stand any of the mathematical processes of elimination and differentiation. They should be taken as they are and used for the purpose of design as indicated above. In Eq. (1) m denotes the average diameter of the bed material moving on the bed of the canal and does not give any idea about the quantity of bed material rolling on the bed. Though it is admitted that the quantity of rolling material does utilize a part of the energy of the flowing water, yet it has not been possible as yet to incorporate its effect in these equations. Efforts are being made to do this.

The paper is accompanied by two nomograms for Eq. (1) and two diagrams for Eqs. (2) and (3).

TABLE I.

STATEMENT GIVING THE VALUES OF $P/\sqrt{Q}$, $R/Q^{\cdot 345}$ AND THEIR PERCENTAGE DEVIATIONS FROM THE MEAN FOR 42 REGULARLY OBSERVED CHANNELS.

Serial No.	Channel	R.D.	Period Observed		$P/\sqrt{Q}$	V of Col. 5.	$R/Q^{\cdot 345}$	V. of Col. 7	$A/Q^{\cdot 845}$	V of Col. 9	S Act./S Cal. in 10^3
			From	To							
	L. C. C.										
1	Hafizabad Disty. ..	3,050	Oct. 1933	Jan. 1939	2·494	—8·9	·465	+5·2	1·124	—2·0	·33/·35
2	Main Line Upper ..	1,37,600	Jan. 1935	Feb. 1939	3·087	+12·7	·410	—7·2	1·166	+1·7	·19/·15
3	Main Line Lower ..	1,49,000	Oct. 1933	Feb. 1939	3·039	+11·0	·47	—5·7	1·173	+2·3	·20/·17
4	Jhang Branch Lower	1,11,700	July 1936	Mar. 1939	2·677	—2·3	·436	—1·4	1·106	—3·6	·23/·18
5	Dhaular Disty. ..	12,000	July 1936	Mar. 1939	2·813	+2·7	·396	—10·4	1·061	—7·5	·22/·20
6	Mian Ali Branch ..	9,500	Nov. 1934	Apr. 1939	2·917	+6·5	·392	—11·3	1·076	—6·2	·22/·22
7	Rakh Branch ..	7,260	Nov. 1934	Apr. 1939	2·743	+0·1	·424	—4·1	1·094	—4·6	·21/·22
8	Jhang Branch ..	7,260	Nov. 1934	Apr. 1939	2·710	—1·1	·443	+2·0	1·117	—2·6	·21/·19
9	Main Line ..	1,81,000	Jan. 1935	Mar. 1937	3·102	+13·3	·408	—7·7	1·173	+2·3	·20/·21

10	Udhoki Disty. ..	2,500	May 1937	Apr. 1939	2·776	+1·4	·419	—5·2	1·122	—2·2	·31/·30
11	Gugiana Disty. ..	7,345	Sep. 1933	Mar. 1939	3·024	+10·4	·420	—5·0	1·230	+7·2	·28/·29
12	Sarangwala Disty.	6,300	Oct. 1933	Mar. 1939	3·164	+15·5	·396	—10·4	1·208	+5·3	·26/·30
13	Jhang Branch ..	1,11,700	Oct. 1933	Mar. 1939	2·823	+3·1	·436	—1·4	1·148	+0·1	·18/·17
14	Khai Disty. ..	4,943	Oct. 1933	Oct. 1934	2·666	—2·7	·442	0	1·138	—0·8	·29/·26
15	Nasrana Disty. ..	3,275	Oct. 1933	Oct. 1934	2·421	—11·6	·443	—2·0	·996	—13·2	·17/·20
16	Jamal Jatti ..	2,300	Oct. 1933	Oct. 1934	3·084	+12·6	·412	—6·8	1·252	+9·2	·33/·29
17	*L. J. C.* Khunan Disty. ..	3,100	Feb. 1936	Aug. 1937	2·789	+1·8	·431	—2·5	1·185	+3·3	·30/·28
18	Pindi Disty. ..	1,550	Feb. 1936	Aug. 1937	2·419	—11·7	·473	+7·0	1·118	—2·5	·27/·28
19	Khatwan Disty. ..	5,020	Feb. 1936	Mar. 1937	2·758	+0·7	·429	—2·9	1·150	+0·3	·31/·25
20	Northern Branch ..	2,27,000	Feb. 1936	Aug. 1937	2·622	—4·3	·455	+2·9	1·126	—1·8	·15/·18
21	Northern Branch ..	2,10,100	Feb. 1936	Aug. 1937	2·491	—9·1	·478	+8·1	1·124	—2·0	·15/·18

TABLE I—(*continued*).

Serial No.	Channel	R.D.	Period Observed From	Period Observed To	$P/\sqrt{Q}$	V of Col 5.	$R/Q^{\cdot 345}$	V. of Col. 7	$A/Q^{\cdot 845}$	V of Col. 9	S Act. / S Cal. in 10^3
22	Northern Branch ..	2,04,200	Feb. 1936	Aug. 1937	2·671	—2·5	·463	+4·8	1·162	+1·3	·14/·17
23	Rurala Disty. ..	1,700	Feb. 1936	Aug. 1937	2·466	—10·0	·466	+5·4	1·121	—2·3	·27/·28
24	Northern Branch Upper	2,72,600	Dec. 1936	Dec. 1937	2·613	—4·6	·473	+7·0	1·168	+1·8	·15/·17
25	Northern Branch Lower	2,81,500	Aug. 1936	Dec. 1937	2·747	+0·3	·445	+0·7	1·157	+0·9	·15/·17
26	Sillanwali Disty. ..	7,000	July 1936	Dec. 1937	2·880	+5·1	·438	—0·9	1·232	+7·4	·34/·30
27	N. B. U/S Ludewala..	1,63,000	Sep. 1933	Jan. 1936	2·637	—3·7	·455	+2·9	1·128	—1·7	·13/·17
28	N. B. D/S Ludewala..	1,70,289	Sep. 1933	Jan. 1936	2·679	—2·2	·450	+1·8	1·139	—0·7	·16/·18
29	Bhek Disty. ..	1,500	Sep. 1933	Jan. 1936	2·765	+0·9	·433	—2·0	1·153	+0·5	·28/·28
30	Sulki Branch ..	2,300	Oct. 1935	Dec. 1935	2·987	+9·1	·385	—12·9	1·092	—4·8	·20/·22

31	Northern Branch Lower	73,500	Feb. 1935	June 1936	2·690	+1·8	·453	+2·5	1·144	—0·3	·17/·18
32	Mitha Lak Disty. ..	4,000	Feb. 1935	June 1936	2·194	—19·9	·518	+17·2	1·089	—5·1	·20/·24
33	Fatehpur Disty. ..	10,200	Feb. 1935	Apr. 1936	2·574	—6·0	·486	+10·0	1·211	+5·6	·22/·27
34	Southern Branch ..	1,02,500	Sep. 1933	Nov. 1934	2·915	+6·4	·449	+1·6	1·235	+7·7	·14/·17
35	Kirana Disty. ..	2,675	Oct. 1933	Dec. 1934	2·878	+5·1	·421	—4·8	1·149	+0·2	·20/·20
36	Lalian Disty. ..	1,350	Oct. 1933	Nov. 1934	2·359	—13·9	·497	+12·4	1·112	—3·1	·16/·20
37	*U. B. D. C.* Aliwal Disty. ..	1,500	Feb. 1934	Feb. 1936	2·927	+6·9	·395	—10·6	1·108	—3·4	·30/·34
38	*L. B. D. C.* Main Line ..	1,15,000	Mar. 1938	Nov. 1938	2·830	+3·3	·475	+7·5	1·244	+8·5	·13/·12
39	Dhunniwala Disty. ..	18,500	Mar. 1938	July 1938	2·809	+2·6	·456	+3·2	1·234	+7·6	·21/·24
40	Jandwala Minor ..	3,050	Mar. 1938	Nov. 1938	2·652	—3·2	·462	+4·5	1·179	+2·8	·17/·26
41	Main Line ..	93,400	Mar. 1938	Nov. 1938	2·806	+2·4	·476	+7·7	1·235	+7·7	·12/·12
42	*S. C. C.* Akhara Disty. ..	9,050	May 1936	June 1938	2·347	—14·3	·451	+2·0	1·013	—11·7	·20/·26

N. B. V denotes percentage variation from the mean of 42 channels

TABLE II

Serial No.	Canal	Channel	R. D.	Date	Q	S×10³	D Actual	D Calculated	$\frac{\text{D Act.} - \text{D Cal.}}{\text{D Act.}} \times 100$
1	L. C. C. ..	Jhang Branch ..	7,260	28-7-41	2,974·73	·220	7·49	7·08	5·5
2	,, ..	Rakh Branch ..	,,	26-7-41	1,199·11	·200	5·56	5·62	1·1
3	,, ..	Udhoki Disty. ..	2,372	28-7-41	39·99	·300	1·66	1·78	7·2
4	,, ..	M. L. L. ..	1,49,000	2-6-41	4,796·91	·205	8·39	8·36	0·4
5	,, ..	U. Gugera Br. ..	2,500	16-7-41	5,263·22	·140	10·84	9·90	8·7
6	,, ..	Lakhuana Disty. ..	10,000	17-7-41	113·41	·240	2·31	2·63	13·9
7	,, ..	Mianali Branch ..	95,000	17-4-41	413·20	·200	3·79	4·11	8·4
8	,, ..	Khurianwala Disty. ..	5,000	10-4-41	236·70	·225	3·19	3·34	4·7
9	,, ..	Shahkot Disty. ..	12,000	19-4-41	165·26	·235	2·70	2·96	9·6
10	,, ..	L. Gugera Branch ..	2,59,000	10-7-41	1,134·11	·175	5·28	5·81	10·0
11	,, ..	Do. ..	2,72,500	10-7-41	879·49	·195	5·48	5·18	5·5
12	,, ..	Do. ..	11,000	10-6-41	1994·39	·230	6·58	6·19	5·9
13	,, ..	Burala Branch ..	6,000	13-6-41	1,659·16	·210	6·62	6·07	8·3
14	U. B. D. C.	Lahore Branch ..	3,000	14-11-35	1,302·69	0·300	4·67	4·95	6·0

15	U. B. D. C. ..	Main Branch ..	8,200	13-6-35	2,692·96	0·300	6·13	6·13	0
16	,, ..	Aliwal Disty. ..	1,500	1-5-35	86·70	0·270	2·28	2·32	1·8
17	L. B. D. C. ..	Main Line ..	1,15,000	31-5-38	5,966·18	0·140	10·41	10·27	1·3
18	,, ..	Do. ..	93,400	8-8-38	6,120·83	0·120	10·96	10·95	0·1
19	,, ..	Pandwala Minor ..	3,050	27-8-38	103·02	0·170	2·70	2·90	7·4
20	,, ..	Dhuniwala ..	18,500	19-3-38	46·79	0·210	2·36	2·13	9·7
21	Sirhind ..	Abohar Branch ..	1,53,000	9-5-38	2,885·60	0·125	9·74	8·65	11·2
22	L. C. C. ..	Main Line ..	1,81,000	29-3-37	4,561·33	·220	8·22	8·02	2·4
23	,, ..	Main Line Upper ..	1,37,600	2-10-39	9,854·70	·180	11·10	10·83	2·4
24	,, ..	J. B. L. ..	1,11,700	15-1-39	586·51	·230	4·64	4·33	6·7
25	,, ..	Dhaular Disty. ..	12,000	10-3-39	311·08	·220	3·55	3·65	2·8
26	,, ..	Gojra Disty. ..	3,000	16-1-39	56·23	·280	1·80	2·02	12·2
27	,, ..	Titranwala Disty. ..	3,000	17-2-39	41·11	·340	1·63	1·72	5·5
28	,, ..	Gugiana Disty. ..	7,345	25-2-39	29·54	·300	1·60	1·63	1·9
29	,, ..	Jhang Branch ..	2,21,000	13-3-39	2,079·32	·175	6·62	6·94	4·8
30	,, ..	Khai Disty. ..	4,943	25-9-34	45·49	·290	2·07	1·87	9·7
31	,, ..	Nasrana Disty. ..	3,275	4-6-34	288·98	·180	3·73	3·85	3·2
32	,, ..	Jamal Jatti ..	2,300	19-7-34	34·84	·240	1·97	1·86	5·6
33	L. J. C. ..	Khunan Disty. ..	3,100	1-4-37	6·19	·300	1·13	1·03	8·8

TABLE II.—(*concld.*)

Serial No.	Canal	Channel	R. D.	Date	Q	S×10³	D Actual	D Calculated	(D Act. — D Cal.) / D Act. × 100
34	L. J. C. ..	Khatwan Disty. ..	5,020	19-3-37	30·01	·320	1·75	1·60	8·6
35	,, ..	Northern Branch ..	2,27,000	21-4-37	673·40	·160	4·97	5·15	3·6
36	,, ..	Do. ..	2,10,100	7-1-37	704·34	·150	5·03	5·35	6·4
37	,, ..	Do. ..	2,04,200	23-3-37	803·16	·170	5·34	5·31	0·6
38	,, ..	Northern Branch Upper	2,72,600	26-11-37	600·89	·160	4·76	4·98	4·6
39	,, ..	Do. Lower	2,81,500	23-3-37	545·08	·150	4·75	4·96	4·4
40	,, ..	Manguana Disty. ..	3,000	19-2-37	26·79	·360	1·52	1·48	2·6
41	,, ..	N. B. D/S Ludewala ..	1,70,289	6-1-36	770·05	·140	5·26	5·63	7·0
42	,, ..	Bhek Distributary ..	1,500	2-1-36	58·34	·300	2·13	1·99	6·6
43	,, ..	Northern Branch ..	73,500	2-4-36	1,506·69	·190	6·16	6·12	0·6
44	,, ..	Fatehpur Disty. ..	10,200	2-4-36	48·82	·220	2·40	2·12	11·7
45	,, ..	Southern Branch ..	1,02,500	17-3-34	862·50	·210	4·77	5·01	5·0
46	,, ..	Lallian Distributary ..	1,700	28-11-34	396·93	·160	4·78	4·41	7·7
47	,, ..	Kirana Distributary ..	2,675	5-3-34	470·65	·210	3·89	4·19	7·7

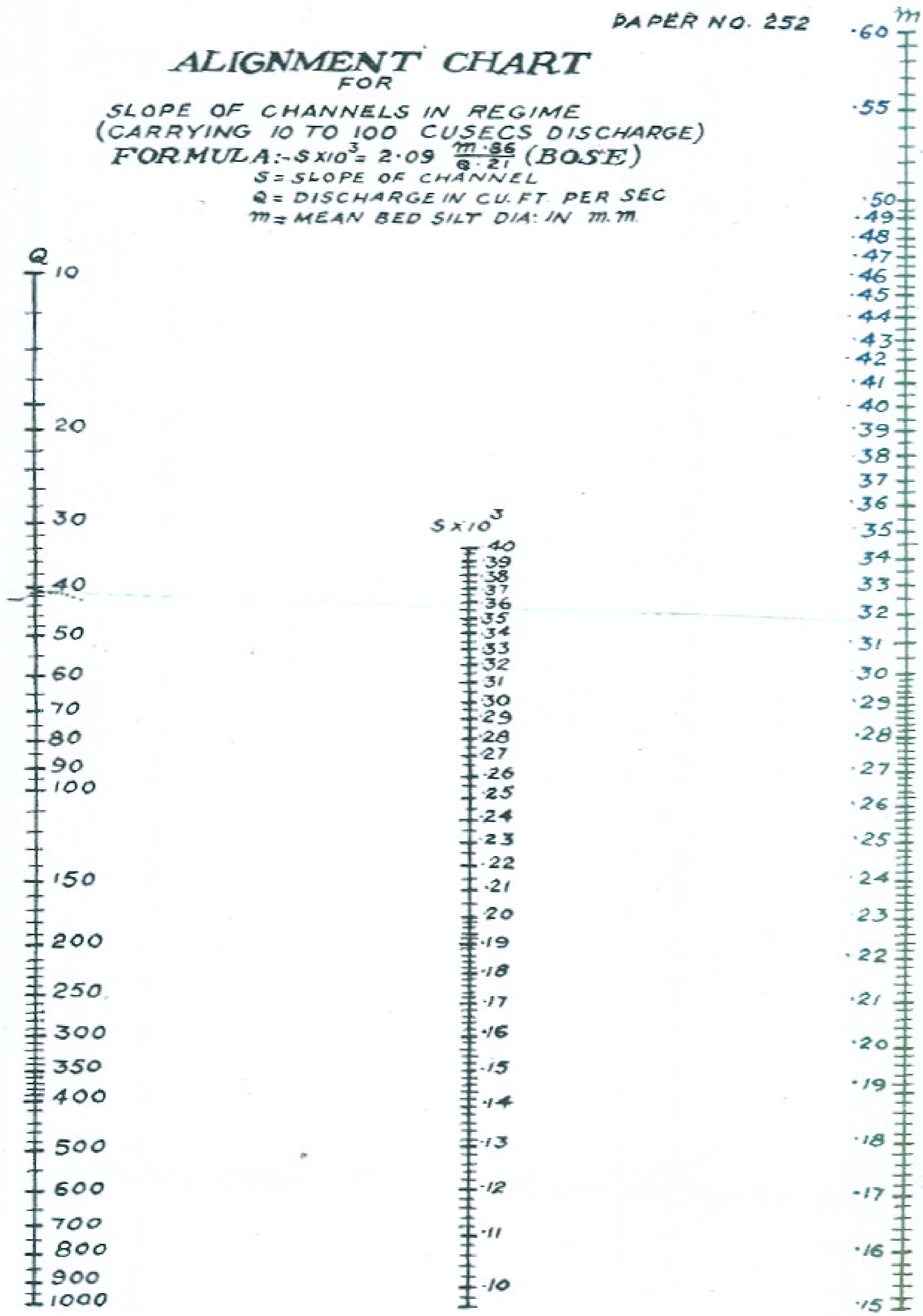
PAPER NO. 252

ALIGNMENT CHART
FOR

SLOPE OF CHANNELS IN REGIME
(CARRYING 10 TO 100 CUSECS DISCHARGE)

FORMULA:- $S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$ (BOSE)

S = SLOPE OF CHANNEL
Q = DISCHARGE IN CU. FT. PER SEC
m = MEAN BED SILT DIA: IN m.m.



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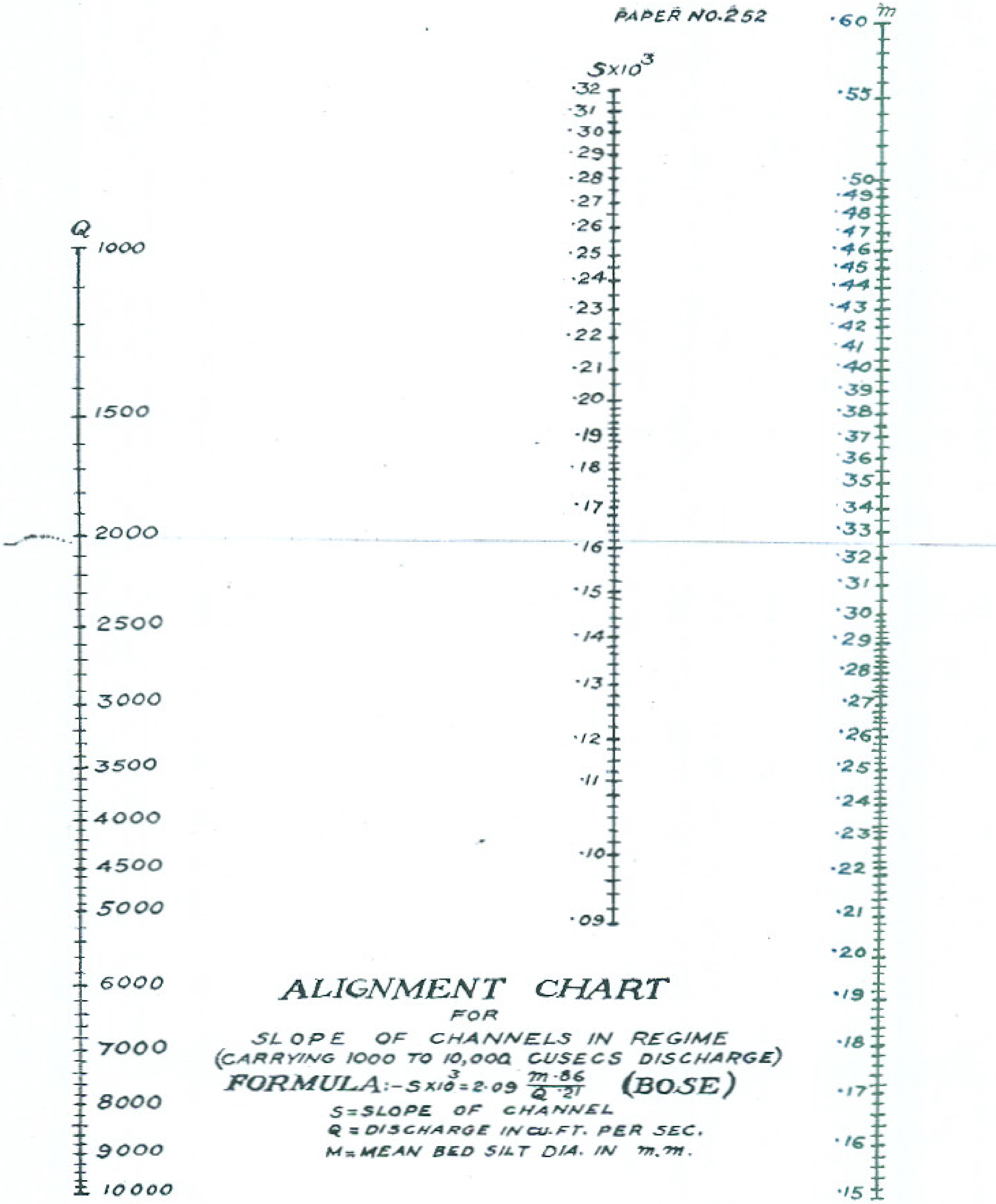


ALIGNMENT CHART

FOR

SLOPE OF CHANNELS IN REGIME

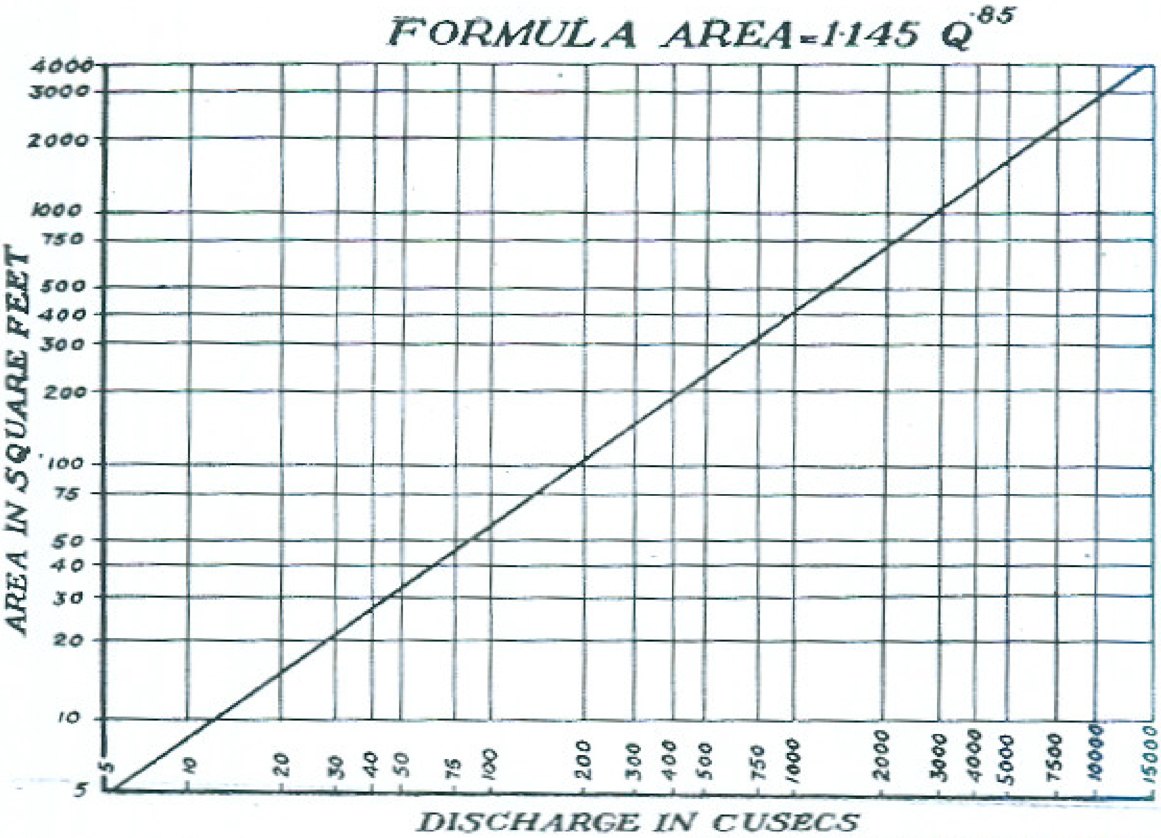
(CARRYING 1000 TO 10,000 CUSECS DISCHARGE)

FORMULA:– $S \times 10^3 = 2{\cdot}09 \dfrac{m^{\cdot 86}}{Q^{\cdot 21}}$ (BOSE)

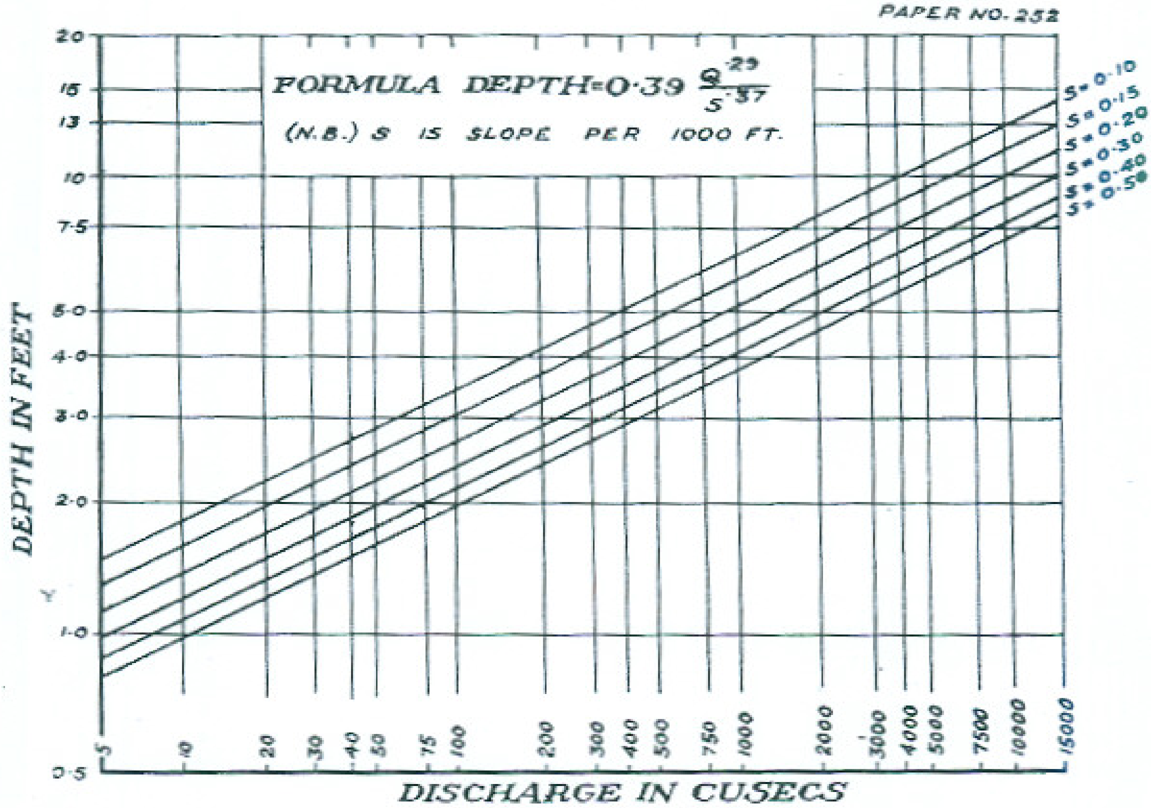
S = SLOPE OF CHANNEL

Q = DISCHARGE IN CU. FT. PER SEC.

M = MEAN BED SILT DIA. IN m.m.



PUNJAB ENGINEERING CONGRESS
1942



PUNJAB ENGINEERING CONGRESS
1942

DISCUSSION

Dr. N. K. Bose in introducing the paper stated that in the paper under discussion the authors had been mainly concerned with the "Design of Channels in Alluvium" as distinct from the "Theory of Channels in Alluvium." Enough had been done since Mr. Lacey wrote his paper on "Stable Channels in Alluvium" to show that there were a number of fundamentally correct relationships between the different hydraulic constants of a channel in regime. These were

$$V=C_1\sqrt{R} \quad \ldots \quad (1)$$

$$P=C_2 Q^{\frac{1}{2}} \quad \ldots \quad (2)$$

$$R=C_3 Q^{\frac{1}{3}} \quad \ldots \quad (3)$$

$$S\times 10^3=\frac{2{\cdot}09\ m^{\cdot 86}}{2{\cdot}09\ Q^{\cdot 21}} \quad \ldots \quad (4)$$

Of these equations, (2) and (3) were mainly used for the purpose of designing the linear dimensions of a channel. Theoretically these two equations were almost perfect—the correlation between P, Q and R, Q being very high. Herewith come in the practical difficulty of the problem. The two constants C_2 and C_3 fluctuated widely about their mean values and hence in actual practice the values of P and R as derived from (2) and (3) were very much different from what was obtained in nature.

In the paper, attempts had been made to analyse the cause of these divergences of P and R from the calculated value and suggestions had been made to replace them by A, the area of the waterway. It was shown that from the practical point of view A was a better hydraulic constant than P and R while theoretically it was as good. To fix the linear dimensions of the section more closely, it was now necessary to make a choice between the following constants: W, watersurface width; B, bed width; and D, the average depth. W had the same drawback as P, while between B and D, D was better correlated with Q than B. The correlation between D and Q was as high as 99·92 per cent. which was only slightly improved by the introduction of the slope. The reason why slope had been introduced in spite of this was due to the fact that the slope came in with a high power in the regression equation.

$$D=0{\cdot}29\quad\frac{Q^{\cdot 29}}{S^{0\cdot 37}}$$

Dr. Bose quoted from Tipitt's "Methods of Statistics" to explain the point:

"A low correlation coefficient does not necessarily mean that x is incapable of having an important influence on y; it may mean that an insufficiently large range of **x** has been tried. Or if **x** cannot be varied, it may be that although its effect on y as measured by the correlation coefficient is small relative to the disturbing factors, its absolute effect as measured by the regression coefficient is important. The correlation coefficient between the yield of some crop over several plots and quantities of fertilizers used may be low, but if the regression is appreciable, the total advantage of the use of fertilizer by the whole agricultural industry will be considerable. In such cases, excepting as an indication of the existance of association, the coefficient of correlation is an unsuitable constant and that of reggression is more suitable."

As Mr. Erry was responsible for the idea of introducing D in the equation Dr. Bose said he would leave it to Mr. Erry to give his idea about it.

Mr. K. R. Erry said that Dr. Bose had already explained the mathematical portions of the paper. He, therefore, dealt with some practical aspects.

Kennedy's theory of the design of channels had, by common consent, been discarded due to its obvious shortcomings. Of all the subsequent theories propounded by various authors from time to time, that propounded by Mr. Lacey occupied the foremost position. The fundamental equations of Lacey theory were :

$$B = 2{\cdot}667\,Q^{\frac{1}{2}} \qquad .. \quad (1)$$

$$R = 0{\cdot}472\,(Q/F)^{\frac{1}{3}} \qquad .. \quad (2)$$

$$V = 1{\cdot}115\,\sqrt{FR} \qquad .. \quad (3)$$

$$S = 0{\cdot}000542\,\frac{F^{5/3}}{Q^{\frac{1}{6}}} \qquad .. \quad (4)$$

Q, the discharge of a channel was always known or could easily be determined. But the determination of "F" was not so easy. In fact for new projects the determination of "F" was generally a matter of shrewd guess—of course by experts. For remodelling schemes of old channels "F" could be calculated from Formulæ (2), (3) and (4). But here a practical difficulty arose. The value of "F" calculated from the three formulæ was usually not the same. Even for the same reach of the canal generally three different values of "F" were obtained. And only experts could decide what value of "F" might be adopted for purposes of design of the Remodelling Scheme. This was one of the chief objections against universal adoption of Lacey's otherwise most excellent theory.

There was yet another aspect of the matter. The Practical Engineer required for construction purposes, the designed width and depth of a channel. But the Lacey theory only gave him the wetted perimeter P and the Hydraulic Mean Depth R. To calculate designed width and depth from P & R the designer had to assume some side slope. This was generally taken as ½ to 1 and the design worked out accordingly.

Mr. Erry said it was a well-known fact that the side slope was never the same from the head of canal down to its tail-end. The side slope was determined mostly by the stiffness of berm soil and might be more or less than ½ to 1. But there was no practical way at present to account for these variations with the result that when full supply was let into the canal certain reaches started widening and other reaches started berming up. This upset the design so carefully worked out by experts and huge sums of money were subsequently required for re-modelling and re-remodelling *ad infinitum.*

In the paper before the house, both the above practical difficulties had been overcome. All the formulæ proposed in the paper contained easily determinable quantities:

From formula (1), page 67, surface slope was calculated from the authorized discharge and the mean diameter of bed silt m measured in millimeters.

From formula (2), page 70, the designed cross sectional area of a channel was calculated from Q, the authorized full supply discharge.

Formula (3), page 71, gave the designed mean depth D from the authorized discharge Q and surface slope S.

Dividing area of cross section A by the calculated mean depth D was obtained, the designed mean width of the channel, which was independent of side slopes.

This was all that Practical Engineer required from the designer. He could keep any side slopes to suit the field conditions, keeping the designed mean width and depth.

Thus the theory of design proposed in the paper fulfilled the requirements of the designer as well as those of the Practical Engineer and yet left the Practical Engineer some margin of freeplay to adopt the design to suit the conditions on the spot.

Mr. Erry continued that as Dr. Bose had already shown, the formulæ proposed in the paper fitted in with the observed data of all regime sites on Punjab canals better than any other existing formulæ on the subject. By statistical analysis the formulæ gave a correlation factor as high as 99·95 per cent. In addition, Mr. Erry said they offered certain decided advantages in practical design of channels. For these reasons the authors ventured to hope that with any modification and improvements that might be found necessary in the light of suggestions made by the learned engineers who would take part in the discussion, these formulæ would in future form the basis of design of Irrigation Channels.

Mr. C. C. Inglis stated that the fourth formula, which was originated by Dr. Bose some 6 years ago, was undoubtedly a very useful stability formula ; but it required a knowledge of the mean diameter of bed material of each channel before the slope could be worked out. Assuming that the grade of sand at the head of a canal could be estimated, even then the grade, as we proceeded down the canal and in each offtake, differed from that at the head, the bed material getting finer and finer down the canal. It was also relatively finer in the offtakes and roughly the grade in a canal system varied as $Q^{1/10}$. This point was dealt with in detail in a paper entitled "Divergence from regime in alluvial channels" presented by Mr. Inglis at the 1941 Research Officers' Meeting at Simla and was being published in the 1941-42 Annual Report (Technical) of the Central Board of Irrigation.

The second formula $A=1{\cdot}145\ Q^{\cdot 85}$ resembled Lacey's formula $A=1{\cdot}25\ Q^{\cdot 833}/f^{\frac{1}{3}}$, which, however, brought in 'sand grade'; and as sand grade undoubtedly caused an inverse variation in A, Lacey's formula had this advantage as a general formula.

Coming now to the third formula.

$$D=0{\cdot}39\ Q^{\cdot 29}/S^{\cdot 37} \qquad \text{.. (3)}$$

D in this formula was exactly the same as Kennedy's original D in his formula

$$V_o=0{\cdot}84\ D^{0\cdot 64} \qquad \text{.. (A)}$$

As this third formula brought in slope, and as this slope was identical with that derived from formula (1), formula (3) should be re-written as

$$D=\cdot 297\ Q^{\cdot 368}/m^{\cdot 314} \qquad \text{.. (3A)}$$

It would be interesting to know whether this formula gave as high a correlation as formula (3). Presumably it would not.

This formula might be compared with Lacey's formula

$$R=\cdot 472\ Q^{\frac{1}{3}}/f^{\frac{1}{3}} \qquad \text{.. (B)}$$

or with Kennedy $D \propto Q^{\cdot 305}/C^{\cdot 61}$ .. (C)

(assuming $W_m \propto Q^{\frac{1}{2}}$)

These formulas of Dr. Bose were essentially "Canal-system, stability, formulas" which applied to typical stable channels in the Punjab. In these the silt charge at canal heads was *super-regime*, and at the tails, *sub-regime*. Lacey's formulas on the other hand were essentially regime formulas, which held at only those points where the sand charge was 'regime sand charge'—*i.e.* where the sand exposed on the bed consisted of a normal population curve of particles. Thus, Dr. Bose's formulas took into account average divergence from regime relative to discharge in Punjab channels and were suitable for applying to such conditions; whereas the Lacey formulas, being basic regime formulas, were of general application; but they required modification when applied to stable, but non-regime conditions, under which conditions slope f and $fVR = \frac{V^2}{R}$ differed. It was presumed that column 7 of Table II was the actual slope. If estimated slopes, bed-width, and values of m were added this would add considerably to the interest of the statement and might please be shown.

Mr. Gerald Lacey remarked that the authors were to be congratulated on the production of a valuable practical paper which should also lead eventually to some advance in regime theory. It was clear that there was unanimity of opinion on the form that equations in terms of the water surface slope per thousand, S*, the discharge, Q, and the cross sectional area, A, should assume and, as the authors had shown, the main difficulty was the determination of the linear dimensions of the section.

The speaker in 1930 (Procs. Inst. C. E., Vol. 229, page 375) had suggested for the slope the equation

$$S^* = 0{\cdot}56\ f^{5/3}/Q^{\frac{1}{6}}$$

and put forward a tentative relationship in which the silt factor varied as the square root of the average diameter of silt grade. In general terms his equation could therefore be written

$$S^* = C\ m^{\cdot 833}/Q^{\cdot 1667}$$

The Bose equation took the form

$$S^* = 2{\cdot}09\ m^{\cdot 860}/Q^{\cdot 2100}$$

The latter relationship as the authors admitted was not a perfect one but it had considerable statistical backing. Slope was a vital factor in regime design and it was essential to know if the slope demanded was available. Errors in the cross section could at least be amended but defective slope was fatal.

The Lacey 1930 equation for the cross sectional area A (Procs. Inst. C. E. Col. 229, page 270) took the form

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

Substituting for V the ratio Q/A this equation reduced to

$$A = 1{\cdot}250\ Q^{\cdot 8333}\ \ {\cdot 333}$$

and should be compared with the equation put forward in the paper

$$A = 1{\cdot}145\ Q^{\cdot 8500}$$

The general resemblance of the two equations was very striking. The interesting feature of the Punjab expression was that the silt grade vanished as a variable. Indeed a disconcerting characteristic of the silt grade was its tendency to vanish from regime relationships and in this respect it was as baffling as the silt factor. Thus in the two previous equations of Dr. Bose

$$P=2{\cdot}8\ Q^{\frac{1}{2}}$$

$$R=0{\cdot}47\ Q^{\frac{1}{3}}$$

the silt grade failed to find a place, although in the Lacey equation

$$R=0{\cdot}47\ (Q/f)^{\frac{1}{3}}$$

the silt factor entered. Now yet a third Punjab equation was put forward in which the silt grade found no place. It was well to remember however that if it vanished in one equation it was very apt to re-appear in another

It was not quite correct to state that the speaker was forced to fall back upon the water-surface width W. He had suggested in 1941 that in equations connected with the cross sectional area A the horizontal width and the vertical depth both entered rather than the wetted perimeter P and the hydraulic mean depth. R. In this contention he, the speaker had been correct, but the authors' paper went to show that the mean depth was not the best variable to employ and this implied that the water surface width was also defective as a variable.

It was clear that the authors' depth, the mean central depth, neglecting the side segments was none other than Kennedy's D, and it was true therefore of the authors that they had been forced to fall back on Kennedy.

The authors had set themselves the task of determining all the dimensions of a channel, and also the slope S*, from the discharge Q, and the bed silt grade 'm' alone.

This being so it was clear that the equation for depth was expressed in the wrong form.

The depth equation could be written directly

$$D=0{\cdot}297\ Q^{\cdot 368}/m^{\cdot 318}$$

and that for width

$$W=3.857\ Q^{\cdot 482}\ m^{\cdot 318}$$

The diagrams should have been prepared on these lines. If the authors' diagrams were used the determination of W was a very lengthy indirect process. From Q and m the slope S* was determined, and from Q the cross sectional area A was determined. Using the determined value of S* and that of Q the value of D was read from the diagram and eventually W obtained by dividing A by D. That was surely an exceedingly clumsy way of setting to work.

The speaker suspected that by introducing S* as a variable (when from the terms of the problem it was as a fact unknown) the authors had failed to detect that the silt grade entered into the depth equation.

The previous Bose equation, $R = \cdot 47\ Q^{\frac{1}{2}}$ was markedly defective in that the silt grade did not enter.

When there was no well-defined horizontal bed it was most difficult to determine the Kennedy depth D. A general solution could be obtained by equations for the equivalent depth D and the equivalent width W. Assuming that the ratios of lateral and vertical reductions were constant and that the water surface was given by W_s and the maximum, or central depth by D_c, the following equations could be derived :

$$W/D = W_s/D_c, \text{ assumed}$$

and hence

$$D = D_c\,(A/Ae)^{\frac{1}{2}}$$

The ratio A/A_e was none other than WD/W_sD_c

or the ratio D_m/D_c, equal to 'Z', or the Blench and King shape actor.

The following table gave actual values of D as averaged by the authors and as computed from the speaker's equation for D. Five cross sections had been selected at random from those supplied through the courtesy of the Punjab Research Institute, Lahore :

S. No.	Depth as given by authors	Equivalent D	'Z'
1 ..	1·60′	1·62′	0·830
2 ..	2·74′	2·84′	0·870
3 ..	3·46′	3·44′	0·914
4 ..	3·74′	3·72′	0·934
5 ..	8·04′	7·99′	0·906

It was strongly recommended that the equivalent depth and width should be employed in future statistical analysis. It was clear that if the shape factor was a constant, as for semi-elliptical channels it was possible to design in terms of W_s and D_c by employing the shape factor 0·7854.

Dr. J. K. Malhotra congratulated the authors on producing a very useful contribution to the subject of silt movement and design of channels. The paper presented very lucidly the results of recent investigations in the Irrigation Research Institute, and would be highly useful to the designers, inasmuch as the whole design was reduced to very simple and intelligible rules.

There were, however, a few points in the paper which would bear amplification.

For example, formula 1 on page 67, which contained the value of the average bed silt diameter, required to be qualified with the proviso that the value of *m* was obtained by an analysis of particles whose maximum size was ·6 mm. For sites containing very coarse and very fine silts this formula would perhaps need some modification. In this connection a reference was invited to a note by one of the authors (Dr. N. K. Bose) on the application of this formula to the sites in Sind. It was found that the slopes actually obtained were in some cases much greater than those given by the formula. A possible explanation of this was that the silt at the Sind sites was very fine, and did not therefore behave as an incoherent medium.

Some remarks might also be made about the Lacey's PQ formula given on page 68. This formula had stood the test of statistical analysis, and as pointed out in the paper the constant had been rather difficult to fix. That however was a difficulty which would be encountered in all formulae. Thus it would be possible that if a slope discharge and silt size relationship were derived for sites other than those studied in the Institute, the constant in formula 1 on page 67 would be different from 2·09.

Dr. Malhotra added that some explanation was also due from him in regard to formula 'B' on page 68. The formula was derived from some data chosen at random from the observations then available. It was however he, and not Mr. Lacey, who pointed out that the formula could be derived from the equations given in his paper. Mr. Lacey later wrote to him to say that the derivations had been previously obtained by Messrs. Ercheverry and Inglis, and that the use of his equations (1) and (3) in effect amounted to using formula 'B' for finding the hydraulic mean depth. It was also told to him by Dr. E. McKenzie Taylor that a note of this formula was also given in a private memorandum book maintained by Mr. Montagu. No credit was due to him in any case, for the derivation, which was a matter of simple algebra. The only thing which he then pointed out was that while Mr. Lacey's formulae gave

$$R = \cdot 47\ (Q/F)^{\frac{1}{3}},$$

the silt factor did not enter into formula 'B'. Later by introducing the mean silt size, regardless of the very small improvement in the correlation coefficient, he had found that the formula 'B' could be made to correspond very closely to Mr. Lacey's Qf formula. Perhaps it would be desirable to introduce the silt factor in his formula ' A ' also, as it was noticed that the coefficient was higher for the Punjab silts than for the finer Sind silts.

As a matter of interest Dr. Malhotra mentioned that the observations carried out at the Punjab regime sites, which were referred to on page 69, were a consequence of a note written by him to clarify Lacey's Theory of Shock. While Mr. Lacey had later made some changes in this theory, it was good to see that these observations had otherwise led to some very useful results.

On page 70 the authors referred to the correlation between A and Q and gave it as 99·94 per cent. Just as a technical detail he suggested that this should read as the correlation between A and Q is ·9994. It is not usual to express correlations as percentages.

On page 71 the authors had introduced the mean central depth, neglecting the slope segment. This was a greatly useful step, as the depth was much more familiar to the designer, than the hydraulic mean depth. There was however one thing about it, that where the bed was somewhat undulating, or where the transition from the bed to the sides of slopes was not clearly defined, it was difficult to fix.

Dr. Malhotra suggested that some more definite and less discretionary method might be laid down for the determination of the depth.

Formula 3 was likely to be very useful, and the correlation coefficient was very high indeed. But it would seem by reference to Table II that a certain amount of variation between the actual and the calculated values still persisted. This however might be due to the fact that only daily values had been taken and it was possible that if monthly average was struck, the actual and the calculated values would agree even more closely.

It would also have been useful if the orders of maximum divergence had been found with formula ' B ', and compared with that given by formula (3). In Table I the values of R/Q.345 were indeed given, but they did not enable one to institute a comparison between the respective values of formulae ' B ' and (3).

The linking up of the side slopes with the nature of berm soil was a very valuable idea. It was now possible for the designer not to be tied down to any particular shape of the channel, *e.g.* Mr. Lacey's Elliptical channel, and to use his own discretion in fixing the exact slopes suited to the country.

Dr. Malhotra emphasised the warning given in the first para on page 73. These formulae must be used as they stand, only within the range of values of the various elements, from which they had been derived. It would for example be too much to expect that these formulae would hold equally well on Sind and U. P. channels.

Dr. Malhotra congratulated the authors once again on a paper which would greatly advance the subject of Channel Design.

MR. A. N. WILSON congratulated the authors on the bold departure from the use of the P=Q relation in the design of channels, but in doing so they had proposed an A. Q. relation. Dr. Bose in his introductory remarks stated that the P=Q formula was fundamentally correct, while in the paper itself it was claimed that the A=Q relation was fundamentally correct. The two statements were incompatible and were the direct opposite of one another. It was suggested that neither the P=Q nor the $A \times Q$ relations was fundamentally correct, even though they appeared to fit the data well and were useful empirical formulae.

It was permissible to rewrite the relations in another form without substitution or similar process, thus if—$P=2{\cdot}67/Q$, then (squaring and dividing by PR) $V=1{\cdot}37\ P/R$ ....(1)
Similarly if—

$A=1{\cdot}145\ Q^{0{\cdot}85}$ then $Q/A=Q/1{\cdot}145\ Q^{0{\cdot}85}$ or $V=0{\cdot}87\ \ Q^{0{\cdot}15}$ (2).

Now (1) and (2) were the direct opposites of one another, in that in the former case velocity was determined solely by shape of section and was independent of discharge, whereas in the latter case velocity was solely dependent on discharge and was independent of shape.

It was suggested that neither of these hypotheses were true, and that in fact velocity was dependent both on discharge and on shape of channel section.

The authors had partly reverted to the Kennedy Theory that the shape of a channel section was to some extent determined by berm conditions, and this appeared to have some justification, and it was suggested that the data upon which this decision was made would be of general interest.

The probable effect of berms on the shape of channel with some data of the resistance to erosion of berm clays was given in Indian Engineering May to September 1938, but only a fraction of the available data was reproduced, and the complete data showed that the resistance of berm clays was extremely variable, berm clays being capable of resisting velocities varying from 1·30 to 5·70 ft. per second. The conclusion which might well be drawn from the available data was that the passive or potential resistance to erosion of berm clays did not necessarily have a determining effect on channel shape, but was probably only one factor in effective berm resistance. It seemed possible that berm resistance or side pressure on the section was more or less constant, and might have only a minor effect on shape in most cases.

As an illustration of the inadequacy of the Punjab Research data for the purpose of establishing correct general formulae, and also to show the possibility that only a fraction of the variations of the coefficient in the P=Q and A=Q relations could be fairly attributed to the effect of berm conditions, it was pointed out that there was a considerable variety of other similar relations which fitted the Punjab

Research data more closely. On the average these relations fitted the data with about one-third of the variation of coefficient found in the case of the P=Q relation, and half in the case of the A=Q relation, so that it did not seem reasonable to attribute more than this minimum variation of coefficient to a physical condition such as berms, since greater variations appeared to be due to error in the relation used. Further, although these other relations fitted the Punjab Research data very closely, most of them led to some absurdity if carried to a logical conclusion, especially if applied to channels outside the limited range of silt factor typical of the Punjab Research channels.

As an example of such a relation which fitted the Research data closely and which was worked out as a first approximation and could probably be improved, $P+10R^{1\cdot 42}=5\cdot 68\sqrt{Q}$ may be compared with the P—Q and A—Q relations, using the data given in the Punjab Research Institute report for 1937. The table below shows the average variation of the coefficient, and the number of cases of variation within percentage limits :

Relation.	Coefficient.	Mean Variation.	0—2%	2—5%	5—10%	Over 10%	Total.
P—Q ..	2·77	7·05%	4	6	7	7	24
A—Q ..	1·145	4·06%	6	11	6	1	24
$P+10R^{1\cdot 42}$ ..	5·68	1·94%	14	9	1	0	24

It would be found that neither $P+10R^{1\cdot 42}$ nor the A—Q relation applied to channels with low silt factors such as those in Sind or on the Sutlej Valley Project, so that these relations were not fundamentally correct, in spite of fitting the Research data closely.

It was pointed out that a correlation of 99·94 per cent. might sound very impressive, but although a correlation factor might serve a useful purpose, it was certainly misleading to the average engineer, unless its implications were fully understood. Apparently such a correlation meant that on the average one must expect the coefficient to vary by about 4 per cent., and to find a considerable number of cases of variation of 8 per cent. The P—Q relation was given as having a correlation factor of +·99 in the Research Report of 1937, and this apparently meant an average variation of coefficient of 7 per cent., with a number of cases of about 15 per cent. variation, and odd cases of 20 per cent.

It might be mentioned that certain channels included in table (1) had been omitted from table (2), and *vice versa*. The omissions might have been accidental, but it would be interesting to know how the cases omitted would fit the formulae, since it was an elementary principle of statistical work that selection of data should be entirely random within the physical conditions laid down beforehand, and it was not permissible to use one set of data to establish one relation and another set for a second relation, especially when the two relations were to be used together for a single purpose.

L. ISHAR DASS began with equation (B) on page 68. $R = \cdot 47\ Q^{\frac{1}{3}}$. This, he said, was arrived at by Dr. Malhotra on analysis of data along with the other relationships :

$$V = 1 \cdot 12\ R^{\frac{1}{2}}$$

$$P = 2 \cdot 8\ Q^{\frac{1}{2}}$$

These three coefficients were interchangeable. Taking in general terms :

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

$$P = C_1\ Q^{\frac{1}{2}}$$

$$R \times C_2\ R^{\frac{1}{3}}$$

We find—

$$C_2 = \frac{1}{(C\ C_1)\ \frac{2}{3}}$$

Substituting values of $C_2 = \frac{1}{(2 \cdot 8 \times 1 \cdot 12)^{\frac{2}{3}}} = \cdot 47$

This expression $C\ C_1 = \sqrt{\frac{Q}{R^{3/2}}}$ and was true for all values of R from lowest discharges to the highest in artificial channels as well as in streams and rivers. Thus relationship $C\ C_2 = \sqrt{\frac{Q}{R^{3/2}}}$ was also independently arrived at by the speaker by method of correlation analysis of the Punjab data. The correlation coefficient between Q and R was 99·98 per cent. This Product $C\ C_1$ one might call silt and Silt and Soil Factor was indication of the grade of silt and nature of soil through which the channel passed or in other words $C\ C_1$ represented the grade of silt and the nature of the soil of the section of the channel.

Lacey's channel with

its value if $\sqrt{4/_3 \times 8/_3} = 3 \cdot 08$

For average Punjab data it was $2 \cdot 8 \times 1 \cdot 12 = 3 \cdot 13$

For Sind canal its value was approximately $\cdot 8 \times 2 \cdot 5 = 2 \cdot 0$

Therefore coefficient in the equation $R = C_2\ Q^{\frac{1}{3}}$ would be

$$C_2 = \frac{1}{(331)\ \frac{2}{3}} \quad \text{and } R = \frac{1}{(C\ C_1)\ ^{\frac{2}{3}}\ Q^{\frac{1}{3}}}$$

It was unfortunate, therefore, that the authors had departed from this fundamental law in Hydraulics and had taken $C_2 = R/Q^{.345}$. The change in the Index though was small no doubt, but what the speaker objected to was the departure from fundamental equation.

This departure from fundamental law was also reflected in the equation (1) $S^3_{10} = 2{\cdot}09 \frac{m^{.85}}{Q^{.21}}$. The speaker emphasised on the correlation analysis of m with R, because R represented more the Hydraulic data than does the Q. The relationship arrived at between M and R is $M = \frac{1}{CR^{\frac{1}{2}}}$. Now substituting for R from $R = \frac{1}{(C_1C_2) \quad Q^{\frac{1}{6}}}$

$M. = \frac{1}{K\ Q^{\frac{1}{6}}}$. This K would be in terms of coefficient $C\ C_1$.

Therefore speaker's slope equation would be $S^3_{10} = \frac{K\ M^n}{Q^{\frac{1}{6}}}$

It was regrettable that the authors had not published the full hydraulic data. That must be published to enable others a closer examination.

Dr. Bose had traversed a lot in the domain of finding empirical formulae depending entirely on results of his correlation analysis. In this he was departing from fundamental laws. It was actually found in case of discharge formula $Q = CBH^n$ that actually we get by plotting or analysis $Q = CBH^{1{\cdot}58}$ or $CBH^{1{\cdot}55}$ or $CBH^{1{\cdot}6}$ and so on.

This was what actual analysis showed, the index of H depending on the set of data were adopted. After all, what was this correlation analysis. It was nothing but a mean value found out by mathematical process what no one found by plotting the data and striking a mean line.

The results which depended on the data used whether it preponderated data of one set of conditions on varied data of all sets of condition. The speaker sounded a note of caution. When the observed data used was available, the speaker might send a further note.

Mr. G. R. Sawhney congratulated the authors on their having moved in the right direction towards finding a correct solution for our most important problem.

Every one owed at least one of his virtues to his dislike of some-one else, with the result that our Pundits very promptly sprang a new shock upon our poor alluvial channels every time we met. Use of mathematics was a ballast for the soul to fix it, not to stall it, nor even to jostle out a fresh set of indices and coefficients by its usage.

The monograms for determining the design were based on the mean bed silt diameter in m.m. The bed of the channel was taken as uniformly level and average depth D, so as to pass through the centre of the rectangle, ignoring the slope segments, and finally the side slopes were suggested to be given according to the nature of the soil. Mr. Sawhney asked the authors to tell them how every engineer would be supplied with the accurate detail to fulfil the first and the last condition and how and where they expected to find such ideal bed and depth condition along the channel.

To suit their convenience or to sidetrack their difficulty, the authors neglected slope segments, and with the same breath by bringing in the nature of soil they introduced flatter slopes in which case the slope segments would not remain negligible and even the conveniently accepted value of D might change.

The data collected by men of different thought seemed to confirm with Lacey Bose or even Ishar Dass theory depending on the selection of sites and eliminating unsuitable exceptions.

The data of Table I had been collected from 42 specially selected sites along canals all over the Province. The speaker knew from experience how much care was taken and thought given for selection of each such site; and this being the case it was not surprising that the authors got nearly 100 per cent. correlation between A and Q. He doubted very much if the variations would remain within the same limits if the data was collected at different sites on the same channels.

The speaker asked if the observations for slopes included, wholly or partly any curved reaches of any channels. If not the authors should also have included such reaches before coming to conclusions, as a good deal of length of our channels is made up of curves, and curves have a nasty habit of upsetting assumed slopes.

It was the unfortunate man who had to carry out some remo-delling scheme and was made to force these formulae to fit in where they should not, that had to face the drums and not the authors. Remodellings carried out on these lines in Nili Bar Circle and Sidhnai Canals gave rather disappointing results.

Our doctor was not so lucky as the proverbial doctor, because instead of the dead being not able to tell the tale, the tails would be swinging up and below the one-foot gauge in our case.

The speaker suggested that special endeavour should be made to bring the channels on which good conditions were exceptions, bad ones the rule; to better conditions by proper maintenance as per note lately issued *vide* C. E.'s No. 6699/S. W. G., dated 26th September, 1941, and only then collect the necessary data and sit down to evolve new formulae or equations otherwise as accepted by the authors themselves these would suffer from one defect or the other and thus they would be no better than learned jargons of a quack.

The authors in replying thanked those members who took part in the discussion. Two points had come out clear from these discussions. One was that the slope discharge formula given by one of the authors "is undoubtedly a very useful stability formula" (Inglis). As pointed out by Mr. Inglis the main difficulty in applying this formula in designing channels was that the silt grade became finer as we went down the system. Mr. Inglis had worked out a relationship between Q and m in a canal system. This would be different for different canal systems and would depend on the silt selective capacity of the distributary heads of the off-taking channels. Unless this capacity was standardised the relationships worked out by Mr. Inglis would not serve any useful purpose.

The next point about designing the cross-section of a channel had raised more controversy. It was indeed to clear this point that the present paper was written.

It had been pointed out by many indeed by almost all that the third relation between D and Q was identical with Kennedy's equation $V_o = 0{\cdot}84\ D^{0 \cdot 64}$ and the second one was identical with Lacey's Equation $A = 1{\cdot}250\ Q^{\cdot 833}/f^{1/3}$. The authors felt proud that their efforts had been compared with those of Kennedy and Lacey—two classic names in canal hydraulics. But a point that had been missed by almost all excepting Mr. Lacey was that the problem of the design of a channel in alluvium could be divided into two parts:

1. Determination of the slope.
2. Determination of the linear dimensions of the X-section of the channel.

As mentioned by Mr. Lacey "Slope was a vital factor in regime design and it was essential to know if the slope demanded was available. Errors in the X-section could at least be amended but defective slope was fatal."

The present paper deals mainly with the second part of the problem.

As Mr. Inglis had said these formulae applied to Punjab condition only but his contention that there was super-regime at the head and sub-regime at the tail of a canal system was not understood. By "regime channels" the author meant that the channels were in stable equilibrium under the conditions of discharge, silt charge and grade and bank conditions to which these were subject for a considerable length of time. If any of these quantities was changed the equilibrium would be upset and the channel would migrate to a different regime. In this conception there was no room for sub-regïme or superregime. There was one and a unique regime. (The information required by Mr. Inglis was given in the attached table).

Mr. Lacey remarked that in the Punjab relation

$$P = 2{\cdot}8\ Q^{\frac{1}{2}}$$

$$R = 0{\cdot}47\ Q^{\frac{1}{3}}$$

silt grade did not enter. It was really this characteristic of these two equations that led the authors to try some other relationship. In the second equation now proposed the silt grade again failed to appear.

Fundamentally, it would be correct to say that the three equations $P-Q$, $R-Q$, and $A-Q$ should involve the silt grade but in the Punjab data, the range of the silt grade was limited and as such failed not only to influence the correlation coefficient but the regression also. One of the authors had been all along aware of this fact but it was not this aspect of the question that had forced him to abandon $P-Q$ and $R-Q$ relationships as unsuitable for the purpose of design. It was really the survey for the determination of "shock" at regime sites that opened his eyes to the very patent fact which must have been very well known to all canal engineers that the nature of the berm soil determined the width and, consequently, the wetted perimeter of a channel. In this paper, efforts had been made to get round this difficulty by proposing to use $A-Q$ instead of $P-Q$ and $R-Q$. One equation, however, did not fix the linear dimensions of the cross-section of a channel. Hence the authors had been forced to use the $D-Q$ relationship. This difficulty had not been appreciated by such critics of the paper as Messrs. Wilson, Isher Das and Sawhney. They looked upon the paper as a mathematical exercise to fit in a number of formula to a set of data collected by the authors.

As remarked by Mr. Lacey the independent variables of a channel in fine alluvium were the discharge Q and the silt charge and grade. The purpose of the paper had been to recognize the soil characteristic as a third variable. If this characteristic had not entered the problem, the design of alluvial channels would have been comparatively easier at least statistically. But as it was, the soil characteristics determined to a great extent the ultimate dimensions of a channel and it was the purpose of all reliable and useful designs to be able to work out these ultimate dimensions correctly. The paper under discussion was an humble attempt to put forth such a design.