PAPER No. 101.
DESIGN OF CANALS.

By PIR MOHAMED IBRAHIM, I. S. E.

The writer when in Bikaner Circle thought that it was a tedious business to design a canal for side slope and Kutter's N different from those given in the Kennedy's or Garret's diagrams. This feeling induced him to prepare the diagrams now offered which, it is hoped, are *general and concise.*

The aim of this paper is simply to indicate the use of the diagrams and the formulas on which they are based.

The two formulas used are Kennedy's and Chezy's with Kutter's coefficient.

$V = m \cdot 84 d^{\cdot 64}$ $(m = C.V.R.)$ ..... Kennedy .. 1

$V = C\sqrt{RS}$ ..... Chezy .. 2

$$C = \frac{41 \cdot 6 + \frac{1 \cdot 811}{N} + \frac{\cdot 00281}{S}}{\left\{1 + (41 \cdot 6 + \frac{\cdot 00281}{S}) \frac{N}{\sqrt{R}}\right.}$$ Kutter

or $V = f(S.N.R.)\sqrt{RS}$ ———————— .. 3

as C is a function of bed slope, Kutter's N, and hydraulic mean depth.

Now area is a function of H. M. D., depth and side slopes of the channels.

$A = f(R.d.K)$ ———————— .. 4

$\therefore Q = f(R.d.k) \times f(S.N.R.)\sqrt{RS}$ ———————— .. 5

Besides from 1 and 3

$\cdot 84 m d^{\cdot 64} = f(S.N.R.)\sqrt{RS}$ ———————— .. 6

Hence from 5 and 6 it is obvious that design of a channel involves the following variables :—

1.	Side slope of channel	..K	These three determine the section of a channel completely.
2.	H. M. D.	..R	
3.	Depth of channel	..d	
4.	C. V. R.	..m	
5.	Discharge	..Q	
6.	Kutter's N	..N	
7.	Slope of channel	..S	

Given any five, the other two can easily be found by combining diagrams I and III or II and III.

Diagram I or II.

(*a*) *Description.*—The diagrams deal with the five variables K, m, Q, R, d, given any four the fifth can be found direct from the diagram ; or given any three innumerable pairs of two can be found to satisfy the condition required by Kennedy's formula. The main diagram deals with four variables m, Q, R and d but a small attachment on the right modifies m with varying side slopes of channel.

The diagram I deals with discharges ·5 cusecs to 200 cusecs and the diagram II with discharges from 160 cusecs to 10,000 cusecs.

The diagram has two series of curves—one for H, m, d and the other for discharge—and two axes—one on the left for depth of channel and the other on the right for C. V. R.

The C. V. R. axis is modified for various side slopes by means of a small diagram on the right, *i. e.*, if side slope is $\frac{1}{2}$: 1 the axis to be used is the vertical line through $\frac{1}{2}$ and so on.

(*b*) *Method of using the diagrams I and II.*—The rule for using the diagrams is " Collect and read together either series (whichever are known completely) and project on the unknown."

(*a*) Suppose K, m and Q are known. Along the vertical line through K locate a point for m and draw a line horizontally through this point to the curve Q (of the given value). Through the point thus found draw a vertical line. The corresponding values on R-curves and d-axis satisfy Kennedy's formula and hence if R or d is given the value of d or R is fixed.

Example.—Channel with $\frac{1}{2}$ to 1 side slope C. V. R.=·85. Discharge=2,100 cusecs, find a few corresponding values of d and R. Also what is R if d=8 feet and d if R=8·34.

From diagram II

R	d
6	6·5
6·5	7·22
7·4	8·02
8·1	10·16
8·341	11·46
7·275	8·50

(*b*) If R, d and Q are given

R and d should be read together, *i. e.*, draw a horizontal line through the known d to the curve for R and, through the point thus found draw a vertical line (project) to intersect the curve for Q. Through the point thus found draw a horizontal line in the small diagram attached (on right) C. V. R. and K (side slopes) corresponding to various points on the horizontal line satisfy Kennedy's equation.

Example :—(2) d=5·5, R=2·3, Q=100.

Read d 5·5 horizontally with curves or R=2·3 and project it vertically on the curve of Q=100. Draw a line horizontally through the point thus found and we get

Side slope.	C. V. R.
0 : 1	0·933
1/4 : 1	0·987
1/2 : 1	1·056
3/4 : 1	1·055
1 : 1	1·009
$1\frac{1}{4}$: 1	0·946
$1\frac{1}{2}$: 1	0·877
$1\frac{3}{4}$: 1	0·810
2 : 1	0·746
$2\frac{1}{4}$: 1	0·690
$2\frac{1}{2}$: 1	0·650

Note 1.—Water flowing in an earthen channel tries to erode it. The channel tries to resist erosion by adopting a shape, which offers maximum friction to the water, thus allowing the least discharge to pass.

From the example below it is obvious that a trapezoidal channel with given depth, H. M. D., and C. V. R. ; the least discharge passes when its side slopes are $\frac{1}{\sqrt{3}}$: 1=·5773 : 1 justifying the general practice of accepting side slopes of earthen channels as ·5 : 1.

Example (*a*).—Depth of channel is 4 feet : its H. M. D.=2·4 and C. V. R.=·9 find its discharge for different side slopes :

Diagram I : Read d=4′ horizontally with the curve R=2·4 through the point thus found draw a vertical line.

On the line K=O locate m=·9 and draw from it a horizontal line to the above vertical line, reading on black curves Q=87·5 cusecs.

Repeating the same with different values of K we get the following table :

K=	0	$\frac{1}{4}$	$\frac{1}{2}$	·5773	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$
Q=	87·5	81·6	76·2	75·8	76·8	80·5	85·2	92·0	100·4	108·0	110·5

2. A thick line is drawn on the diagrams I and II to give the section of a normal channel (as per Wood's paper).

But the writer thinks that a channel to be stable, must have a particular ratio between depth and H. M. D.—on which mostly depends the value of Kutter's C. For a channel of particular depth its H. M. D. must be such that the variations in discharge (near about the H. M. D.), due to the variations of depth, are slight. Such a ratio between the depth and H. M. D. is given by a curve passing through the apexes of H. M. D. curves. For a channel of certain depth and discharges it gives a lesser H. M. D. than that of Wood's, *i. e.*, the ratio of bed width to depth proposed in this paper for a certain discharge is the smaller of the two.

The thick line drawn and referred to above denotes the ratio of $\frac{B}{d}$ as proposed by Wood. The use of it is made in Example 3.

The use of the line proposed is as follows.

Example (b).—Design a stable channel to carry 18 cusecs, side slope $\frac{1}{2}$: 1 C. V. R.=1.

Diagram I on (K=$\frac{1}{2}$) axis, locate (m=1) draw a horizontal through it to Q=18 curve, project this point vertically to line joining the apexes of curves, there R=1·333, d=2·05.

Example III.—Design a normal channel (as per normal data of design Kennedy Channels) to carry 18 cusecs.

N=·0225, side slope $\frac{1}{2}$: 1, C. V. R.=1.

Diagram I.—On $\frac{1}{2}$: 1 side-slope axis locate m=1 draw a horizontal line through it to Q=18 curve, project this point vertically on to the thick curve R = 1·33 and horizontally opposite to it d = 1·95 and critical velocity V=1·28.

Note 3.—In a case where value of m is more or less than that given in the diagrams I or II a suitable multiple may be selected to bring it within the range of diagram. Multiply Q also with the same multiple and use the diagram as usual.

Example IV.—Q=100 cusecs, slope is 1 in 8,000 or ·000125
Side slope $\frac{1}{2}$: 1 m=·8
m=·8 on K=$\frac{1}{2}$ axis is outside the range of diagram.

Say we multiply m by $\frac{3}{2}$ and also Q by $\frac{3}{2}$. The new m=1·2 and Q=150 cusecs.

On $\frac{1}{2}$ side slope line locate 1·2 draw a horizontal line through it to Q=150 cusecs. Through the point found draw a vertical line, and we get the following corresponding Rs and ds

d=	2·6	2·7	2·8	2·9	3	3·25	3·5	3·75	4
R=	2·245	2·315	2·37	2·425	2·47	2 56	2·65	2·70	2·76

Diagram III.—This diagram deals with five variables M. d. S. N. R. (Three being common to Diagram I and II). There are three curves for each value of N—first for channels having a slope of 1 in 1,000 (or ·0001) second for channels having a slope of 1 in 10,000 (or ·00001) and the third for channels with a slope of 1 in 15,000 (or ·00006). For channels with intermediate slopes the points are interpolated in the proportion shown on the top of the diagram.

The use of this diagram is the same as that of I or II excepting the attachment modifying d for various values of m is on the left instead of the right.

Example V.—If a canal has got a slope of 1 in 8,000 (·000125) and value of N.=·02 and C. V. R.=·85. Make a table of corresponding d and R. Assume R=7 and read it with ·02 ·000125 (by interpolating

between $\cdot^{02}$ ·0001 and $\cdot^{02}$ ·00001 : at ·2 of the distance from $\cdot^{02}$ ·00001) and project it vertically to S=·000125. Along the axis through m=·85, d=9·757 and so on.

R=7	7·5	8	8·5	9	8·34	
d=9·757	10·3	11·25	11·82	12·61	11·5	

Note.—Comparing it with the table given in example I the depth of the channel=11·5 (Q=2100, K=$\frac{1}{2}$ and M, N, S as given above). The velocity of the channel as given horizontally opposite to d=11·5 on m=·85 axis is 3·465. Hence $B=\frac{Q}{vd}$=52·75 feet.

Example VI.—Design the distributary given in the example IV. (N=·0225)

now N=·0225 S=·000125 m=·8 make a table of corresponding R and d, as above.

d=2·6	2·7	2·8	2·9	3	3·25	3·5	3·75	4
R=2·245	2·33	2·43	2·49	2·65	4·31	3·03	3·15	3·35

Comparing this table with that given in the example IV depth of channel=2·6 feet and the velocity as in the above example=1·24 feet/sec

Hence mean width $B=\frac{Q}{vd}=\frac{100}{2·6\times1·24}$=31 feet

Hence bed width=$B-\frac{d}{2}$=31−1·3=29·7 feet.

Example VII.—A channel has R=6.

S=·13‰ (or $\frac{1}{7777}$) N=·013 what is its depth,

if m=·9 ? What is its velocity ?

Read R=6 with N=$\cdot^{013}$ ·00013 (interpolating between $\cdot^{013}$, ·0001 and $\cdot^{013}$, ·00001 at ·17 of the distance from S ·00001) and project it vertically on S=·00013. Through the point thus found draw a horizontal line to the attachment, the corresponding values of d and m can be read directly. If m=·9, d=14·76

The horizontal line, last drawn, cuts the velocity—axis (drawn separately on left) at V=4·23.

Example VIII.—Find the slope and velocity of the channel given in Example III.

On m=1, locate d=1·95 and draw horizontal line through the point thus found.

Also draw a horizontal line through R=1·33 to ·0225

·0003 (assuming the channel has a slope of 1 in 3333) and through the point thus found draw a vertical line to intersect the above horizontal line. Here S=·000292.

Repeating the above (with ·0225 $\cdot_{000292}$) to find a more accurate value of S, S=·00029.

Hence slope ·00029 is correct.

Opposite to the point m=1, d=1·95,

V=1·285.

NOTE.—The diagram III can also be used for solving formula

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

$$=f(N, R, S)\sqrt{RS}$$

Given any three of V, S, N, R the fourth can be found or given two an innumerable number of the other two can be found satisfying the above equation. In this case the attachment is neglected and velocity axis used instead of d—axis.

Example IX.—A river has a mean slope of ·2 per thousand, a discharge of 3500 cusecs, area of 885·4 sq. feet, wetted perimeter=108·918. Find N.

$$R=\frac{885\cdot4}{108\cdot918}=8\cdot13,\ V=\frac{3500}{885\cdot4}=3\cdot953$$

Read V=3·953 horizontally with S=·0002 project the point thus found to R=8·13. This point is between ·0225 $_{.0002}$ and ·02 $_{.0002}$. N is about ·0217.

To use Diagrams I and III or II and III in combination.

This can more clearly be illustrated by examples :—

Example X.—Given the following data, find the depth and width of channel.

N=·013 (lime concrete)
S=·13 per 1000
K=side slope=1 : 1
m=C. V. R.=1·395
Q=2125 cusecs
} Bikaner Canal.

In the diagram II on the vertical line through 1 : 1 interpolate the value for (C. V. R.) m=1·395. Draw a line horizontally through this point to the curve Q=2125. Draw a vertical line through this point and tabulate corresponding R's and d's

d=	6·5	7	7·5	8	8·5	9	9·5
R=	5·72	6·02	6·26	6·45	6·67	6·83	6·94

In the diagram III on the vertical line through m=1·395 locate a point for d (taking one at a time from the above table) through this point draw a horizontal line to S=·00013, and through the point thus found draw vertical line (interpolating between ·013 $_{.001}$ and ·013, at ·17 of the distance between the two from ·013 $_{.0001}$) to the N=curve for ·013 $_{.00013}$ and read the corresponding R on the right side.

d=	6·5	7	7·5	8	8·5	9	9·5
R=	5·27	5·68	6·07	6·45	6·88	7·11	7·77

Comparing the two tables we find that the required channel has depth of 8 feet and H. M. D.=6·45

Velocity of the channel is found in the same way as in Example VIII and is 3·43 feet per second.

$$\text{Hence mean width of the channel} = \frac{2125}{4{\cdot}435 \times 8} = 60 \text{ feet.}$$

Note.—In some cases d and B are given and it is required to find V, or m and R.

$$\text{Now H. M. D. (R)} = \frac{Bd}{B+Kd}$$

Where B=mean width of channel

d=depth of channel

K=is a constant which varies with side-slopes of channel.

Table for side slopes and K

Side slope.	K.
0·00 : 1	2·0000
0·25 : 1	1·8700
0·50 :1	1·7350
0·5773 : 1	1·7325
0·75 : 1	1·7500
1·00 : 1	1·8284
1·25 : 1	1·9516
1·50 : 1	2·1056
1·75 : 1	2·2810
2·00 : 1	2·4721
2·25 : 1	2·6744
2·50 : 1	2·8852

Example XI.—Find the C. V. R. and velocity of the following channel

Q=2100 cusecs
N=·02
S=·000125
d=11·5
Bed width=47, Hence B=52·75
side slope=½ : 1

$$R = \frac{Bd}{B+Kd} = \frac{52{\cdot}75 \times 11{\cdot}5}{52{\cdot}75 + 1{\cdot}7325 \times 11{\cdot}5} = 8{\cdot}342$$

K is taken from the table above

Turning to diagram II draw a horizontal through d to R and from the point thus found draw a vertical line to Q and horizontally opposite to the last point on ½ (slope) axis C. V. R. is ·867.

Diagram III.—From where horizontal line through R meets N_S draw vertical line to S=·00125, and we find horizontally opposite to last point on velocity axis V=3·465.

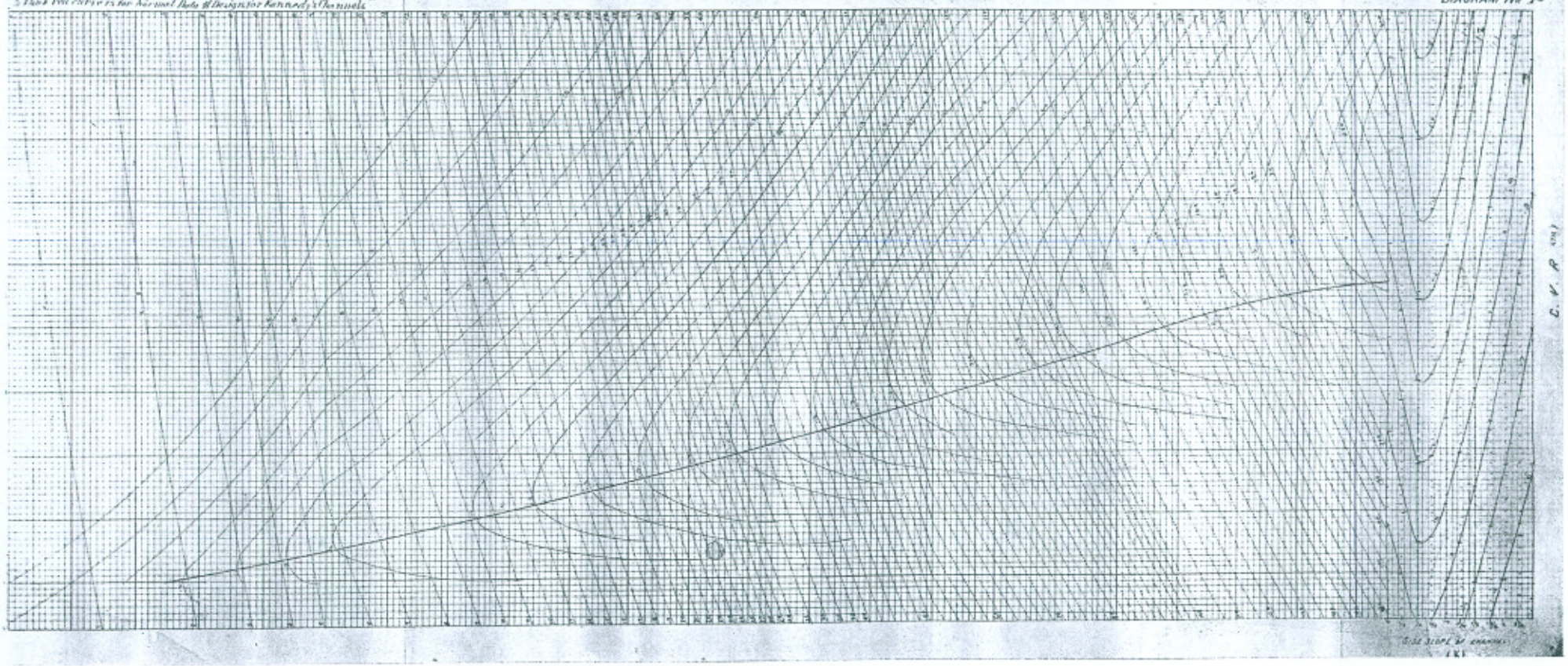
Note

1 Red curves are for H.M.D. (R)

2 Black curves are for discharge (Q)

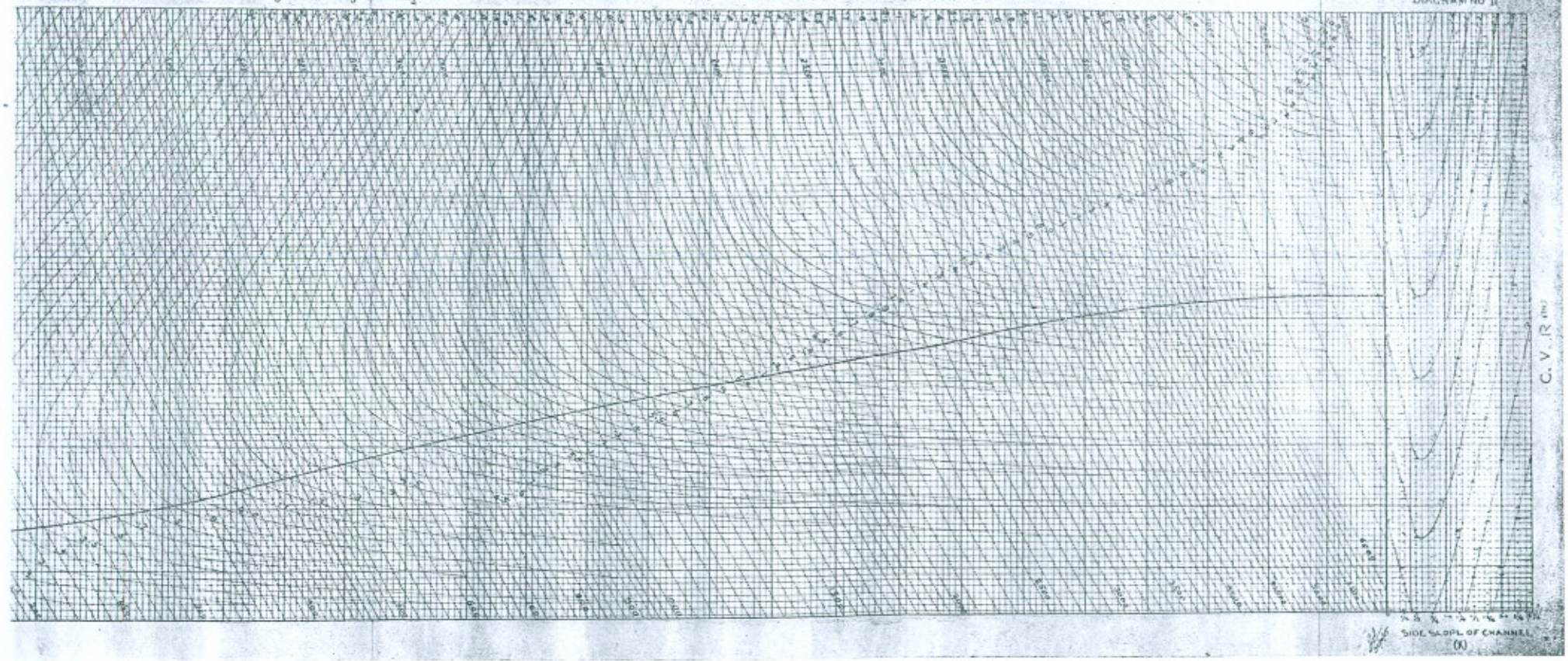
3 Thick red curve is for "Normal Data of Design for Kennedy's Channels"

DIAGRAM No. I



NOTE.
1. RED CURVES ARE FOR H.M.O. (R)
2. BLACK CURVES ARE FOR DISCHARGE (Q)
3. Thick red curve is for "Normal Data of Design for Kennedy's Channels"

DIAGRAM NO II



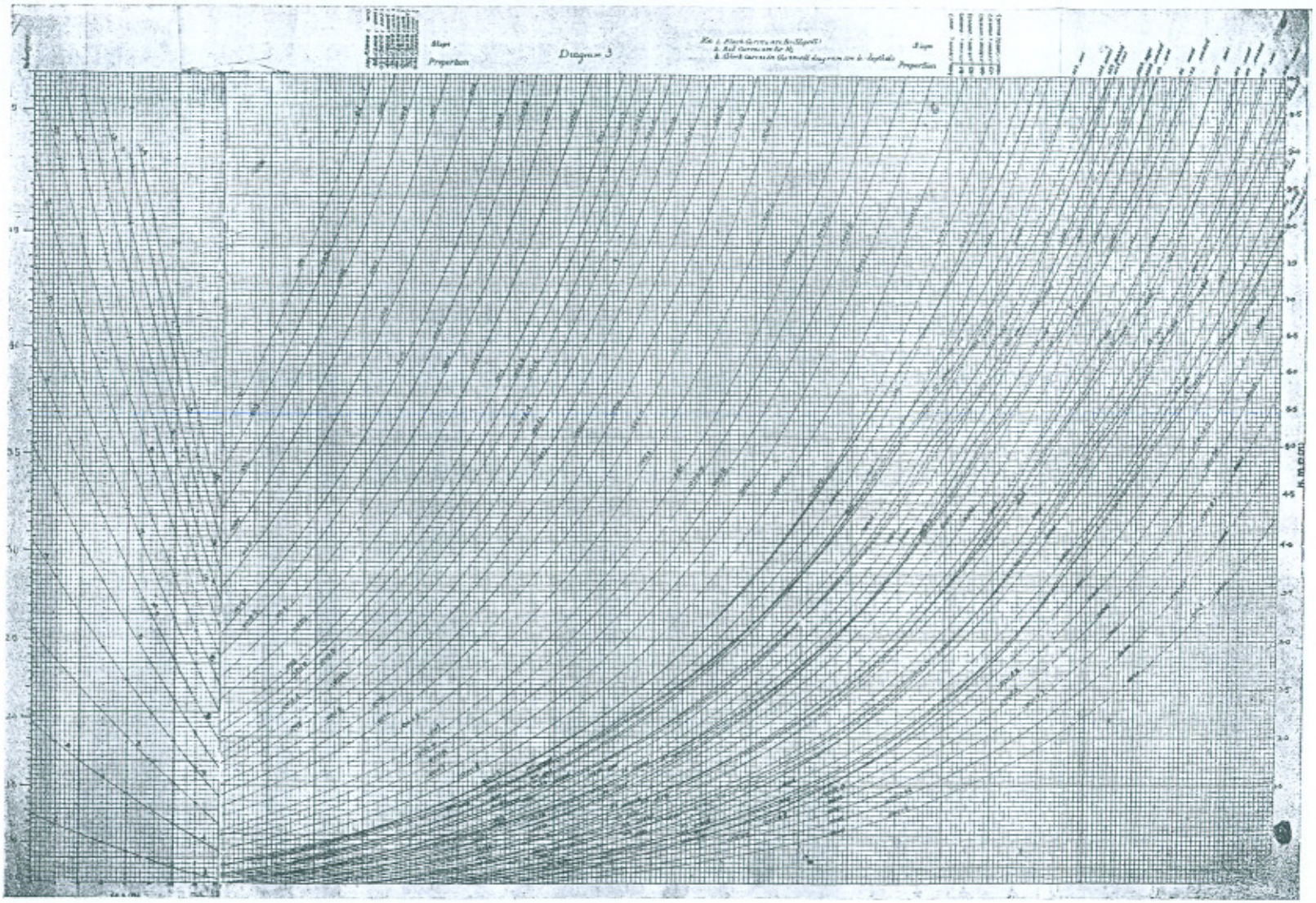


Diagram 3

DISCUSSION.

PIR MOHAMMAD IBRAHIM when introducing his paper regretted that his diagrams were not printed in colours (*a*) ; and that due to the omission of the words "red" and "black" (colours of curves and axes) and misprints (*b*) some portions of his paper were unintelligible specially the portion relating to the use of the diagrams. He explained the formulæ on which the diagrams were based, the use of the diagrams, and the advantages they had over Kennedy's and Garrett's diagrams. The main advantages being :—

(1) Conciseness
(2) Channels having various co-efficients of rugosity (Kutter's N) can be designed.
(3) Channels with various side-slopes, can be designed.

(*a*) Owing to expense.
(*b*) Corrigenda slip attached.

(Ed.).

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Corrigenda.

Page 54, line 4. *Read* " pairs of the other two " *for* " pairs of two."
Page 54, line 10. *Read* " H. M. D. " *for* ' H. m. d."
Page 54, line 17. *Read* " d and R or m_K and Q " *for* " either series."
Page 54, line 17. *Add* " remaining known to read the " between " the " and " unknown."
Page 54. After line 18 *add* the following note :—
" m_K signifies m on an axis through a given K."
Page 56. After line 7 from the bottom, *add* the following :—
" To use the diagram collect and read together R and N or d_m and s (whichever are known completely) and project on to the remaining known to read the unknown, d_m signifies d on an axis through a given m. "
Page 57, lines 5 and 6 from bottom,
Read " ·0225 $_{.0003}$ " *for* " ·0225 ·0003."

L. JAGAN NATH remarked that the area of a channel A could be expressed as a function of R d and K by elimination of b.

thus $A = \frac{R\,d^2}{d-R}\left\{2\sqrt{1+K^2} - K\right\}$

but R did not fix the size of a channel. It was b and d which fixed its boundaries rigidly ; as a reference to any diagrams such as in Buckley's Facts and Figures would show that channels differing very widely in the ratio of $\frac{b}{d}$ had the same value of R ; for example 50′ × 3′ and 20′ × 3½′ have the same value of R, 2·75′. The ratio $\frac{b}{d}$ in these cases was 16·67 and 5·71 which showed that the ratio $\frac{b}{d}$ had got a wider range than $\frac{d}{R}$ and

therefore was better suited for such diagrams. Moreover b and d appealed to the mind more directly and perhaps for the same reason it had been chosen by Messrs. Kennedy and Garrett in their diagrams.

2. The author in Note 1 on page 55 assumed a channel with its d, R and V as constants and Q wetted perimeter and bed-width as variables. Under the assumption made minimum discharge would pass when the side slopes were ·577 to 1 but this was not due to the section offering the maximum resistance as supposed by the author, but on the other hand, it was due to the cross-sectional area and W. P. being the minimum at this slope *irrespective of the materials of the channel.* All the fundamental formulæ for channel flow were based on the assumption that the total resistance offered by the channel was proportional to its W. P. and steady flow was established when the work done by water in descending the slope was equal to the resistance offered by the W. P. Since the W. P. was the least so the resistance offered was the least and not the maximum.

3. Page 55, last para. The best relation for the design of a channel was $\frac{b}{d}$ as had been said before. A little reference to Kennedy diagrams would show that for a particular C. V. R. and discharge, the point of intersection of their curves fixed the cross section once for all. Any other section would not fulfil the necessary conditions.

In the diagrams Nos. I and II under review, various pairs of d and R were obtained to play with and unless diagram III came to their rescue to give similar pairs of d and R it was impossible to find the section ; because the required section would be that which was common to both the pairs of d and R as shown in the example No. 10 on page 58.

If it was claimed on the other hand that the best sections were those which lay on the thick line joining the apexes of the R curves which was said to be based on the " Normal data of design for Kennedy channel," then it virtually fell back to the ratio of $\frac{b}{d}$ which was then more important than the ratio $\frac{d}{R}$ selected by the author.

4. Page 56, Diagram III. It was said to have been drawn for 3 values of bed slope only, *viz.*, 1/1,000, 1/10,000 and 1/15,000. For other values of slope results required interpolation. This interpolation was made use of in Major Garrett's Tables to suit them for other values of N and it was here where their drawback lay. All possible mistakes crept in interpolation and in such tables must be avoided. For this very reason alone, Mr. Kennedy's Tables were the best as they were direct reading though they had their own limitations as pointed by the author in the shape of not having far-reaching values of N and side-slopes, though they covered all that was wanted for earthen channels. It was suggested that any improvement to them in their own style would be valuable.

5. He pointed out the following errors :—

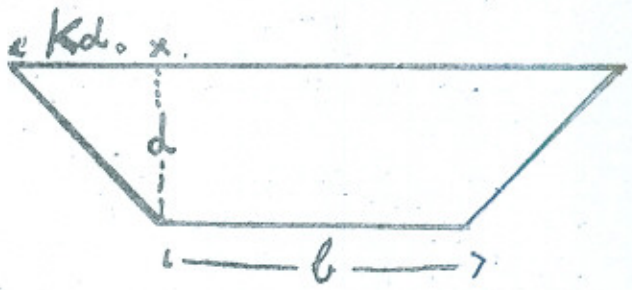
Page 56, line 30, M should be m.

Page 56, line 7, M should be m.

Page 57, line 15, 4·31 seems to be wrong.

Page 59, letter K is used twice. Already it denotes side-slopes, now it is used in $2\sqrt{1+K^2} - K$.

6. He gave the following proof of minimum section and W. P. with side slopes of ·577 to 1.



$$\text{Area} = (b + Kd) \times d$$

$$\text{W. P.} = b + 2d\sqrt{1+K^2}$$

$$R. = \frac{bd + Kd^2}{b+2d\sqrt{1+K^2}}$$

$$\therefore \quad bR+2Rd\sqrt{1+K^2} = bd+Kd^2$$

$$\therefore \quad 2Rd\sqrt{1+K^2} - Kd^2 = bd-bR = b(d-R)$$

$$\therefore \quad b = \frac{2Rd\sqrt{1+K^2} - Kd^2}{d-R}$$

Substitute values of b in A

$$A = \frac{2Rd\sqrt{1+K^2} - Kd^2}{d-R} \times d + Kd^2$$

$$= \frac{2Rd^2\sqrt{1+K^2} - Kd^3 + Kd^3 - RKd2}{d-R}$$

$$= \frac{Rd^2}{d-R}\left\{2\sqrt{1+K^2} - K\right\}$$

$$\frac{dA}{dK} = \frac{Rd^2}{d-R}\left\{2 \times \tfrac{1}{2}(1+K^2)^{-\frac{1}{2}} \times 2K - 1\right\} = 0$$

$$\therefore \frac{2K}{(1+K^2)^{\frac{1}{2}}} = 1$$

Square $4K^2 = 1+K^2$

$$\therefore \; 3K^2 = 1 \text{ or } K = \sqrt{\frac{1}{3}}$$

$$= \sqrt{\frac{3}{3}}$$

$$\frac{d^2A}{dK^2} = 2\left\{(1+K^2)^{-\frac{1}{2}} - K\tfrac{1}{2}(1+K^2)^{-\frac{3}{2}} \times 2K\right\}$$

$$= 2\left\{\frac{1}{(1+K^2)^{\frac{1}{2}}} - \frac{K^2}{(1+K^2)^{\frac{3}{2}}}\right\}$$

$$= 2\left\{\frac{1+K^2-K^2}{(1+K^2)^{\frac{3}{2}}}\right\} = \frac{2}{(1+K^2)^{\frac{3}{2}}}$$

which is a positive quantity, hence $\sqrt{\frac{1}{3}}$ is a minimum value.

Also P is a minimum quantity.

$P = b+2\,d\sqrt{1+K^2}$ put in value of b

$$= \frac{2\,R\,d\sqrt{1+K^2} - Kd^2}{d-R} + 2\,d\sqrt{1+K^2}$$

$$= \frac{2\,Rd\sqrt{1+K^2} - Kd^2 + 2\,d^2\sqrt{1+K^2} - 2\,Rd\sqrt{1+K^2}}{d-R.}$$

$$= \frac{d^2}{d-R}\left\{2\sqrt{1+K^2} - K\right\}$$ Same as before for Area.

PIR MOHAMMAD IBRAHIM replied that the first objection was that he had used D and R, but as he had said it was to make the diagram simple. The number of variables would not be simplified if he had done otherwise.

By interpolating we could read up to the second place of decimals.