1963

Study of spur dikes

D. R. Joshi
Lehigh University

Recommended Citation

Joshi, D. R., "Study of spur dikes" (1963). *Theses and Dissertations*. 3139.
https://preserve.lehigh.edu/etd/3139

STUDY OF SPUR DIKES

by

D. R. Joshi

A THESIS
Presented to the Graduate Faculty
of Lehigh University
in Candidacy for the Degree of
Master of Science

Lehigh University
1963

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

January 9, 1963
(date)

Professor in charge

W. J. Eney
Head of the Department of
Civil Engineering

ACKNOWLEDGEMENT

The author is pleased to extend his thanks to Professor J. B. Herbich, Chairman of the Hydraulics Division of the Department of Civil Engineering, Lehigh University for his kind and valuable guidance and assistance throughout the study which appreciably eased his work, and for valuable suggestions and corrections in this report. His thanks also are extended to the members of the technical staff of Fritz Engineering Laboratory for their help.

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1
2.	EARLIER STUDIES	3
3.	THE CURRENT PROGRAM	5
4.	THEORETICAL APPROACH	6
	4.1 MECHANISM OF SCOUR	6
	4.2 DIMENSIONAL ANALYSIS	8
5.	MOVABLE BED STUDIES	10
	5.1 DESCRIPTION OF EQUIPMENT	10
	A. Head Tank, Motor and Pump	10
	B. Venturi meter	10
	C. Testing Tank	11
	D. Dikes	11
6.	METHOD OF TESTING	13
	6.1 BED MATERIAL	13
	6.2 RUNNING TIME FOR TESTS	13
7.	DESCRIPTION OF TESTS	14
	7.1 TEST NO. 1	15
	7.2 TEST NO. 2	16
	7.3 TEST NO. 3	16
	7.4 TEST NO. 4	17
	7.5 TEST NO. 5	17
	7.6 TEST NO. 6	17
	7.7 TEST NO. 7	18
8.	CONCLUSIONS	19
	FIGURES	20 to 38
	REFERENCES	39
	VITA	41

LIST OF FIGURES

Figure Page

1. Top View of Tank 20

2. Grain Size Disbribution Curve 21

3. No Sediment Supply (Scour depth versus Cumulative Time) 22

4. With Sediment Supply (Scour depth versus Cumulative Time) 23

5. Scour Pattern of Test No. 1 (Dike Length 1'-6") 24

6. Scour Pattern of Test No. 2 (Dike Length 1'-6") 25

7. Scour Pattern of Test No. 3 (Dike Length 1'-6") 26

8. Scour Pattern of Test No. 4 (Dike Length 0'-10") 27

9. Scour Pattern of Test No. 5 (Dike Length 0'-10") 28

10. Scour Pattern of Test No. 6 (Dike Length 2'-4") 29

11. Scour Pattern of Test No. 7 (Dike Length 2'-4") 30

12. Test No. 7 - Particulars for Different Sections Where the Froude Number is calculated 31

13. Calculations of Froude Number at Sections 1 and 2 32

14. Calculations of Froude Number at Sections 3 and 4 33

15. Calculations of Froude Number at Sections 5 and 6 34

16. Plot of Number of Dikes versus Angle of Maximum Scouring 35

17. Plot of Number of Dikes versus Area of Maximum Scouring 36

18. Plot of Froude Number versus $\frac{D + d_s}{D}$ 37

1. INTRODUCTION

The problem of scour around any obstruction placed in an alluvial channel is of great importance to hydraulic engineers. In practice, a channel is often obstructed in many ways, such as: training dikes, bridge piers, abutments, spur dikes and so forth. To be able to design a safe and economic structure, it is important to have a clear picture of scour phenomenon around these obstructions. Also it has been realized that a sound bridge design involves hydraulic considerations for the safety of the bridge foundation, like the possibility of scour, its magnitude, its effect on the stability of the structure, and methods for minimizing such effect. It is well known that constriction of the flow due to abutments and piers in the channel result in a rise in water-level upstream of the constriction, increase in flow velocity in the constricted area and eddying and separation around the object. At the time of great floods, this produces severe scouring at the abutments and piers, often with devastating results.

In recent years the interest of the engineers has been focused on the usefulness of spur dikes in minimizing scour at the abutments by streamlining the flow and establishing uniform velocity distribution through the opening.

In order to study the variables governing the depth of scour around obstructions such as spur dikes, tests were carried out. The salient features of these tests are summarized herein.

A spur dike is a structure constructed at an angle to the flow direction extending from the bank of an alluvial channel into the main flow. It serves one or more of the following functions:

1. Training of the stream flow
2. Protection of the stream banks from erosion
3. Improvement of depth for navigation.

As the water flows around the spur dike, the flow pattern is changed due to the reduction of the width of channel, and as a result of this the shear distribution around the spur dike is modified. This leads to scouring action until equilibrium is established between the various forces influencing the scouring action.

2. EARLIER STUDIES

Some work has been done on various aspects of the hydraulic characteristics of spur dikes. Lacey worked out maximum scour depth at a spur dike. Based mainly on the field of observations, Claude C. Inglis(11) compared the maximum scour depths with those obtained by Lacey. Andru and J. Blench(13), after analyzing various laboratory and field data on scour at obstructions, concluded that the depth of local scour depends in discharge intensity and the size of bed material. Mushtaq Ahmed(6) conducted investigations on the behavior of spur dikes and drew some conclusions regarding the effect of various parameters on the maximum scour depth.

Much work has been done in regards to the effect of dikes near a bridge opening at Lehigh University. Professor J. B. Herbich's(9) valuable conclusions regarding the effect of the length of dike, shape, and the flow condition in scouring aspects are equally important.

More laboratory investigations have been conducted on problems related to scour at bridge piers. Emmett M. Laursen(2) has concluded that depth of scour for a given geometry of obstruction is dependent on the width of obstruction and the depth of flow when there is an appreciable sediment supply. Ksin-Kuan Liu(14) and M. M. Skinner(14) have given some qualitative results regarding scour at abutments. Carl F. Izzard and Joseph Bradley(6) reported the preliminary findings of an investigation of scour at bridge abutments. R. J. Garde(5), K. Subramanya and K. W. Nambudripad concluded that the maximum scour depth is affected significantly by the size of the sediment, flow condition and size and shape of dikes.

3. THE CURRENT PROGRAM

For the past few years research study in the control of scour at bridge abutments, with spur dikes has been conducted at the Hydraulics Division of Fritz Engineering Laboratory, Lehigh University. In the beginning it involved tests in a fixed-bed model study but later were also made on a movable bed model

Some interesting conclusions were also reached regarding shape, size and location of dikes for effective control of scour in the case of 90° abutments and fixed bed models. They are published in detail by the Institute of Research, Lehigh University(10).

The current program is conducted to get the idea of the effect of dikes on scouring by using different lengths of dikes and different spacing. The purpose of this investigation is the study of the characteristics of scour at the spur dikes in general, with the dikes of different lengths and having different spacings.

4. THEORETICAL APPROACH

4.1 MECHANISM OF SCOUR

Scour is basically a consequence of an inbalance between the rate of sediment transport out of an area and the rate of supply of sediment to that area. At a bridge crossing the area of vital importance is the immediate vicinity of the foundations of the abutments and the piers. The inbalance between the two rates arises from a variety of causes which are so complicated by themselves that they defy a coherent and simplified approach.

There are two kinds of channel constriction scour.

1. General Scour which is caused by a long constriction of flow establishing a new regime of flow, and
2. Local scour which is caused by a local constriction of flow due to abutment piers or dikes.

We shall confine ourselves to the latter.

Due to the complexity of the nature of the various factors involved affecting local scour, most of the studies so far are empirical.

Several investigators have proposed various empirical formulae for the depth of local scour. Some of these express the scour depth as a multiple of Lacey's regime depth D_L in the contracted section.

Lacey proposed the following relationship for computing the maximum scour depth at a contracted section, which he related to the regime flow depth.

$$D_L = 0.47 \left(\frac{Q}{f}\right)^{1/3}$$

in which

D_L is Lacey's regime depth for a straight reach

Q is the total discharge

f is Lacey's silt factor

With the help of Lacey's formula and his assumption that local scour is proportional to regime flow depth, Khosla proposed the following formula

$$D_s = 0.9K \left(\frac{Q^2}{f} \right)^{1/3}$$

in which

D_s is maximum scour measured from the water surface

Q is discharge per foot width

K is the factor depending on type of obstruction

Ahmed and Blench similarly relate the depth of maximum scour to a mean flow intensity, and to some extent on bed material. Laursen, on the other hand, concludes that with bed load movement continuing during the scouring process, the maximum local scour is independent of sediment size and flow obstruction. He concluded that the maximum scour depth below the stream bed may be four times the depth of general scour in case of an embankment extending to the edge of the main channel with neighboring scour holes overlapping, and as much as twelve times when the main channel is constricted with no overlap of adjacent scour holes.

A recent study by Liu, Chang and Skinner indicates that the effect of flow velocity on scour may be appreciable and that if the bed load is appreciable, the constriction ratio has no appreciable effect on scour depth; but if there is no bed load, the limiting scour is a function of constriction ratio.

4.2 DIMENSIONAL ANALYSIS

Consideration of the phenomenon of local scour with the aid of dimensional analysis may also prove helpful.

The following more important independent variables may be considered to effect the scour

h	depth of approach flow
V	velocity of approach flow
B	width of channel
W	representative fall velocity of bed material
ρ	density of water
μ	dynamic viscosity of water-sediment mixture
g	gravitational constant
d	opening ratio
θ	skew angle of dike
G	geometry of spur dike

So that D_s, the scour depth, can be related to these variables as follows:

$$D_s = f_1(h, V, B, W, \rho, \mu, G, d, \theta)$$

If h, V and ρ are selected as repeating variables the above equation may be converted into a group of dimensionless π -terms as follows, with the π -terms arranged in order of their importance.

$$\frac{D_s}{h} = f_2 \left(G, d, \theta, \frac{V^2}{gh}, \frac{B}{h}, \frac{W}{V}, \frac{Vh\rho}{\mu}\right)$$

But the magnitude of the task of determining the details of this relationship is rather enormous and the exact relationship can only be established by conducting numerous experiments in the laboratory which would be time consuming too.

5. MOVABLE BED STUDIES

5.1 DESCRIPTION OF EQUIPMENT

A short account of the various units of the testing equipment used for the study is given below.

A. Head Tank, Motor and Pump

An overhead tank supplies water to the testing tank by gravity. A constant head was maintained in this tank by an overflow channel leading directly to the sump. The pump used was a De Laval, Model 10/8, with a maximum 1750 rpm and a capacity of 1800 gpm against a head of 70 feet. This pump was driven by a 25 HP Westinghouse Model HF motor with a maximum of 1720 rpm.

B. Venturi meter

Located adjacent to the testing tank was an 8-inch by 5-inch Venturi meter which was connected with the head tank by an 8-inch iron pipe. It was calibrated to read

$$Q = 1.465\sqrt{\Delta H}$$

where

Q is the discharge of water in

ΔH is the differential height in manometer in feet of liquid

C. Testing Tank (Fig. 1)

The testing tank available for use was 35 feet long, 10 feet wide and 2 feet deep and served as a flood plane across which constriction could be placed. The tank was divided in two equal sections each 5 feet wide by means of a wooden plank wall. The purpose of which is to minimize the work of the testing of different spacings of dikes.

A recessed section was formed in the central 10-foot length by raising the floor of the tank by 5 inches on either side of this section. When a sand layer of 2-inch depth was spread on the floor this gave the test section a 7-inch deep sand layer which was sufficient to measure the anticipated scour.

A baffle made of wire gauge and filled with well graded stones was placed at the head of the tank so as to obtain a uniform flow across the width of the tank. That this served the purpose was testified by measurements of velocity in the preliminary testing of the previous studies. A tailgate at the downstream end of the tank regulated the water level in the tank.

D. Dikes

Different lengths of dikes with different spacing were tested. Dikes of 0'-10", 1'-6" and 2'-4" with spacing of 4'-6", 2'-3", 1'-1.5" and a single dike were tested in the two sections of the tanks. The dikes were made of wooden plank and were fixed to the base of the tank by means of another plank attached at the bottom and with weights on both sides.

6. METHOD OF TESTING

Before the commencement of the tests, several points had to be considered and settled regarding the procedure for the tests. Some of them were conditioned by the limitation of the study, others were established by previous studies here and elsewhere.

6.1 BED MATERIAL

The bed material used in the tank was a New Jersey medium sand with an average diameter of 0.30 mm. The grain size distribution curve of the sand is shown in Fig. 2.

6.2 RUNNING TIME FOR TESTS

It has been shown that the depth of scour caused by a contracted flow increases rapidly with time, though the rate of scour decreases rapidly as the depth increases. In Figs. 3 and 4 two curves are shown of scour depth plotted against time, one with the bed load supply in the scour hole and the other without it. After a certain period of time the increase in scour is so small that the scour depth may appear to have reached a limit.

It was reasonable to choose from the graphs a practical value of the running time for tests within which most of the scour took place. A value of six hours was chosen, since the increase in scour depth after this period was found to be negligible.

7. DESCRIPTION OF TESTS

Without any dikes in the two sections the test was carried out to check that the velocity in both the sections was the same. Before any test the sand bed in the tank was carefully leveled, first by a hand tool and then by a wooden board hung from a movable bridge over the tank. A point gauge which was calibrated to read up to 0.001-foot and which was attached to the bridge was used for leveling the bed and also for contouring the scour pattern.

In order to establish the flow slowly and gradually the tailgate end was first raised and then water in the tank was diverted slowly through the baffle. After the first flow of 0.8 c.f.s. was established the tailgate end was lowered and water level adjusted to 2 inches in the test.

Water was gradually stopped after six hours of run and then the scour pattern was contoured. After each test, several photographs of the scoured bed was taken and photo-mosaics prepared. The scour pattern and the effect of dikes in connection with various tests can be judged from Fig. 5 to Fig. 11.

The above procedure was common for all the tests. In all the tests it was observed that, as was proved by previous laboratory studies, the scour at first increased rapidly with time though with a with a rapidly decreasing rate. In fact most of the scour took place within the first 4 or 4 and 1/2 hours, after which the movement of the bed-material was so small that is seemed to pass into what Liu, Chang and Skinner describe as the second stage of scour-formation establishment of scour.

7.1 TEST NO. 1 (Fig. 5)

In the first test the dike lengths used was 1'-6" in both the sections and was placed in the middle of the tank. The main object of this test was to observe the velocity in both the sections and also the scour pattern. It was observed that the velocity is the same in both the sections and also the scour pattern obtained after six hours of flow was practically the same in both the sections. This proved that all the conditions in both the sections are the same. The entering velocity in the section was kept 0.482 ft./sec.

$$Q = V_1 \times A$$

$$= 0.482 \times 10 \times 2/12$$

$$= 0.8 \text{ c.f.s.}$$

Q at the section a-a at the dike

$$= 0.8 = V_2 (10 - 3) \times 2/12$$

$$V_2 = 0.69 \text{ ft./sec.}$$

and this velocity was kept for all the tests at the dike.

The procedure of the test is the same as explained previously. The scour pattern for this test is shown in Fig. 5.

7.2 TEST NO. 2

In this test dikes having lengths of 1'-6" were used. Three dikes were placed in one section and five dikes in the other section.

The velocity at the dike was kept as 0.69 f.p.s and accordingly the discharge was 0.8 c.f.s. After running the test for six hours the scour pattern was made by contours of equal scouring. The photographs of the scour pattern were taken. The scour pattern is shown in Fig. 6. From the scour pattern it is seen that the effect of scouring at dikes other than the first one is not much. However, the number of dikes affects the scouring inclination and the depth of maximum scouring at the first dike.

7.3 TEST NO. 3

In this test dikes having lengths of 1'-6" were used. One dike was placed in one section and nine dikes were placed in the other section. The spacing of the dikes are shown in Fig. 12. Velocity was 0.69 f.p.s and the scour pattern was obtained which is shown in Fig. 7. There was not effective scouring at the dikes other than the first one.

7.4 TEST NO. 4

In this test dikes having lengths of 0'-10" were used. Three dikes were placed in one section and five dikes in the other section.

The new discharge was calculated as the same velocity as in the previous test was to be maintained

$$Q = 0.69\ (10 - 1.66) \times 2/12$$
$$= 0.956 \text{ c.f.s.}$$

After running the test for six hours the scour patterns were obtained. These are shown in Fig. 8.

7.5 TEST NO. 5

In this test dikes having lengths of 0'-10" were used. One dike was placed in one section and nine dikes were placed in the other section. Discharge was kept 0.956 c.f.s. to have 0.69f.ps velocity at the dike. As before the scour pattern was obtained after running the test for six hours. The scour pattern is shown in Fig. 9.

7.6 TEST NO. 6

In this test dikes having lengths of 2'-4" were used. Three dikes were placed in one section and five dikes in the other section.

The discharge was calculated as the same velocity as in previous test was to be maintained

$$Q = 0.69\ (10 - 4.66) \times 2/12$$
$$= 0.615 \text{ c.f.s.}$$

7.7 TEST NO. 7

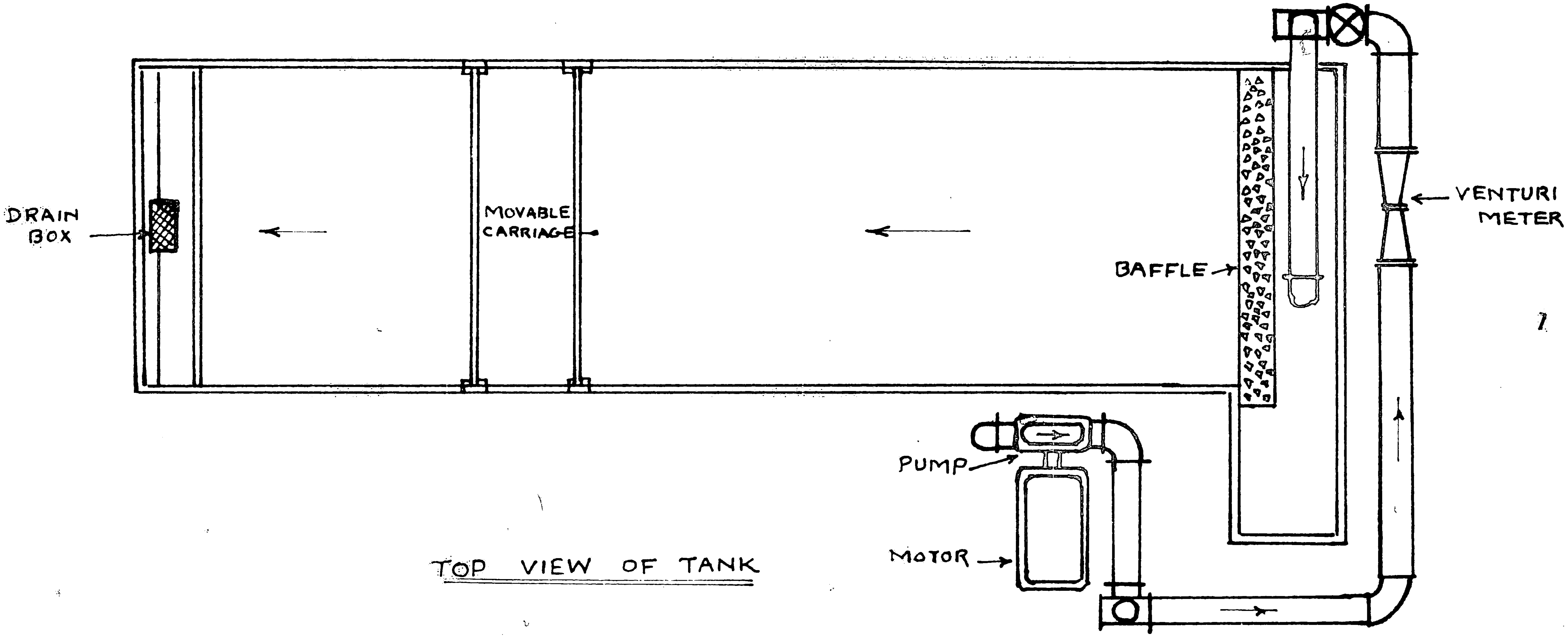
In this test dikes having lengths of 2'-4" were used. One dike was placed in one section and nine dikes were placed in the other section. Discharge was kept 0.615 c.f.s. to have 0.69 f.p.s. velocity at the dike. As before the scour pattern was obtained after running the test for six hours. The scour pattern is shown in Fig. 11.

8. CONCLUSIONS

The effect of the dike was observed with a constant velocity through the openings by varying the lengths and spacings of the dikes. The scour at the first dike was obtained from the scour patterns and the area of maximum scouring was measured in sq. inches for all the tests and was plotted against the number of dikes (Fig. 17). It was found that the area of maximum scouring at the first dike increases with the increase in number of dikes put in a section. Also from the plot it was observed that the maximum area of scouring at the first dike in each test increased with the increase in the length of the dikes.

The maximum scouring at the first dike in each test took place at some inclination with the dike and this inclination was also measured from the scour patterns. A plot was made of inclination of scouring versus the number of dikes (Fig. 16) and it was observed that the inclination of the maximum scouring with the first dike decreased with the increase in the number of dikes.

For test No. 9 the Froude numbers at six sections for distance 3, 6, 9, 12, 15, 18, 21, 24, 27 and 30 inches from the dike end were calculated and a plot of Froude number versus a nondimensionalized term $\frac{D + d_s}{D}$ was made (Fig. 18). Where D is the depth of water, d_s is the depth of scouring and it was observed that the Froude number increases with the decrease in the ratio $\frac{D + d_s}{D}$.



TOP VIEW OF TANK

Fig. 1

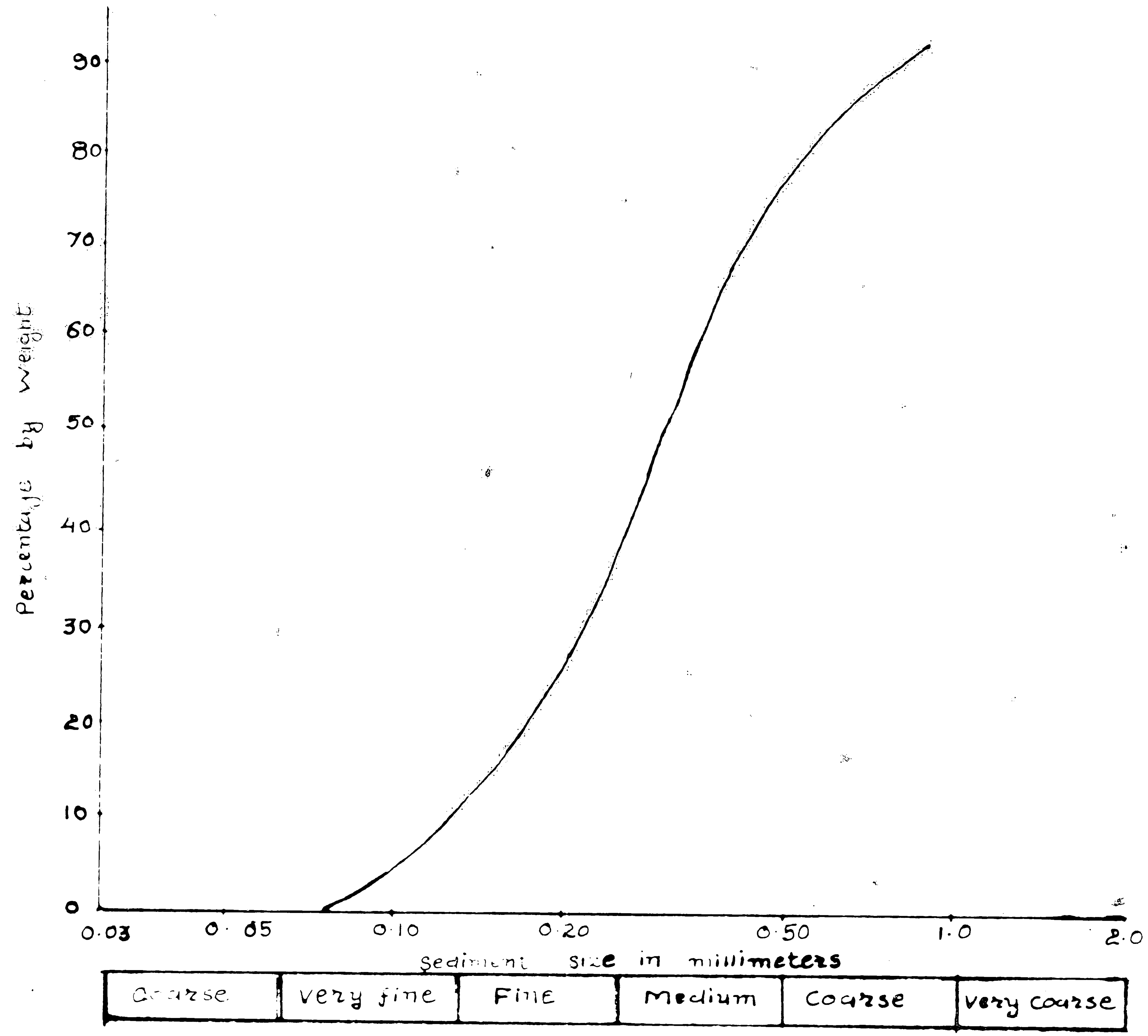


Fig 2 GRAIN SIZE DISTRIBUTION CURVE

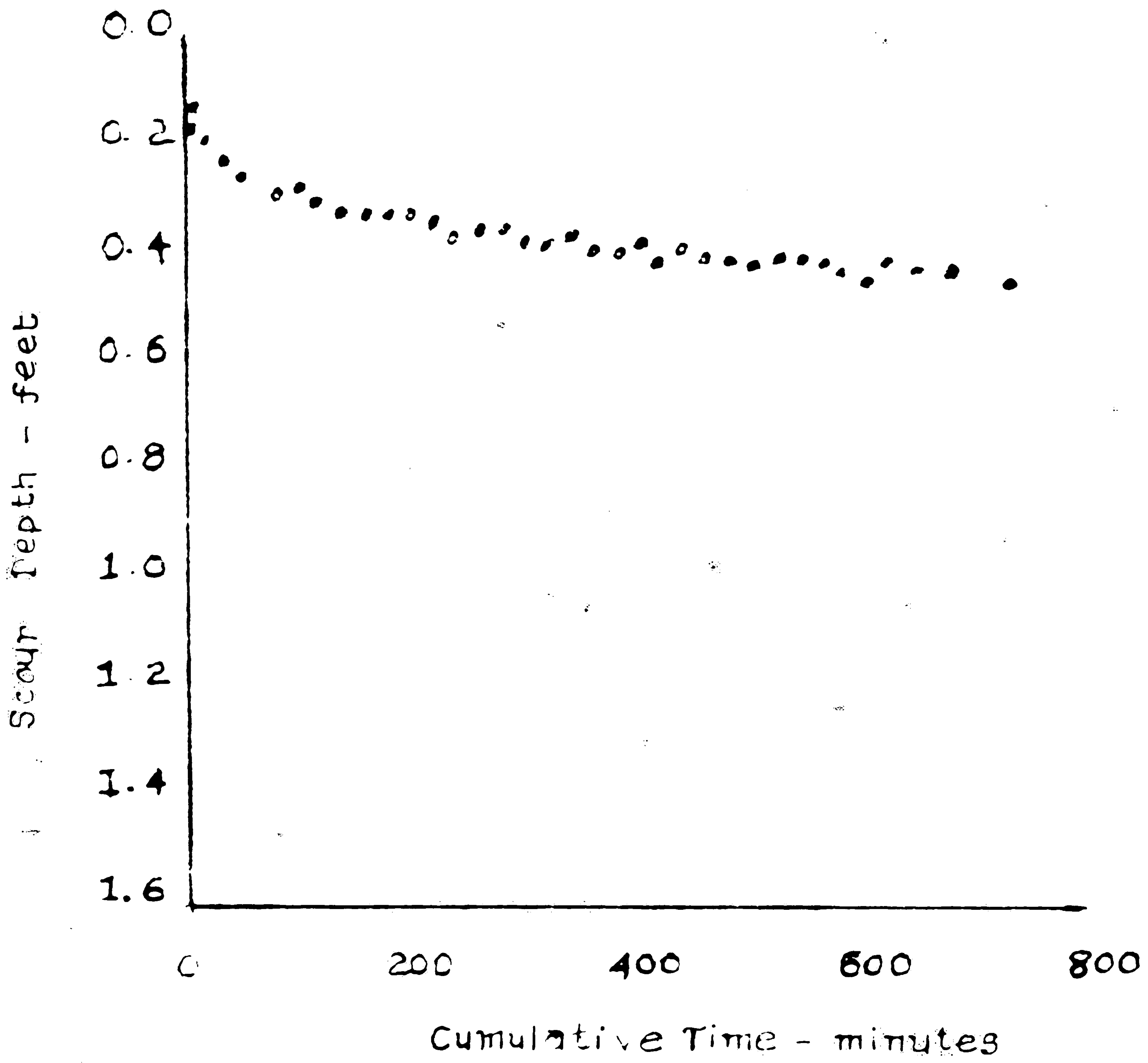


FIG.3. NO SEDIMENT SUPPLY

(Figure from Reference)

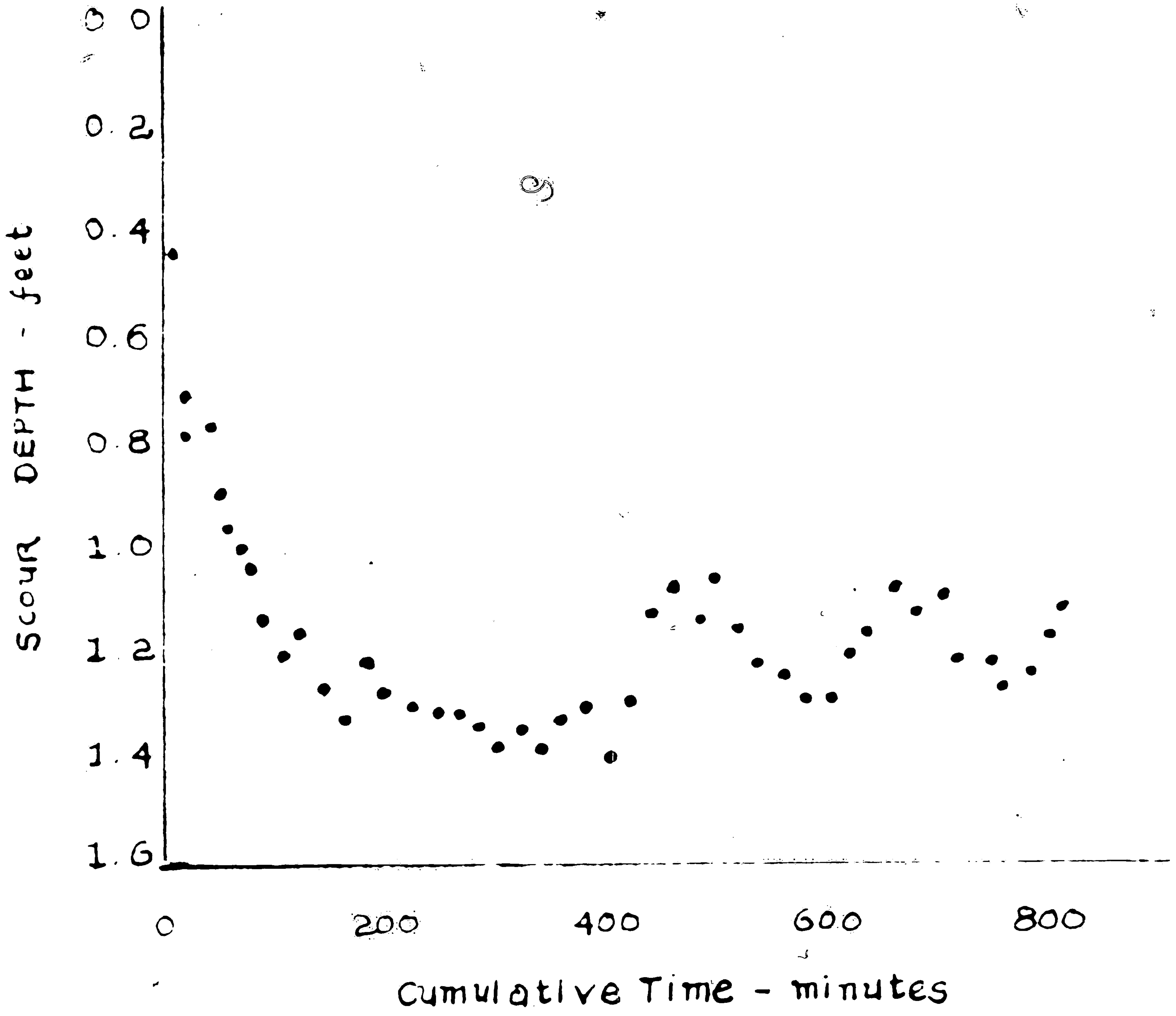
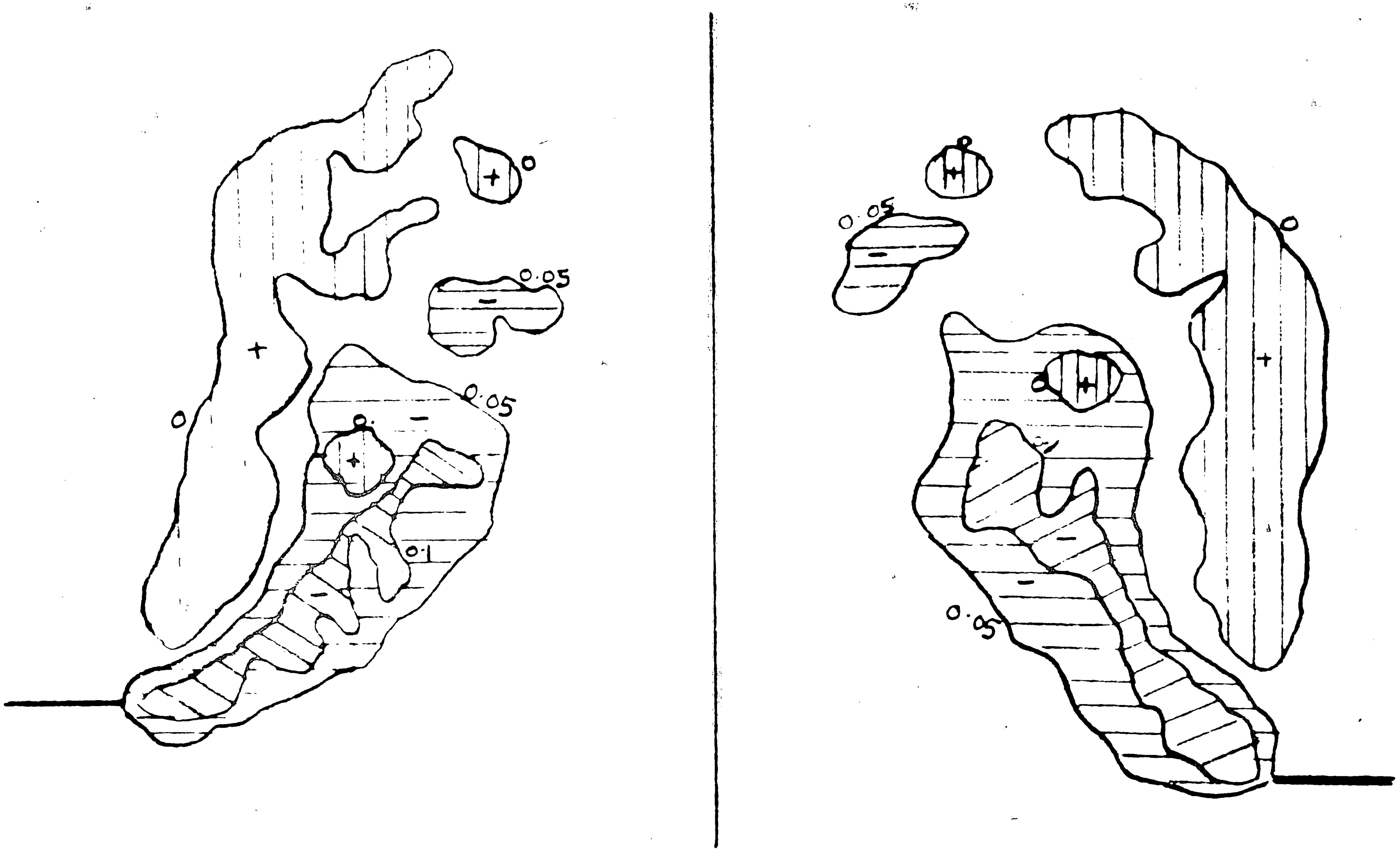
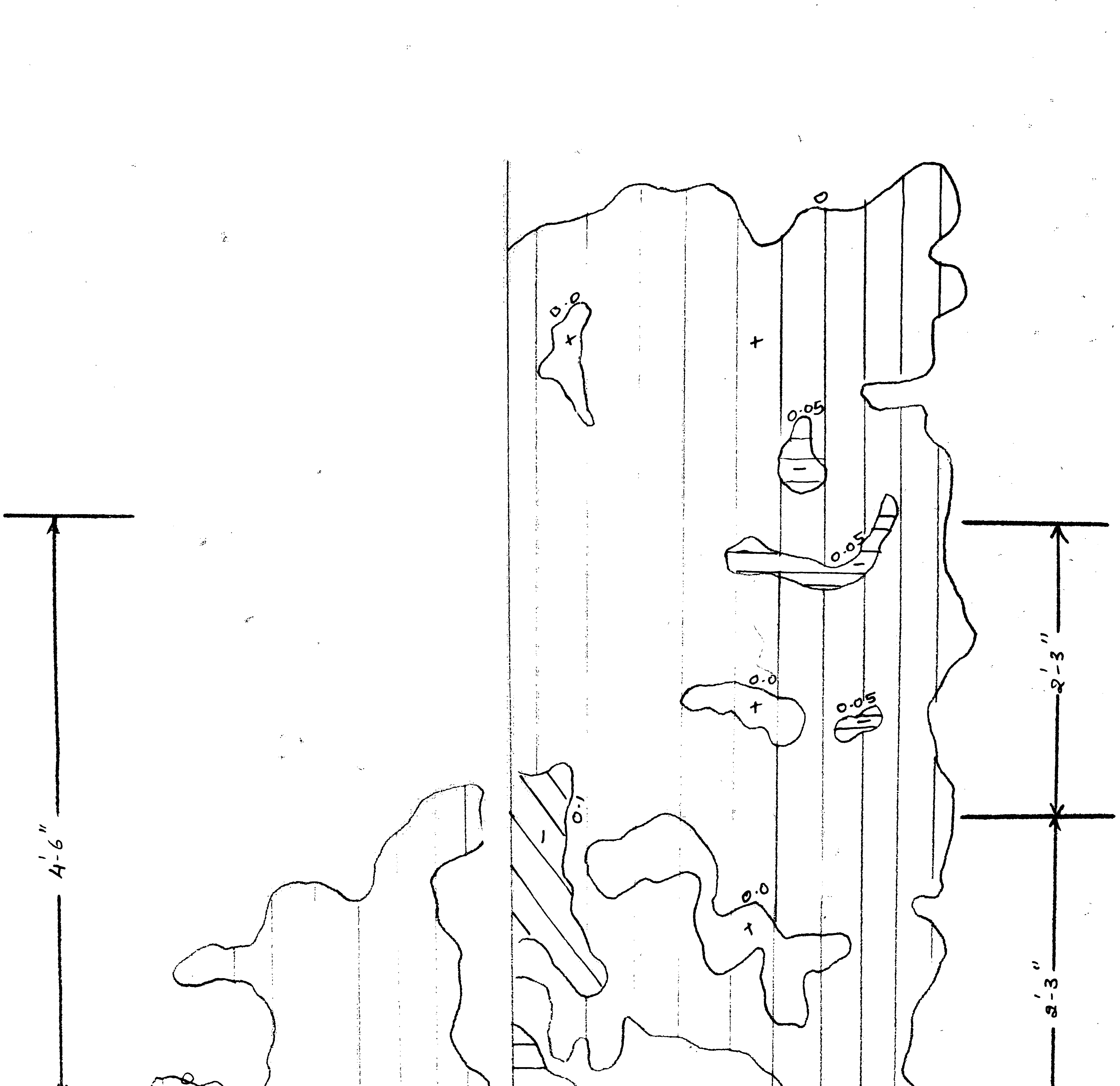


Fig. 4. With sediment supply

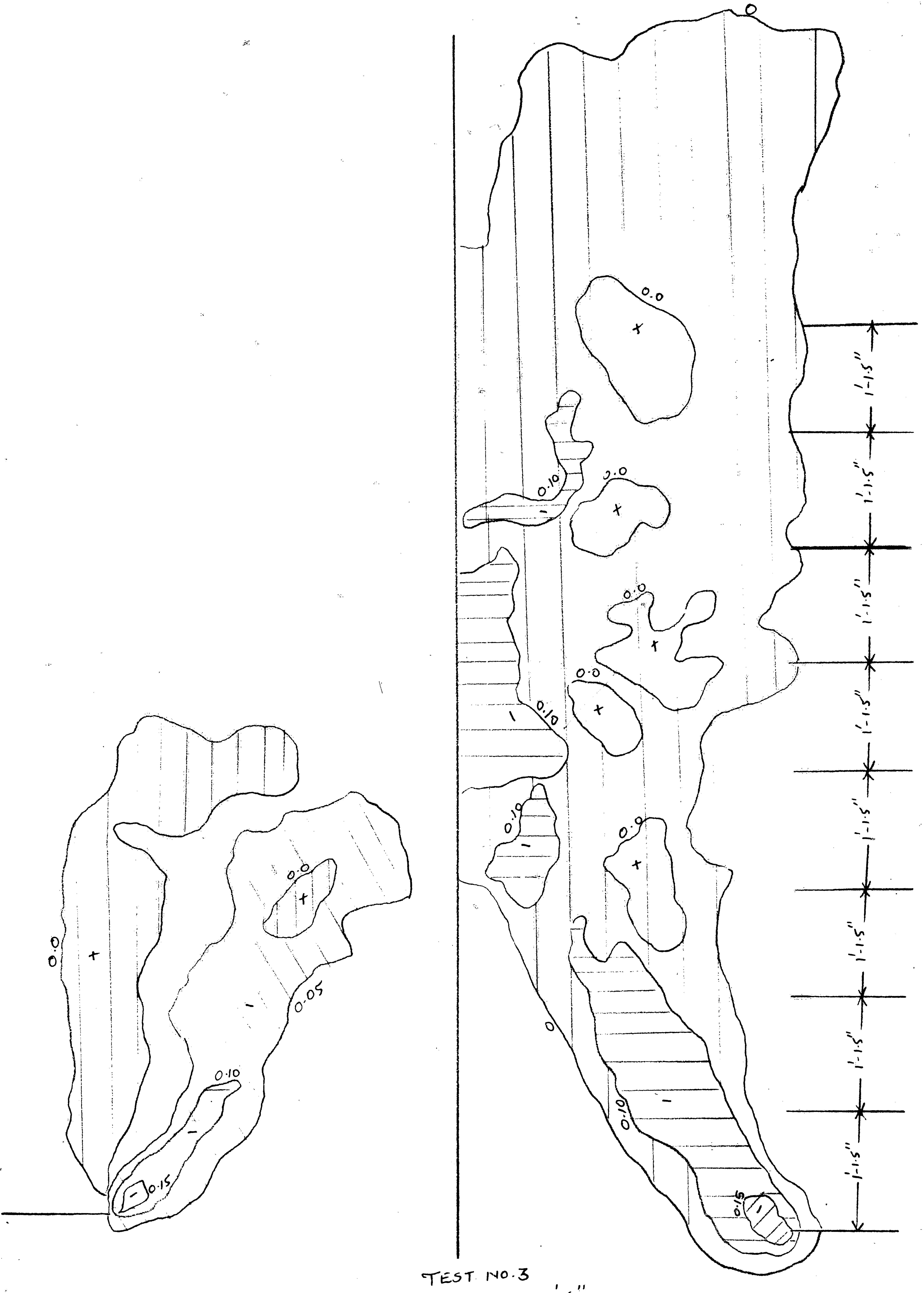
(Fig. taken from reference)



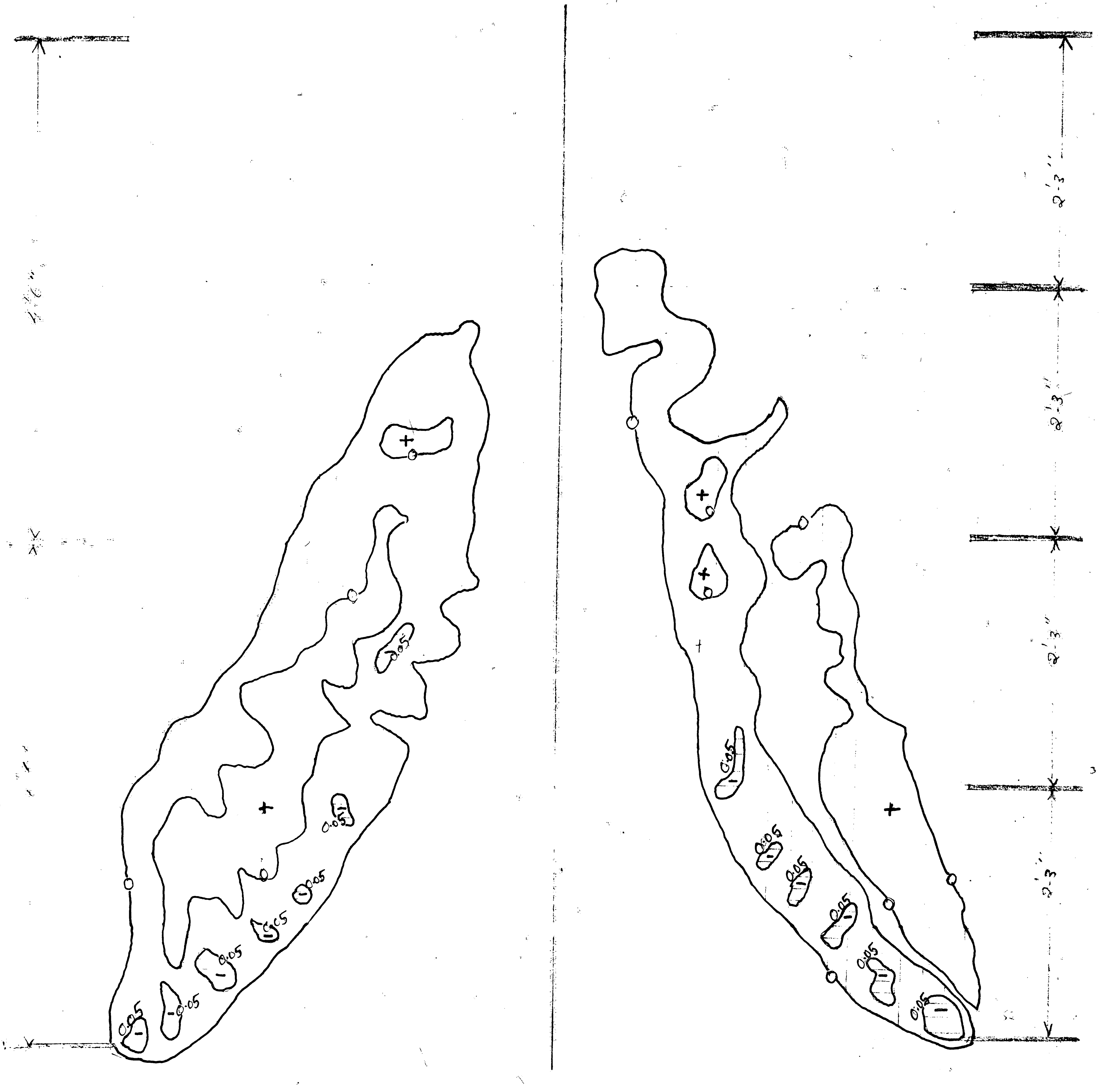
TEST·NO1
Dike Length 1'-6"
Fig. 5



TEST. NO. 2
Dike length 1'-6"
Fig. 6



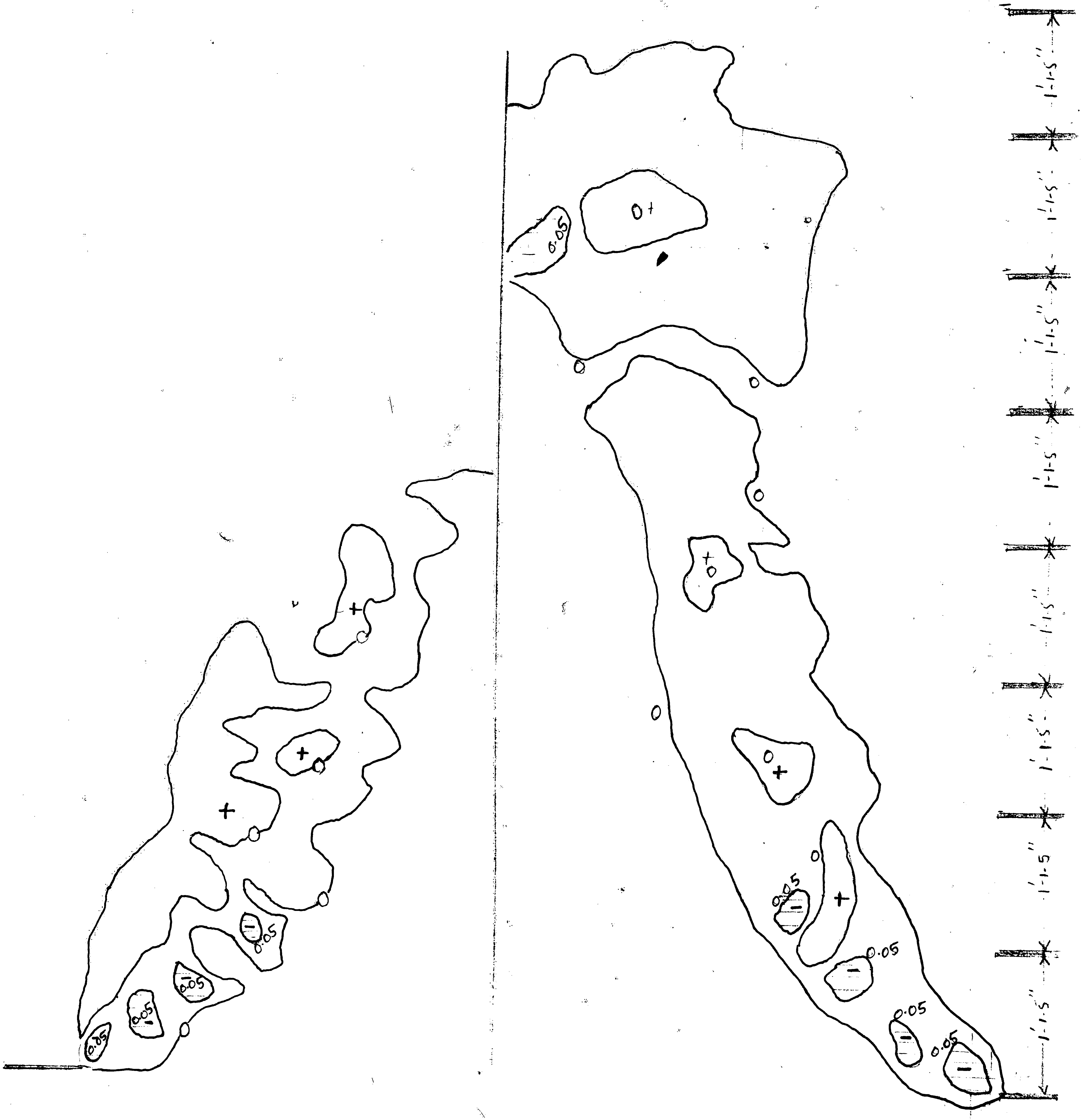
TEST NO. 3
Dike length 1'-6''
Fig. 7



Test- No 4

DIKE LENGTH 0'-10"

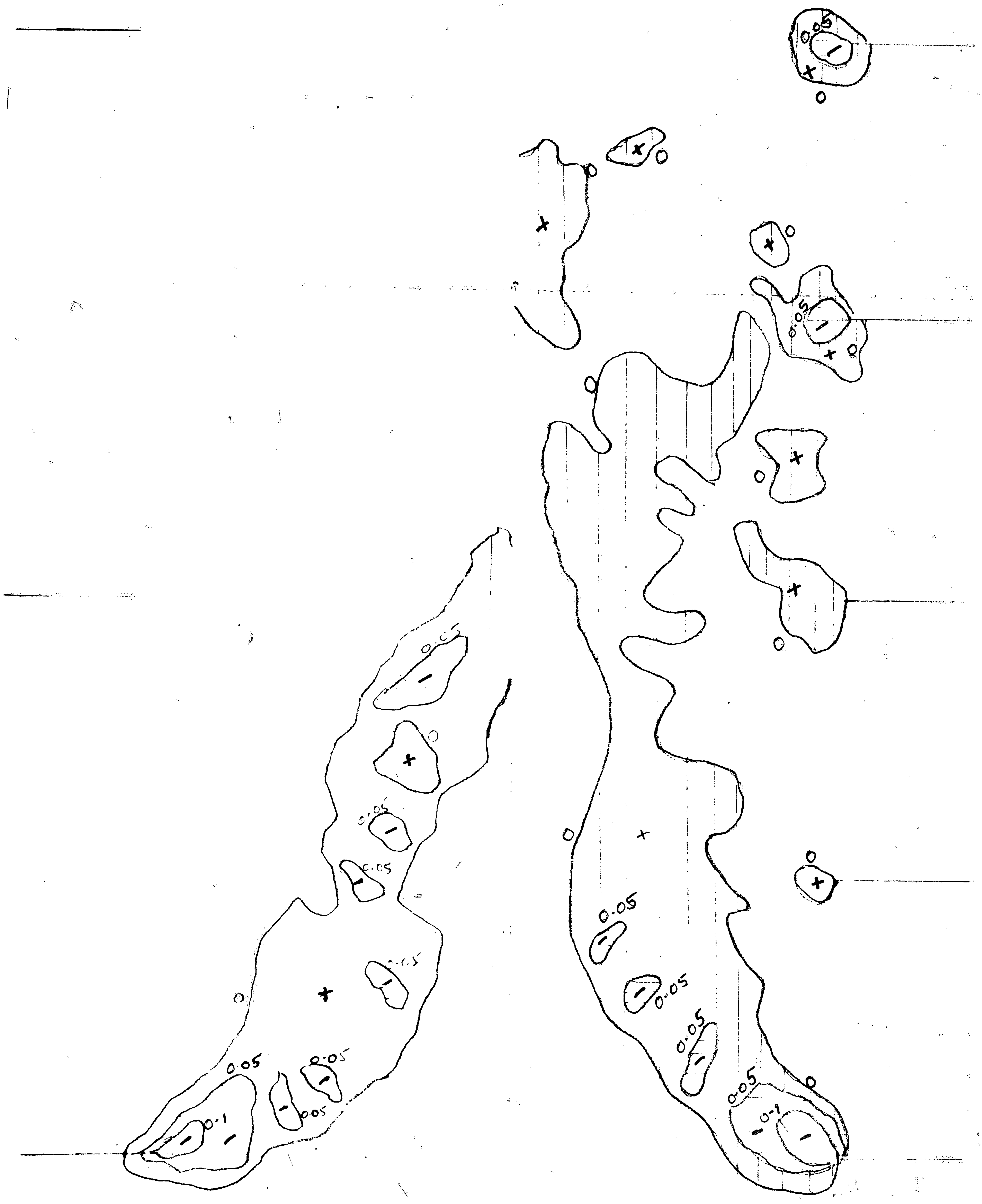
Fig 1108



Test no 5

Dike Length 6'-10"

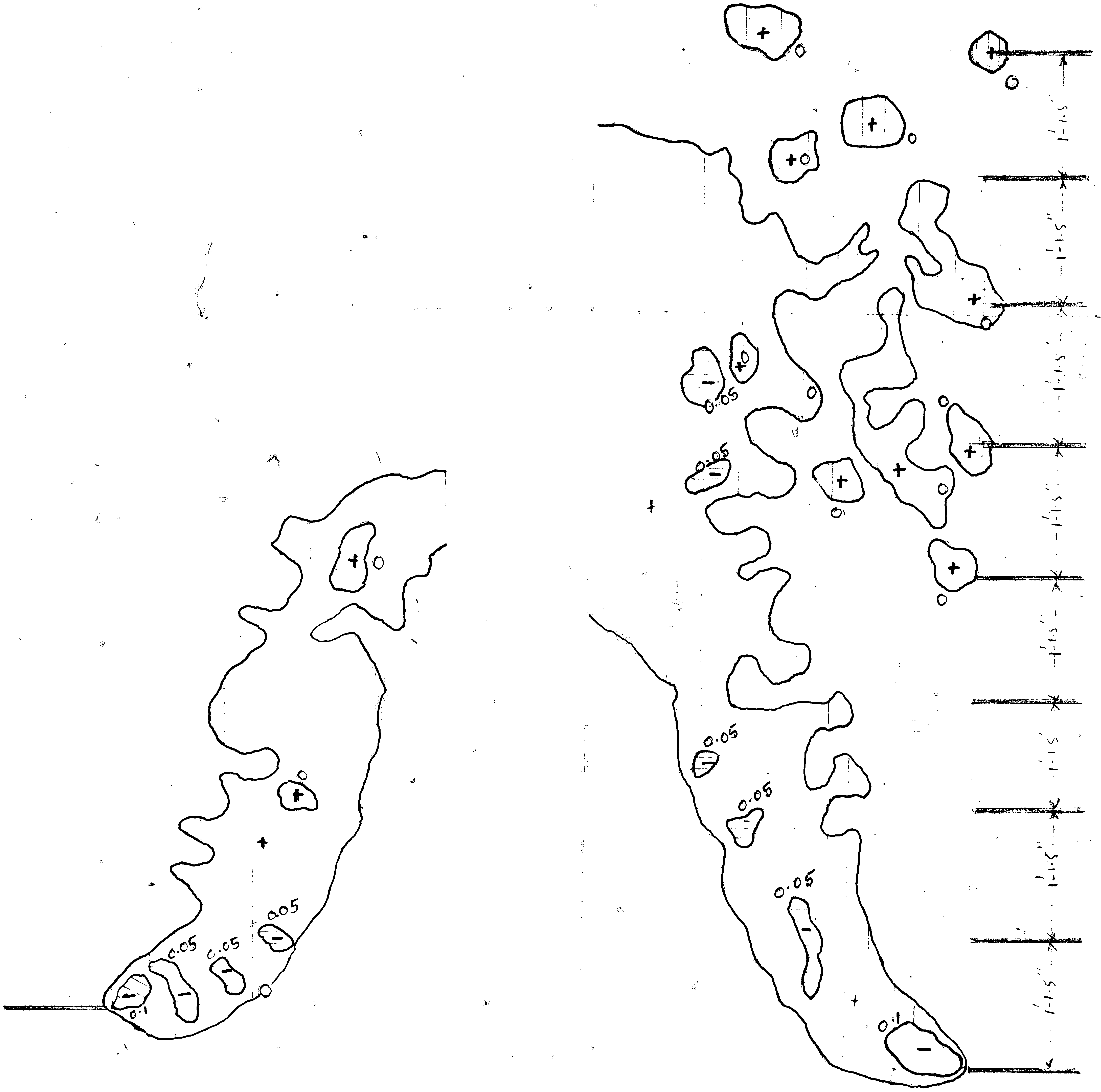
Fig no 9



Test No G

Dike length 2'-4"

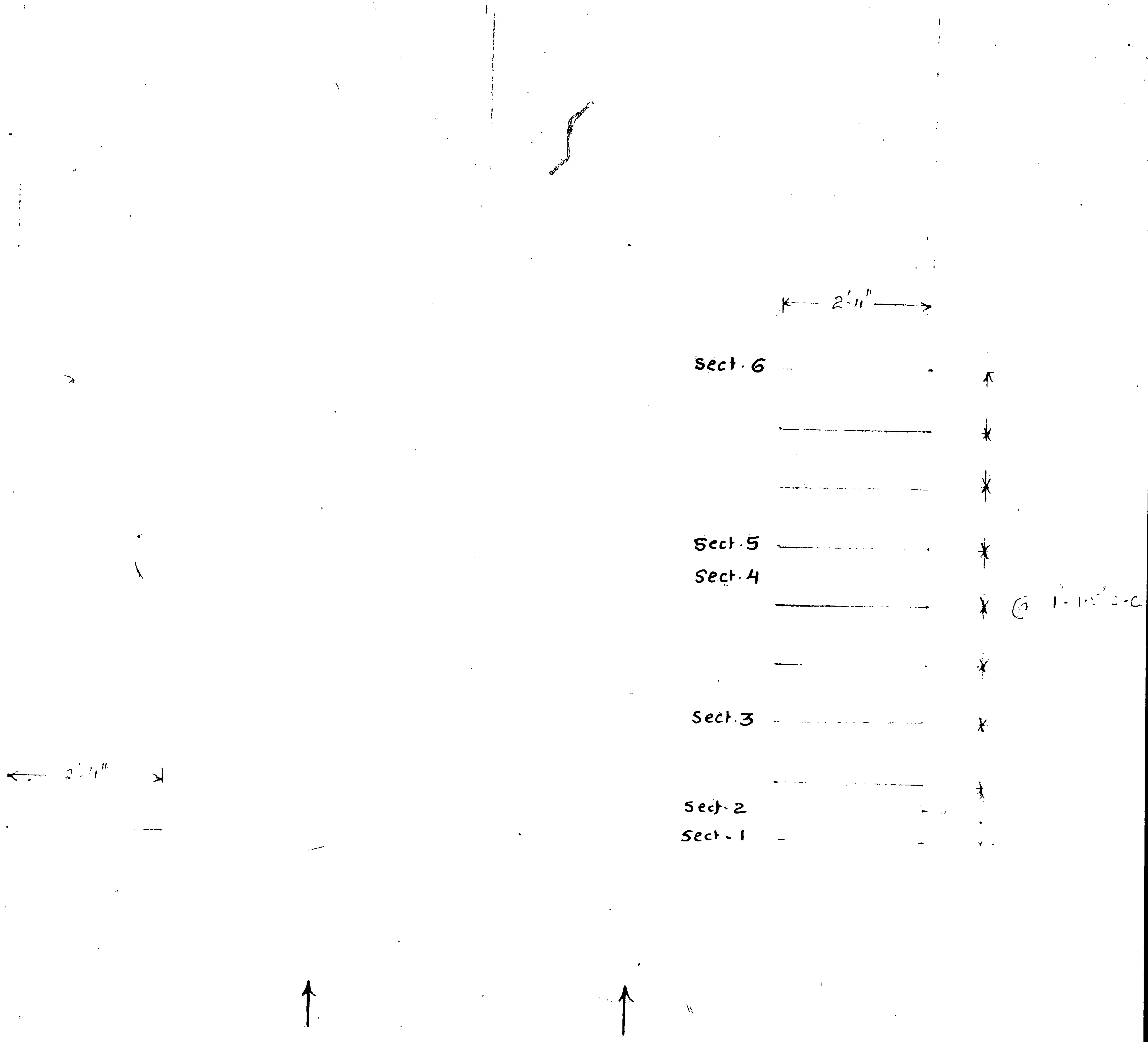
Fig No 10



Test No 7

Dike length 2'-4"

Fig. No 11



Test No 7.

Particulars for Different Sections Where the Froude Number calculated

fig No-12

Section-1

	0	3	6	9	12	15	18	21	24	27	30	32	
Depth in inches	3.2	2.8	2.2	2	2	2	2	2	2	2	2	2	→ Depth in inches
Velocity in f.p.s	0.65	0.75	0.7	0.7	0.65	0.65	0.65	0.65	0.6	0.6	0.6	0.6	→ Velocity in f.p.s

→ Distence in inches from the line

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	
Average depth	3.0	2.5	2.1	2	2	2	2	2	2	2	2	→ Average depth in inches
Area	0.0645	0.0520	0.0434	0.0416	0.0416	0.0416	0.0416	0.0416	0.0416	0.0416	0.0278	→ Area in sq ft
Average velocity	0.70	0.725	0.70	0.675	0.65	0.65	0.65	0.625	0.60	0.60	0.60	→ Average Velocity in f.p.s
Discharge	0.0461	0.0377	0.0304	0.0281	0.0270	0.0270	0.0270	0.026	0.0248	0.0248	0.0248	→ Discharge in cfs
Froude number	0.222	0.274	0.288	0.302	0.280	0.280	0.280	0.280	0.280	0.255	0.255	→ Froude number

Total Q = 0.31

Section-2

	0												
Depth	1.26	2	2	2.32	2.5	2.8	2.3	2	2	2	2	2	→ Depth in inches
Velocity	0.6	0.65	0.7	0.7	0.75	0.65	0.70	0.65	0.6	0.6	0.6	0.6	→ Velocity

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	
Average depth	1.63	2.0	2.16	2.41	2.65	2.55	2.15	2	2	2	2	→ Average depth
Area	0.01339	0.0416	0.0448	0.050	0.055	0.053	0.0446	0.0416	0.0416	0.0416	0.0278	→ Area in sq ft
Average velocity	0.625	0.675	0.70	0.725	0.70	0.70	0.675	0.625	0.60	0.60	0.60	→ Average Velocity
Discharge	0.0084	0.0287	0.0312	0.0362	0.0413	0.0384	0.0301	0.0260	0.0248	0.0248	0.0248	→ Discharge Q
Froude number	0.324	0.250	0.302	0.291	0.210	0.235	0.282	0.280	0.258	0.255	0.258	→ Froude Number

Discharge Q = 0.3069

figure 13

Section - 3

0	3		[illegible]	12	15	18	21	24	27	30	32	→ Di[illegible] in[illegible] f[illegible]
[illegible]	2.0	1.38	1.6	2.0	2.18	2.26	2.80	2.20	2.0	2.0	2.0	→ Depth in inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		
1.15	1.69	1.4[illegible]	1.8[illegible]	2.09	2.22	2.53	2.5[illegible]	2.10	2.[illegible]	2.[illegible]		→ Average depth
0.0465	[illegible]	0.031[illegible]	[illegible]0374	0.0439	0.04013	[illegible]352[illegible]	0.0521	0.0436	0.0416	0.0416		→ Area in sq ft
0.65	0.75	0.65	0.70	0.75	0.65	0.7	0.65	0.6	0.6	0.6	0.6	→ Velocity in f.P.S
0.65	0.5	0.675	[illegible]725	0.70	0.675	[illegible]675	0.625	0.6[illegible]	0.6[illegible]	[illegible]		→ Average Velocity
[illegible]264	0.0228	0.0210	0.0271	0.0326	0.0335	0.0354	0.033[illegible]	0.025	0.025	0.0116		→ Discharge in cfs
0.280	0.280	0.336	0.33[illegible]	0.323	0.289	0.2[illegible]5	0.237	0.2[illegible]7	0.25[illegible]	0.258		→ F[illegible]

Q = 0.3021

Section - 4

2	2	2.13	2	1.85	2.27	2.16	1.87	1.6	2.13	2.42	2.2	--> Depth in inches.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		
2	2.0[illegible]	2.0[illegible]	1.97	2.0[illegible]	2.22	[illegible]	1.74	1.[illegible]	2.27	2.31		→ Average depth
0.0416	0.042[illegible]	0.042[illegible]	[illegible]041[illegible]	0.042[illegible]	0.046[illegible]	0.0417	0.0361	0.0383	[illegible]411	[illegible]43		→ Area in sq ft
0.65	0.6	0.6	0.6	0.7	0.65	0.65	0.7	0.75	0.7	0.60	0.6	→ Velocity in f P S
0.6	0.6	[illegible]6	0.65	[illegible]675	0.625	0.675	0.725	0.725	0.65	0.60		→ Average Velocity
[illegible]	[illegible]7	0.0257	0.027[illegible]	0.03[illegible]	[illegible]311	0.0282	0.0262	0.0282	0.032	0.03		→ Discharge in cfs
0.28	[illegible]25[illegible]	[illegible]2[illegible]1	[illegible]25[illegible]	[illegible]31[illegible]	[illegible]2[illegible]2	0.264	[illegible]312	0.362	0.293	0.236		→ F[illegible] Number

Q = 0.3058

fig no 14

Section - 5

Distance in inches from [illegible]	0	3	6	9	12	15	18	21	24	27	30	32
Depth in inches	2.1	2.0	1.8	2.2	1.83	2.0	1.78	2.18	2.27	2.84	2.6	2.8
Velocity in fps	0.6	0.6	0.7	0.65	0.7	0.75	0.75	0.65	0.65	0.6	0.6	0.6

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Average depth	2.05	1.90	2.0	2.02	1.91	1.89	1.98	2.22	2.55	2.72	2.7
Area in sq ft	0.0420	0.0315	0.0416	0.0417	0.0[illegible]	0.0313	0.0411	0.0462	0.0536	0.0565	0.0375
Average Velocity	0.6	0.65	0.675	0.675	0.725	0.75	0.70	0.65	0.625	0.6	0.6
Disch in cfs	0.0256	0.0247	0.0261	0.02[illegible]	0.0288	0.0215	0.0288	0.030	0.0332	0.0336	[illegible]
Froude Number	0.252	0.258	0.315	0.267	0.316	0.323	0.343	0.267	0.296	0.218	0.226

Q = 0.3101

Section - 6

Depth in inches	2.2	2.4	2.18	2.0	1.76	2.4	2.8	1.6	1.78	2.0	2.18	2.0
Velocity in fps	0.6	0.6	0.7	0.65	0.65	0.65	0.65	0.65	0.75	0.70	0.6	0.6

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Average depth	2.3	2.24	2.1	1.88	2.18	2.6	2.2	1.61	1.89	2.09	2.09
Area in sq ft	0.0476	0.0475	0.0434	0.0411	0.0453	0.054	0.0456	0.0358	0.0392	0.0434	0.0434
Average Velocity	0.6	0.65	0.675	0.625	0.65	0.65	0.65	0.7	0.725	0.65	0.6
Disch in cfs	0.0284	0.0285	0.0271	0.026	0.0214	0.035	0.0276	0.024	0.0283	0.028	0.026
Froude Number	0.267	0.230	0.2[illegible]	0.2[illegible]	0.243	0.256	0.237	0.314	0.343	0.302	0.248

Q = 0.3101

figure 15

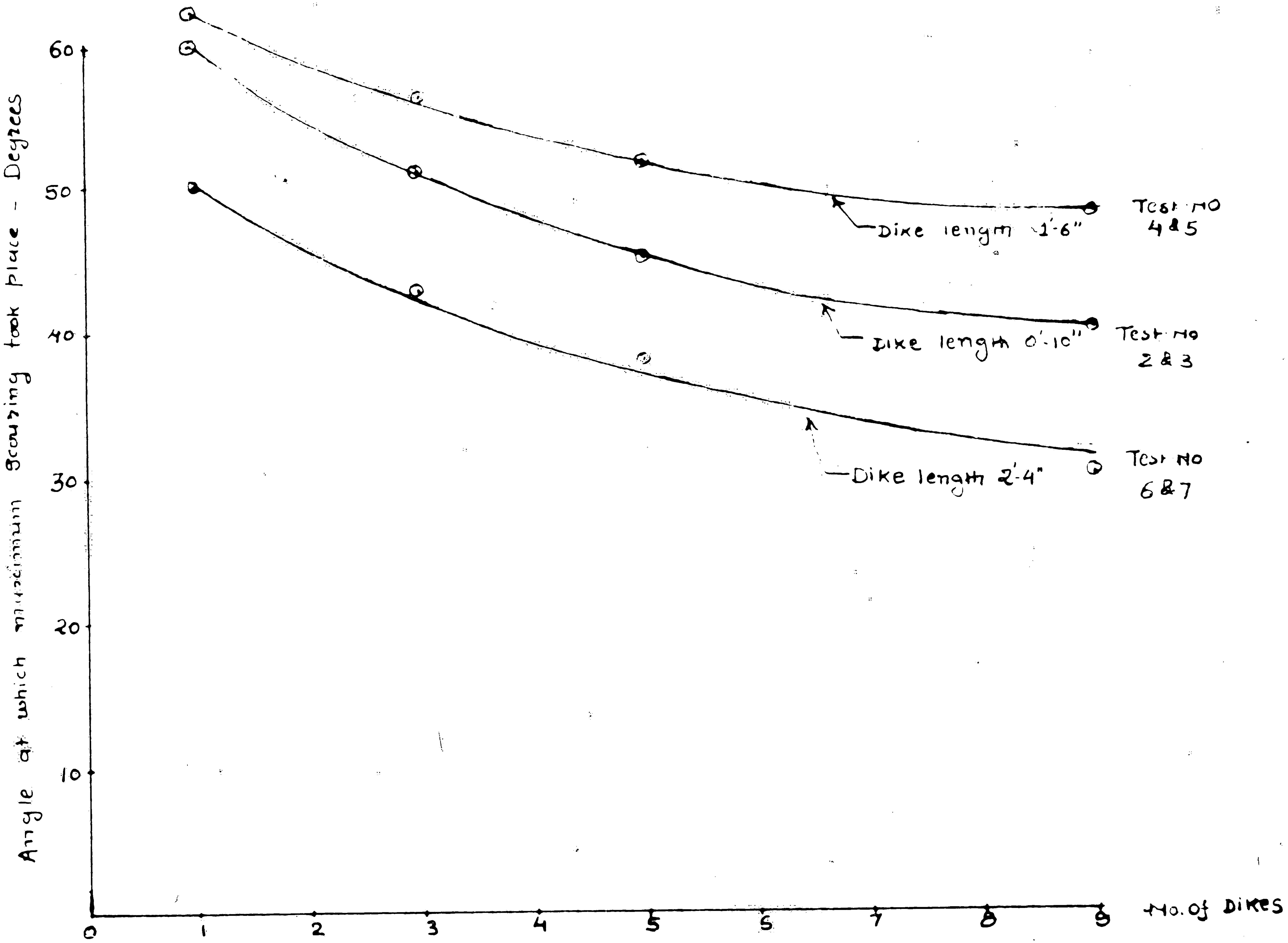

Angle at which maximum scouring took place - Degrees
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
No. of Dikes
Dike length 1'-6"
Test No 4 & 5
Dike length 0'-10"
Test No 2 & 3
Dike length 2'-4"
Test No 6 & 7

Fig. 16

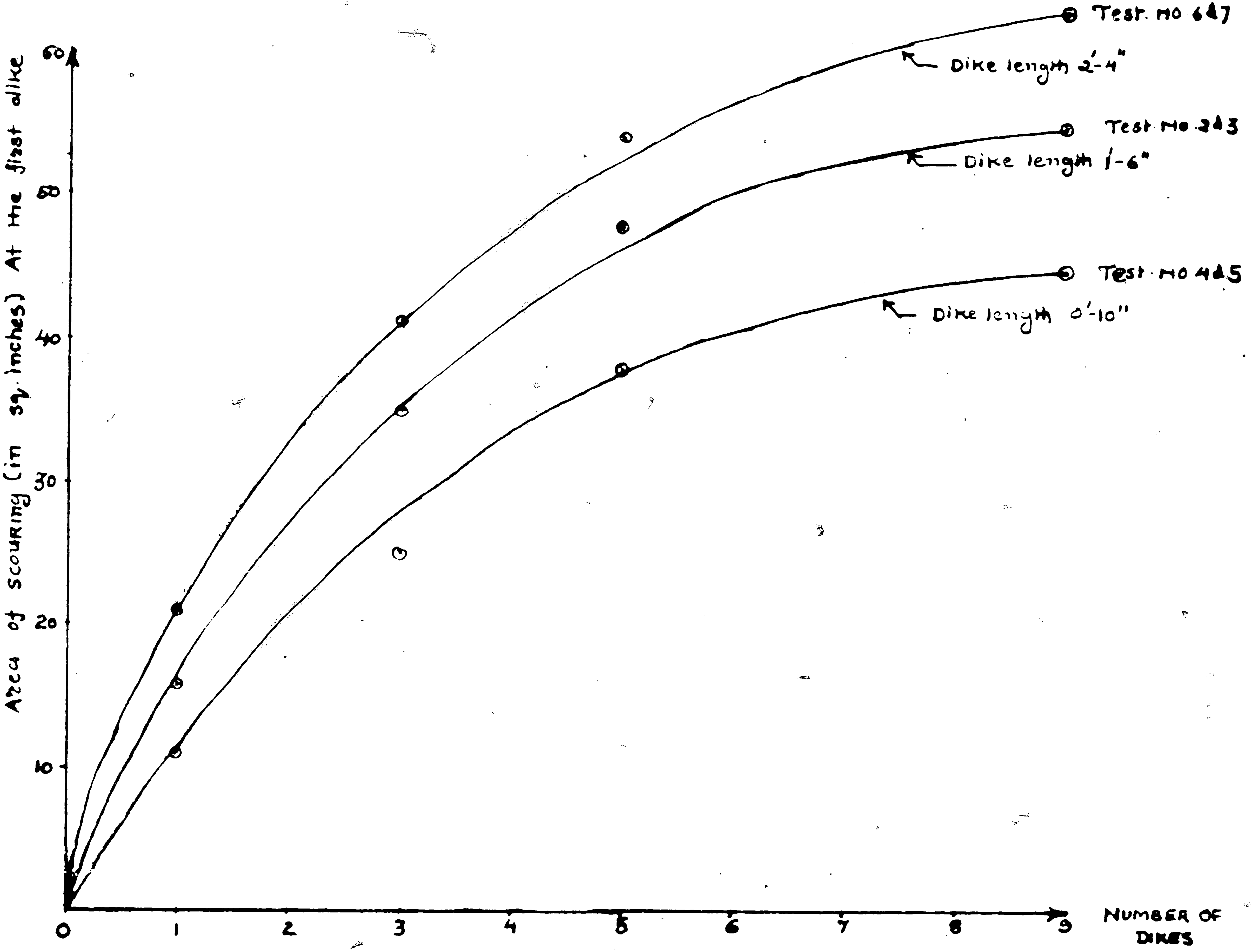
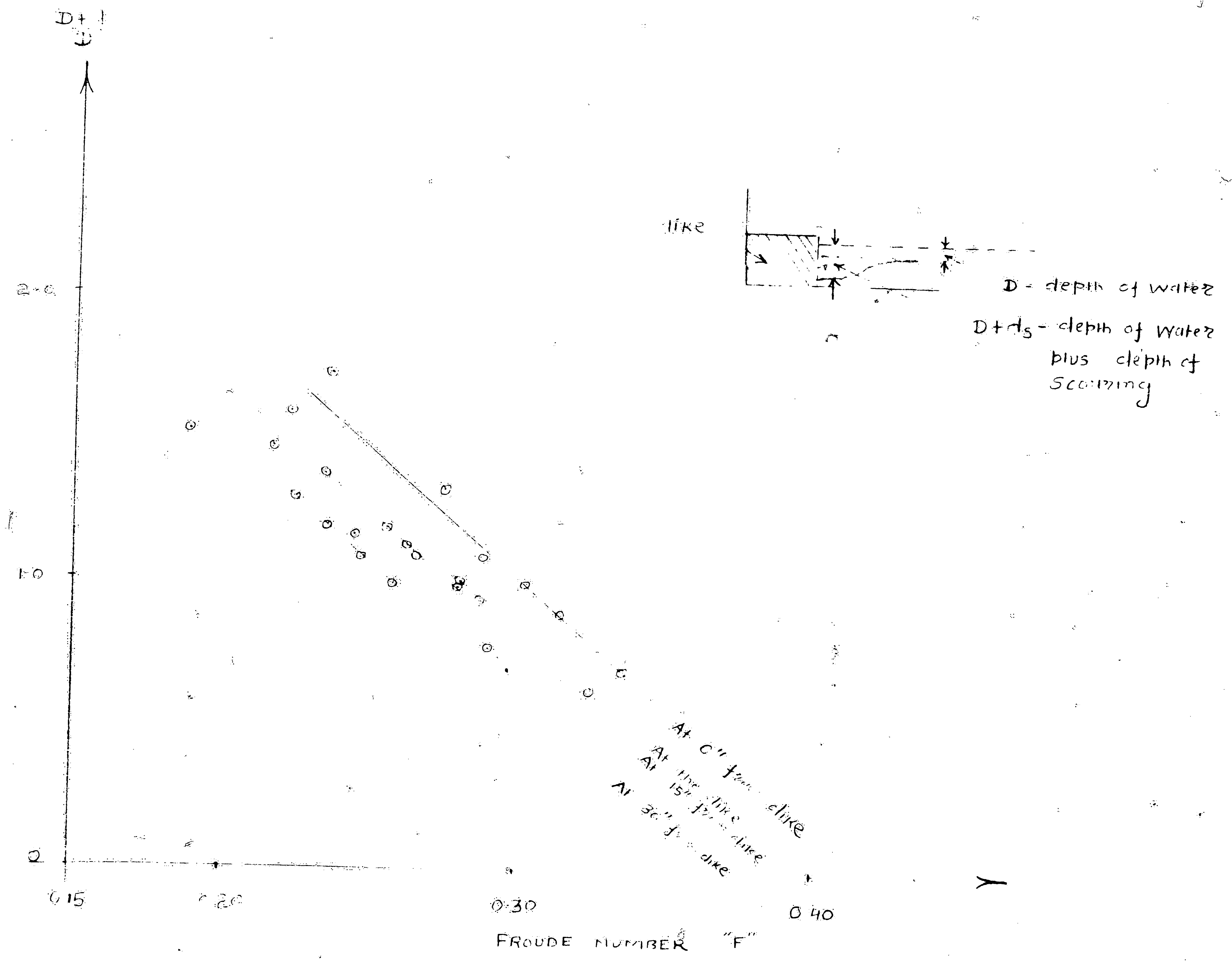

Area of scouring (in sq. inches) At the first dike
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
NUMBER OF DIKES
Test. NO 6 & 7
Dike length 2'-4"
Test. NO 2 & 3
Dike length 1'-6"
Test. NO 4 & 5
Dike length 0'-10"

Fig. NO 17

Fig. no. 18


D + ds / D
2.0
1.0
0
0.15
0.20
0.30
0.40
FROUDE NUMBER "F"
At 6" from dike
At the dike
At 15" from dike
At 30" from dike
dike
D - depth of water
D + ds - depth of water plus depth of scouring

REFERENCES

1. FLOW THROUGH DIVERGING OPEN CHANNEL TRANSITIONS,
   U. S. Department of Agriculture

2. Laursen, E. M. and Toch, A.
   SCOUR AROUND BRIDGE PIERS AND ABUTMENTS,
   Iowa High Research Board Bulletin No. 4, 1956

3. Posey, C. J.
   WHY BRIDGES FAIL IN FLOODS,
   Civil Engineering, February 1949

4. Carter, R. W.
   HIGHWAY HYDRAULICS,
   Proceedings of the Fourth Annual Georgia Highway
   Conference, February 1955

5. Garde, R. J., Subramanya, K. and Mambridripad, K. D.
   STUDY OF SCOUR AROUND SPUR DIKES,
   Proceedings of ASCE, November 1961

6. Ahmed, M.
   EXPERIMENTS ON DESIGN AND BEHAVIOR OF SPUR DIKES,
   Proceedings I. A. H. R., Minnesota, 1953

7. Moulton, L. K., Beicher, C. and Butler, B. E.
   REPORT ON INVESTIGATION OF SCOUR AT BRIDGES CAUSED
   BY FLOODS,
   Highway Research Abstracts, Vol. 27, No. 8, September
   1957

8. Karaki, S. S.
   HYDRAULIC MODEL STUDY OF SPUR DIKES FOR HIGHWAY BRIDGE
   OPENINGS,
   Civil Engineering Section, Colorado State University
   Report No. CER 59 SSK 36, September 1959

REFERENCES (continued)

9. Herbich, J. B.
THE EFFECT OF SPUR DIKES ON FLOOD FLOWS THROUGH BRIDGE CONSTRICTIONS,
Paper presented at 1961 Convention of ASCE,
Boston, Mass., October 1960

10. Kabal, J. C.
DETERMINATION OF THE LENGTH OF SPUR DIKES FOR FLOOD FLOWS THROUGH HIGHWAY BRIDGE ABUTMENTS,
Fritz Engineering Laboratory Report, July 1959

11. Inglis, C. C.
THE BEHAVIOR AND CONTROL OF RIVERS AND CANALS WITH THE AID OF MODELS,
Research Publication No. 13, Part II, CININRS, India

12. Karaki, S. S.
LABORATORY STUDY OF SPUR DIKES FOR HIGHWAY BRIDGE PROTECTION,
Paper presented at 39th meeting of Highway Research
Board, January 1960

13. Blench, J.
REGIME BEHAVIOR OF CANALS AND RIVERS,
Butterworth's Scientific Publication, London, 1957

14. Liu, Chang, Skinner
THE EFFECT OF BRIDGE CONSTRICTION ON SCOUR AND BACK WATER,
Publication of Civil Engineering Section, Colorado
University Report No. CER 60 HWL 22, February 1961

VITA

The author was born as the third child of Mr. and Mrs. R. V. Joshi on September 25, 1936 in Gandevi, India.

After high school graduation at the local school he attended S. V. University, Vallabhvidyanagar, India from June 1953 to June 1958. There he received the degree of Bachelor of Engineering (Civil).

After graduation he worked in the state highway department as a Junior Engineer until September 1961 when he came to Lehigh University for further study.