PAPER No. 341

Sediment Exclusion Methods and Devices at the Intake of Canals

By

MUSHTAQ AHMAD - MOHAMMAD ALI & ABDUL KHALIQ

Prevention of excessive sediment entry into canals is an important problem for channel maintenance. As super silt charge above the normal silt carrying capacity cannot be carried by a channel it would result in silting of the bed, accompanied at times by widening of the channel, and almost always resulting in decreasing its discharging capacity. In fact the entire regime of the channel is up-set and periodical silt clearance of channels becomes imperative and has to be done at great expense. For avoiding excessive silt entry into canals, preventive methods can be adopted only at the intake. Curative methods are used by ejecting excessive sediment after it has entered the canal, by ejecting it in the head reach and putting it back into the river and by proper distribution of silt charge into different off-takes.

In this paper it is proposed to discuss the preventive methods and devices only—that is the methods and devices of silt exclusion at or before the intake of a canal with special reference to basic principles of sediment movement and control.

Basic Principles of Sediment Movement.

To study the methods of sediment exclusion and devices at the intake, it is essential to properly understand and keep in view some of the basic principles of fluvial hydraulics in straight and curved channels; for, each method or device utilises one or more of the basic principles. These are very briefly enumerated below :—

(*i*) From the typical velocity and sediment distribution curves observed[1] in a channel (Figure 1) it can be concluded that:—

(*a*) The velocity decreases from point of maximum velocity near the surface to the bottom more or less logarithtically.

(*b*) More sediment charge is carried for a particular grade near the bed than near the top.

(*c*) The ratio of bed to surface charge increases for coarser material and tends to be equal when we consider the distribution of the finer material.

(*ii*) For bed load transport, the sediment charge moving per unit width of channel has generally been related to T_o the value of the boundry shear or drag and T_c the critical tractive force (which is a function of grain size of the sediment) at which sediment movement just starts. Some of the important relations connecting sediment load per unit width (q_s) and other relevant parameters such as slope (S) discharge per ft. run (q) depth (y), etc are given by :—

1. $q_s = AS^m (q - q_c)$ MacDougall (2)

2. $q_s = An\, T_o\, (T_o - T_c).$ Chang(3)

3. $q_s = \frac{10\, q\gamma}{(\gamma_1 - \gamma)\gamma_1 d} (T_o - T_c)$ Shield (4)

4. $q_s = \cdot 54\, \frac{\gamma^2}{\gamma_1 - \gamma}\, YS\, (YS - Y_c S_c)$ Schoklitsch (5)

5. $q_s = (Aq^{2/3} - Bd)^{3/2}$ Meyer-Peter (6)

6. $q_s = A \left(\frac{V^3}{y} \right)^m$ O'Brien.(7)

7. $q_s = \frac{\Psi}{\gamma^2} T_o (T_o - T_c)$ Straub(8)

$= C_s T_o (T_o - T_c)$

Apparently the bed load will increase with increase of tractive force which implies either increase in depth or slope or both. Relations (1) and (6) show that even increase in q or v will increase the sediment bed load.

(*iii*) The physical law controlling the suspended load distribution according to turbulence theory is expressed by the formula (9)

$$\frac{n}{n_a} = \left\{ \frac{dm - y}{y} \times \frac{a}{y - a} \right\}^{\frac{w}{k\sqrt{T_o/\rho}}} = N^z$$

Where $z = \frac{w}{k\sqrt{gymS}}$

w = is the fall velocity of a particle.

n_a = is sediment concentration at any known height above the bed.

n = is sediment concentration at any height.

y_m = for open channel is the depth of water.

obviously the value of n, the concentration at any depth will require the value of n_a to be known at any other depth, say near the bed. The magnitude of n_a probably depends on the size of bed material and the magnitude of shear stress ; even bed roughness will increase n_a. It should be noted that increase in shear stress or tractive force and decrease in size of particles will tend to increase the suspended sediment ; by howo much—the theory is not yet developed to provide a satisfactory answer.

(*iv*) Considering the mechanics of curvilinear flow it has been established that in a bend the top layer filaments move outwards and the slow moving heavily silt charged bottom filaments move inwards because while flowing in a bend the filaments are forced to deviate from their original straight course and develop a centrifugal force causing a helecoidal cross current which moves the sediment from the concave bank across the channel and deposits it on the convex bank. This provides nature's most effective method of separating silt or sand in flowing streams. Man can utilise this simply by placing the intake of a canal on the concave bend and by providing a sediment removal device at the convex side and he gets the natures most effective sediment excluder.

(*v*) In a channel carrying sediment in suspension, there will be a particular rate of silting depending on the silt concentration (*c*) and the fall velocity of particles (w) in suspension. At the same time turbulence or the mixing process is lifting or diffusing sediment in the direction of decreasing concentration. A balance between these two processes will mean regime condition, when the rate of sedimentation Wc, is greater than $\epsilon \frac{dc}{dy}$ (where ϵ is the sediment transfer co-efficient) then, we have silting, otherwise scouring. To provide desilting basin or a pocket for still pond system we have to create conditions that the rate of silting is very much more than the rate of lifting by turbulent diffusion. The fall velocity W of a particle is given by the formula

$$W = \frac{\gamma d^2}{18}(S_s - S_f)$$

Where S_s, S_f represent the specific gravity of particle and of the fluid and, γ is the specific weight of the fluid. The fall velocity is a complex function of the Reynold No. shape, etc., and can be computed from the functional graph between the Reynold number and a coefficient in the relation

$$F(W) = \epsilon A \gamma \frac{W^2}{2g}.$$

To form a rough idea of the rate of fall in a pool 20′ deep, particles of diameter 1·0mm, 0.1mm, 0·01mm and ·001mm will take **7** seconds, **12** minutes, **20** hours and **80** days respectively to reach the bottom.

Moreover the initiation of sediment movement is given by the tractive force formula. Straub (10) has summarised from the work of various investigators the following values of τ_c—the critical tractive force. For specific diameter of sediment

d_{mm}	1/8	1/4	1/2	1	2	4
τ_c (PFS)	·016	·017	·022	·032	·051	·09

Again from the concept of regime theory, velocity in a given channel can be calculated which would keep it in regime. It means that with the given slit charge and channel dimensions if the velocity is less than the regime velocity, the processes of sediment deposition will start. The mean velocities as permitted in silt stable channels can be calculated by formula of Lacey $v_0 = 1{\cdot}17 \sqrt{fR}$ or Pettis[11] $v = 0{\cdot}8\ Q^{0{\cdot}2}$.

The velocities according to Lacey and Pettis for different Q will be as shown in table below :—

Q cusecs	1	100	1,000	10,000	100,000
Lacey ...	0·8	1·722	2·53	3·713	5·45
Pettis ...	0·8	2·009	3·18	5·048	8·0

In U.S.S.R. (12) the following values have been adopted :—

d_m (mm)	·005	·05	·25	1·0	2·5	5·0	10
Mean Vel (ft./Sec	·49	·66	·98	1·8	2·13	2·62	3·28

The velocities read off from this table are corrected by the following correction coefficient.

Average depth	·93	1·97	3·28	4·92	6·56	8·2	9·84
Correction factor ...	·8	·9	1·0	1·1	1·15	1·2	1·25

Thus whenever the velocity is decreased below the regime velocity the sediment will start depositing in a stream. Therefore, when it is required to bring the suspended charge to bed, the velocities must be reduced below the regime dimension and to stop bed movement a check for T_o has to be made. These processes would be necessary where a pocket is to be designed for still pond system or a desilting work is to be designed.

Practical Application of above Principles in Sediment Exclusion.

Each of the above basic facts of fluvial hydraulics finds an application in sediment exclusion methods and devices. Thus the difference in the the sediment intensity distribution in the bottom and top layers would suggest the following measures :—

(*i*) Draw water into the canal from the top layers only.

(*ii*) The slow moving heavily silt charged bottom layers may be deflected or drawn away from the intake. This would require devices such as vanes, excluder tunnels, skimming walls, platforms etc.

Again the principle of increase of bed load with the increase of shear stress, suggests that to minimise sediment entry into an offtaking channel we must minimise shear stress, so that less sediment moves on the bed. Naturally if less sediment comes to the mouth of the intake the sediment entry will be minimised. To reduce bed shear stress, the slope depth product or velocity gradients near the bed in the vicinity of the intake should be reduced. For this purpose the following methods are adopted :—

(*i*) Creation of pockets with low velocity,

(*ii*) Methods of still pond and semiopen flow, and

(*iii*) Increasing the pond level to decrease the slope.

Now the material in suspension also increases directly with the shear stress and inversely as the grade of bed material. Therefore, to minimise sediment entry we must decrease the slope and velocity gradients near the bed to decrease the bed shear stress. A decrease in bed roughness will also decrease the sediment in suspension.

Location of the canal intake at the outside of a curve and methods to exclude sediment from the inside needs measures to create stable flow curvature by correcting approach conditions above the pocket.

The principles of increasing the rate of sedimentation will be used in designing the desilting works, or pockets for still pond system.

Different methods and devices used for sediment exclusion from the canal intakes will be discussed in succeeding parts of this paper with reference to the principles mentioned above.

PART 1.

1. Creating stable flow curvature in parent stream for locating the intake of a canal on the outside of the curve.

It is well known that when flowing water passess round a curve, the high velocity filaments in the upper part of stream (carrying less silt) will be deviated the least and will travel as straight as possible and pass on to the outer side of the curve and the low velocity silt laden bottom filaments will take a sharp turn and pass to the inner side of the curve collecting sand on the inside. Moreover the lateral unbalanced pressure Z in virture of centrifugal force given by the formula :—

$$Z=2{\cdot}3 \frac{V^2}{g} \text{Log}_{10} (R_2/R_1)$$

(where V is the velocity, R_2 & R_1 are the radii of outer and inner curves of the bend) forces low velocity bottom water at the outside of the bend to move across the channel to the inner-side, thus transporting material across the channel to the convex bank. The flow round a curve causes concentration of flow on the outside of the curve and concentration of the silt charge on the inside. If a canal regulator is located to draw water from the outside of the river bend without any disturbance or change in the direction of flow and the sediment which nature has collected on the inside is withdrawn from inside the bend with the spare discharge available, obviously the canal will draw minimum of silt, providing us with nature's most effective sediment exclusion device.

The experiments conducted in the Irrigation Research Institute for silt exclusion from the right and the left bank off-taking canals at Kotri, Taunsa and Gudu have shown that sediment per cusec per hour entering the canals off-taking from outside of the bend is 1/3 to 1/10 of that passing into the canals located on the inside of the curve.

Experiments on the model of the river Indus at Gudu site constructed on 1/300 horizontal and 1/40 vertical scales with different river approaches both tangential to nose of left and right guide banks and embaying behind the nose of left guide banks were tried. The silt collected per cusec per hour for specific river discharge of 4 & 6 lacs for different sets of the river, are tabulated in table 1. The results clearly show the great advantage the canal taking off from the outside of a curve has over the canal taking off from the other side.

For a meandering river the creation of an effective stable river curvature in the approach channel to canal head is possible by training the river to a definite course by providing training works at suitable places. The problem is simple when only one channel with supply substantially less than the incoming river discharge, takes off from the parent river stream. To utilize the nature's method of sediment exclusion by centrifugal action it is essential that all river stages of excessive sediment, the spare supply in the parent channel above the requirements of off-taking channels should be enough to draw the sediment to be disposed off in the parent channel below the off take point of canals. When the off taking discharge becomes equal to the incoming discharge *i.e.* $\frac{Q \text{ canal}}{Q \text{ river}}$ is nearly equal to 1, for condition of excessive sediment load in the parent channel, the system of sediment exclusion by creating curvature completely fails.

For keeping an off taking canal free from silt-trouble, we must look out for either a natural site, with permanent stable curvature or if this is not possible, as the case generally is for meandering alluvial rivers of West Pakistan, we must keep the point in view while selecting the site as we shall have to artificially create river curvature sooner or later in the interest of sediment exclusion from the canal.

Some examples illustrating the cases where dominant factor in silt exclusion is curvature of flow, natural or artificial, in approach channel, are described below under the following sub-heads :—

(A) Natural river curvature.

(B) Artificially created river curvature.

(A) Natural curvature for exclusion of silt from Canal.

(*a*) Mangla Head Regulator of U. J. C. consists of masonary dam 354 feet long and 80·0 feet high and is ideally located on the outside of a natural stabilized cliff curvature. Water is admitted to the canal through tiers of sluices, the cill of lower of which is at R. L. 859·25. It is a very good example of utilising natural stable river curvature to draw silt-free water from the outside of a curve.

(B) Creation of Artificial Stable Curvature above canal intakes.

The methods and devices used for creating stable curvature at the intake will vary according to the form of the parent channel and number and location of the off takes. The following are some of the conditions under which the problem presents itself for solution.

(*i*) One river channel with one or more intakes located on one side only.

(*ii*) One river channel with intake located on either side of it.

(*iii*) Two rivers channels coming from opposite directions with confluence some distance above the canal heads with the canal intakes located on one or both the sides.

(*i*) **One River channel with intake located on one side only.**

The problem of creating artificial curvature when there is only one parent channel and canal intakes are located on one side of it only, is easy of solution ; for, all that has to be done is to create the curvature so that intake is located on the outside of the curve.

This can be achieved with training works such as spurs alone or in conjunction with an island where necessary. The examples of this type of approach correction at Rupar, Balloki, and Khanki are briefly discussed below :—

At Rupar a series of six spurs with T-heads located on the quadrant of a circle have been constructed for obtaining stabilized channel along the heads of spurs and arresting further erosion of the left bank. The main stream of the river in passing round the curve from Spur No. 6 to Spur No. 2 acquires centrifugal force which helps in bifurcation of flow at head of lower most spur (about one mile above the canal head-works) the channel feeding the canal takes off from outside of the bend whereas the main and steeper channel that turns off to the mid of the weir transports the coarser silt (Fig. 2).

River Ravi above Balloki had been trained by means of system of spurs and left guide bank to form a curved stable channel along the left guide bank which helps in silt exclusion from L. B. D. C. This method invariably forms an island on the inside of a curve within the guide banks and apart from decreasing the flood discharging capacity of the weir and increasing concentration of flow on one side, created cross flow on the upstream side of weir. These points must be provided for in the design. To overcome some of the above difficulties, after detailed investigation by the author,[13] a pitched island with a groyne was proposed (fig.2[a]) with a view to increase the discharging capacity of the weir, to keep the parallel or cross flow away from the work and to use the right side for sediment exclusion with the curved approach. These devices have been constructed and are working satisfactorily.[14]

At Khanki Headworks where again the off-take is only on the left side, the river, (after it is trained by a series of spurs) is bifurcated into two channels, one leading to the intake of Lower Chenab Canal and the right channel is kept alive by working the right undersluices (Fig. 2b) The weir is divided into two parts by a big island which is joined to the right groyne of the central undersluices. Central undersluices had mainly been constructed to maintain stable curvature so that the intake to the pocket is always from the outside of a curve. The silt from the inside of the curve is drawn through the depressed central undersluices.

(ii) **One River channel with intake located on either side.**

The problem of sediment exclusion becomes much more intricate when the channels take off simultaneously from either bank of the barrage, it is especially so, for the channels taking off from the wrong side of the curve. The utilisation of the principle of flow curvature needs special corrective measures for conditions, when :—

(*a*) a permanent control section exists upstreams of headworks and an artificial curvature has to be created by vanes and islands.

(*b*) a permanent control section does not exist and artificial curvature has to be created.

A very good example how good sediment exclusion conditions can be obtained for unfavourably placed canal intakes, when a permanent control section exists, is provided by the devices evolved by Sir Claude Inglis[(15)] for Sukkur Barrage.

At Sukkur Barrage the river apyroach to the barrage is controlled by the two gorges on the two flanks of Bukkur Island. The canals on the left banks had no silt trouble as these were drawing there supplies from the outside of the curve. For the right bank canals artificial curvatures had to be create, by forming islands A & B and the intake to the pocket feeding the right bank canal was shifted up and so located as to draw water from the outside of the curve (Fig. 2) and also provided sediment flushing channel. For this purpose he had to close about 10 days of the barrage which had reduced the discharging capacity of the barrage from $1{\cdot}3\times10^6$ to 1×10^6 cusecs. The devices though working perfectly satisfactorily from the point of view of silt exclusion had the above draw back.

Now when the river is free to mander in a wide Khadir, and permanent natural restraints to pin the river at one place above the barrage are not available, such a restraint has to be created either as guide bank heads or by artificial training groynes upstream. Experiments were made with belly shaped guide banks as shown in Figure 3 to provide the control section as well as to allow the curved flow to cling to the guide bank when suitably corrected.

The guide bank heads in an alluvial meandering river can capture the flow on the left or right side periodically creating favourable curvature for canals off-taking from the guide bank which is free, and unfavourable curvature for canals on the guide bank at the nose on which the flow is captured.

To cater for the conditions when the river captures either of the guide banks and canals take off on either side, stream lined groynes were tried near the curved guide bank heads in model studies carried out at Nandipur Hydraulic Research Station for Gudu Barrage. With flow capturing the left guide bank the bed configuration with and without the stream lined groynes are shown in figures 3 and 3-(a). It will be seen that without the groynes an island forms along the guide bank, which captures the flow, but with stream line groynes a channel opens along the gusde bank for which the conditions were previously unfavourable. The sediment entry into the intake for the two cases are recorded in Table II.

It will be noted that with stream lined groynes we can open up a channel along the wrong side of the curve and we can decrease the sediment entry by about $\frac{20 \text{ to } 80}{\odot \dashrightarrow}$ per cent.

(iii) Two rivers meeting at an angle just above the Headworks when off-taking channel is drawing a small proportion of river supplies.

Marala weir is located immediately below the confluence of the Chenab and the Tawi. The Chenab is dominant of the two rivers (flow in Tawi is 20-40% of flow in Chenab), but as the Tawi is a flashy stream with slope as much as twice the slope in Chenab and so in case of a freshet the detritus load in Tawi is very excessive.

As river Tawi and regulator of U. C. C. are located on the left flank of the weir and as Tawi beyond 30,000 cusecs brings much harmful silt there is a rule that U. C. C. should be closed when discharge in Tawi exceeds 30,000 cusecs.

The Marala method of feeding U. C. C. (full supply discharge 13,000) consisted in maintaining a deep river channel on the right and feeding the canal from right to left has proved to be successful, because of the following reasons :—

(*a*) The main supply of river in excess of the canal requirements is forced to pass bay No. 4, 5, 6, 7 & 8 while the discharge of Tawi was channelised towards bay No. 3 when the canal was in flow and through the undersluices and bay No. 1, 2 & 3 in flood. The discharge in the approach channel to the undersluices decreases in the direction of flow thereby flattening the river slope and causing the deposition of coarse silt at each bifurcation point.

(*b*) There is deposition of silt on the shoal inside of the curve which extends from extreme right hand bays to the nose of the divide groyne.

(*c*) The current while taking a turn round the nose of the divide wall deposited sediment in the pocket ond allowed water to be drawn into the canal from the outside of the curvature. The sediment deposited in the pocket along the wall was withdrawn during sluicing closure.

The number of closures in U. C. C. in 1959 shows that with the increase in frequency and intensity of freshets and floods in Tawi the canal closures are too numerous.

It should be noted that in this case the ratio of canal discharge Q_c to river discharge Q_R which carries excess sediment assuming such Q for Tawi only as 30,000 cusecs we have $\frac{Qc}{QR} < 1/3$.

(iv) Two rivers meeting at an angle just above the Headworks when off-taking channel is drawing a large proportion of river supplies.

At Marala the problem of silt exclusion from canals has become much more vexed after the construction of the M. R. Link. The non-perennial M. R. Link (Q = 20,000) draws its supplies over the shoals above weir bays formed inside of the approach channel to pocket which has to be maintained to feed U. C. C., and thus material scoured from the shoal is washed into M. R. Link. In low and medium stages of river the pocket draws its supplies from introdos of the curve (Fig. 4) and so excessive silt enters M. R. Link which is again located on the inside of the curve within the pocket, whereas U. C. C. is drawing its discharge from the outside of the curve within the pocket. At present the head reach of M. R. Link is heavily silted up (by about 8 feet) and about 7 million cubic feet of sediment has passed into the canal in 1959 only.

The problem of sediment exclusion from M. R. Link and U. C. C. is under study on model of the Chenab and Tawi at Marala Headworks constructed on $\frac{1}{200}$ horizontal and 1/36 vertical scales at Nandipur.

To shift the confluence of the Chenab and the Tawi at a reasonable distance above Headworks and to obtain the curvature of flow in the river channel u/s of undersluices for securing conditions of minimum silt entry into the canals the following measures as detailed in fig. (5) proved to be efficacious on model.

(*i*) The left guide bank was extended and converted into a belly shaped guide bank. The Tawi course was diverted to stick tenaciously to the nose of the left guide bank.

(2) To deflect the Chenab flow in low stages of river along the left guide bank, a apitled head 3000.0′ in length abutted on the bela with earthen shank crossing the right arm of the Chenab was aligned.

(3) To divide the combined flow of the Chenab and Tawi and to deflect the flow into the curvature of left guide bank a pitched island was also constructed on model.

(4) Bay No. 1 was converted into a pocket undersluices by raising a divide wall 1200.0′ in length at groyne No. 1· Bay No. 3 was also converted into undersluices to tap the silt from inside of the approach channel. To keep the high level channel on the right side of the pitched island active and to develop it to take proper share in floods so that left portion of the weir is not overstrained, Bay No. 8 was also converted into undersluices.

(5) Pond level was raised from 808 to 810.

As is apparent from fig. (5a) the confluence of the Chenab and the Tawi has been shifted immediately above the pitched island, and the approach channel to the pocket is such that it is located on the concave side of the bend.

The surface and bed currents within guide banks for a case when discharge incoming in the Chenab is 1,50,000 and that in Tawi is 40,000 cusecs are shown in fig. (5*b*) which depicts that bed currents in the Tawi river starting at and above the nose of left guide bank are drawn towards undersluices in Bay No. 3 whereas top filaments of Chenab river are also drawn towards pocket. The chief advantages of the scheme are :—

(1) Due to mixing of flows from Chenab and Tawi Fig. (5 *c-d*) and consequent neutralization of silt intensity of Tawi flow, the frequency of the closures of Canals is very likely to decrease.

(2) The silt entering the M. R. Link will be about 1/6—1/8 of the silt drawn into it at present.

(3) The right guide bank can look after all the river approaches in the Chenab. Even when the embayment behind the right guide bank has attained its climax there is less likelihood of any danger to guide bank or its shank.

(4) In floods it is possible to restrain the Tawi flow in the channel between pitched island and left guide bank and to pass the Chenab flow in the channel between right guide bank head and the pitched island.

The disadvantages of the scheme are :—

(1) The diversions of main arm of the Chenab and the Tawi are quite difficult operations.

(2) The transportation of stone for the right guide bank head will be a serious problem.

(3) The bela below the point of separation of flow along the right guide bank head may overdevelop in height and extent in spite of the fact that the point of separation of flow will travel downstream with rise in flood stages. The effect of drawdown at the undersluices of Bay No. 8 is not likely to extend to the separation point along the right guide bank head. In case this bela becomes underodable in floods the left hand portion of the weir is likely to be overstrained and the action at the nose of pitched island is likely to be very severe.

(4) Due to severity of the flow at the nose of right and left guide banks and the flanks of pitched island the maintenance of the proposed works will be very heavy.

Further experiments to find out suitable cheap remedial measures are underway. It is one approach and not the final solution.

PART II

II. Drawing Water into the intake from the Top Layers.

It is established by various experimenters (16,17) that an off-take from a straight channel draws greater proportion of silt in its water than its due share depending on tne discharge extraction ratio and the angle of twist. The lower layers which contain the heavier and coarser silt load and less forward momentum are deflected from their course and drawn into the off-take with greater ease than the top layers with considerable greater memomentum.

The factors or devices which affect the ratio of water drawn from the bottom and top half of the upstream channel are :—

(1) The discharge extraction ratio.

(2) Angle and position of intake with the axis of the main stream.

(3) The cill height of the intake.

(4) Skimming wall in front of the intake.

Discharge extraction ratio and angle of intake.

If extraction ratio is large, some curvature of flow which is a function of extraction ratio and angle of twist of off-take is engendered in the parent channel and then the off-take conditions are spoiled. The mechanics of sediment deflection into the off-take and the physical explanation of this phenomenon has been discussed by the Author [18] in one of the earlier papers submitted to the Engineering Congress and a detailed discussion is therefore not done here. In that paper it has been shown from previous work that the intakes draw more than its proper share of sediment. The effect of alignment of channel at the point of off-takes and their location, the length of divide wall and its effect on silt entry and the effect of the discharge extraction ratio on sediment entry have been discussed.

It should also be noted that in a converging portion of a flume the bed water carrying heavy silt concentrates in the mid stream due to acceleration of bed velocity and so if small off taking channel draws its supplies from the upstream converging walls of flume the high velocity·top water has a tendency to flow straight into the off-take.[19]

Height of Cill.

The practice of raising the cill with the object of excluding some silt has been adopted at most of the canal headworks and was advocated by Lt.-Col. Ottlay in 1893 so that water should be drawn over as high a raised cill as possible from a still pond. In 1894, masonry cill of Sirhind Canals was raised by 7. 0′. Since then the off-takes of all canals had raised cill. The raised cill does not provide a complete answer to the problem specially under condition of still pond system when velocity in the approach channel is reduced to deposit silt in the pocket. It will progressively silt up and at a particular level of silt in the pocket the sediment will again be sucked into the canal intake. This method needs sluicing closures, the greater the rate of silting, the more often the sluicing closures will be needed. If the canal intake happens to be on the wrong side of a curve the raised crest will also not help because a very stable ramp will form in front of the raised cill over which the sediment will be drawn into the canal. A raised cill will be specifically help full when it is combined with a favourable curvature of flow, or a periodical flushing is permissible and possible.

When the cill level is kept low and under-shot gates are used, the velocity distribution in the approach will be as shown in figure 6 for different crest settings.

From the vertical velocity distribution formula, the bed shear stress can be worked out in terms of velocity at two heights (y_1 & y_2) above the bed.

$$V_1 = 5{\cdot}75 \sqrt{\tau_o/\rho}\ \log 10\ y_1 + A.$$

$$V_2 = 5{\cdot}75 \sqrt{\tau_o/\rho}\ \log 10\ y_2 + A.$$

$$\therefore \quad \tau_o/\rho = \frac{(V_2 - V_1)^2}{(5{\cdot}75 \log y_2/y_1)^2}$$

$$\tau_o = \rho\, \frac{(V_2 - V_1)^2}{(5{\cdot}75 \log y_2/y_1)^2}$$

Now when the crest is kept low in the zone of withdrawal the velocity distribution shows rapid rise in velocity above the bed, resulting in excessive shear stress. Obviously due to increased bed shear stress, more sediment is picked up from the bed and is drawn into the intake. The crest of the intake can be raised by increasing the length of crest to a hight limited by the pond level and the off-take discharge.

Studies made by the author[20] have shown that the crest height beyond 50% of depth of water u/s of intake is not inducive towards proportional advantage in sediment entry and hence it may not be attempted. The vertical componant of flow in the proximity of cill draws silt in the canal and a considerable part of water which is admitted to the canal over a raised cill is bottom water.

Skimming Walls.

As the angle between flow in the parent channel and in the diversion canal called the angle of twist, is substantial the centrifugal effect consequent of change of direction of flow at the entrance to canal causes disturbance of normal regime of silt transport and therefore allows coarse sediment to rise to the surface to be carried over the cill of diversion regulator.

To counteract this centrifugal action and to neutralize the effect of transverse hydraulic slope of centrifugal flow the modern Egyptian practice is to build low a drowned weir or a cill built across the entrance to the canal in front of headworks controlling its water supply. The slope of the cill or the low weir is equal in magnitude and inverse in direction to that of transverse slope generated by the centrifugal flow. According to Leliavsky[21] the difference between the elevations at the two ends of drowned weir (Z) is given by the relation.

$$Z = \frac{2V^2}{g} \tan \theta/_2$$

where θ is the angle of twist and V is the velocity of flow in the parent channel.

Skimming Wall to Exclude Silt from the intake of Warsak Power Tunnel.

Solid material receiving capacity of Warsak Dam is low (62,000 acre feet of water) and the annual transport of solid by river Kabul is fairly high (27,344) acre feet in 1955), therefore, the reservoir will rapidly silt up and solid material will enter the intake causing rapid wear of the turbines by abrassive action of silt. The bed load of Kabul River will enter the reservoir and will stop moving as soon as the hydrodynomic drag force becomes lower than the force necessary to keep it in movement and the finer material in suspension will deposit lower down. In the upstream part of the reservoir the process of deposition will continue till a natural balance between the incoming and outgoing sediment charge is attained. The critical drag criterion of bed load movement has shown that when the reservoir bed above the intake has silted to an elevation 1200 the fine silt will start entering the intake and the sand will start moving and entering the intake when the reservoir is silted up to an elevation 1217 and above. Thus when the reservoir is silted beyond elevation 1200 the power intake channel starts getting more sediment than its share. The feasibility and design of silt exclusion devices for the intake Power tunnel were tested on complete model of Warsak Dam constructed on 1/40 geometrical scale.

The analysis of velocity distribution (figure 7 (*a*, *b*) in the approach to the intake has revealed that the bed velocity increases in vicinity of intake, discharge per foot run in the centre of each bay decreases from Bay No. 1 to Bay No. 8 and that ratio of the bottom filaments to total flow decreases from bay No. 1 to bay No. 8 indicating that the right hand bays will be drawing more sediment than the left hand bays.

The model observation showed that skimming well as shown in figures with too elevation 1240 to be very efficient as coarse silt excluding device as it was drawing entirely from the top layers.

It was noticed on model that the efficiency of skimming wall is loward with the fall in reservoir level or rise in the reseavoir bed level as is eviden from table.

Bond Level	Without skimming wall			With Wall		Total	Efficiency	
	Coarse silt.	Fine Silt.	Total	Coarse Silt	Fine Silt		With respect to coarse	With respect to total.
	River discharge=24,000 cusecs. Tunnel Dis charge=24,000 Cusecs.							
1269	·04	·22	·26	·00	·10	·10	100	61
1259	·08	·25	·33	·02	·14	·16	75	51
1250	·10	·32	·42	·05	·30	·35	50	17
	Reservoir bed assumed s lted to elevation 1330.							
	River discharge=1,00,000 Cusces. Tunnel discharge =24,000 cusecs.							
1269	0·20 C ft.	2·60 c. ft.	2·80	0·00	1·62	1·62	100	42
1259	0·24 ,,	I·96 ,,	2·20	0·125	1·575	1·70	48	23
1050	0·28 ,,	1·92 ,,	2·20	1·17	I·93	2·10	40	5
	Reservoir bed assumed silted to an elevotion 1200.							
	River discharge =24,000 cusecs. Tunnel discharge =24,000 cusecs.							
1269	1·20	0·24	1·24	0·70	0·20	6·90	41	37
1250	2·50	0·25	2·75	1·70	0·20	1·90	32	30
	Bed assumed silted to elevation =1230							

$$\text{Efficiency}=\left(1-\frac{\text{Silt collected with wall}}{\text{Silt collected without wall}}\right)\times 100.$$

It is obvious from the table that with decrease in depth of water in reservoir U/S of skimming wall the water surface gradient in the vicinity of the skimming wall increase with consequent increase in velocities over the top of skimming wall thus disturbing the normal regimen of velocity distribut on in the vertical column which resultsing greater turbulance and mixing together of bottom and surface filaments thus throwing more silt into suspension.

PART III

Withdrawal of Bottom Layers in the Pocket. (Sediment Excluders and Deflectors.)

When the approach is straight, a method for decreasing sediment entry into the intake is to prevent the heavily silt laden bottom layers entering the intake of canal head by withdrawing the bottom filaments carrying solid charge leading it down the river. While dealing with the bottom layers with heavy sediment discharge two possibilities are open :—

(*a*) Withdraw the bottom heavily silt charged layers through tunnels in front of the intake and put it back into the river. The device is known as sediment excluder.

(*b*) Deflect the bottoms layers above the intake away from it. This can be done by bed or surface vanes.

(*a*) Sediment excluders

The idea of dividing the bottom layers which carry the greater sediment charge and more of heavier material from relatively silt free top layers by horizontal diaphragm in the approach channel and escaping the botton flow separately below the crest of undersluices originated with Elsden.[22] The idea was further developed and now sually tunnels are placed in front of the intake to withdraw bottom water. The efficiency in this note for excluders will be calculated with reference to the still pond system and is defined as below :—

$$\text{Efficeincy} = (1 - S_c/S_o)\ 100$$

Where S_o=is the silt entering the canal per cusec per hour with still pond system and S_c=is the silt entering the canal per cusec per hour when excluder is in operation. To make the excluder work efficiently all measures which increase bed shear stress and throw more sediment into suspension must be avoided and all measures which help in dropping of sediment in the lower layers should be used. These are :—

(1) Decrease the tractive force by flattening river slope in the approach channel.

(2) The Canal discharge and excluder tunnel discharge should not be increased beyond a limit permissible as to create more bed shear than the normal.

(3) All obstructions, protubrances and roughnesses that have the effect of throwing up towards surface a certain quantity of water should be obviated as far as possible.

(4) An excluder in front of an intake located on the outside of a curve in a parent channel will not have maximum efficiency for considerations of discharge.

(5) The shape and placement of the openings of the excluder should be such that the flow is orthognal to the intake of excluder.

Results of special studies carried out on the following aspects of the problem are discussed.

(*a*) Efficiency of excluder in relation to its discharge extraction.

(*b*) The best shape of the excluder.

(*c*) The efficiency of excluder over and above the still pond system.

Before describing the details of the experiments and their results, it is essential to describe the common types of excluders in use.

(1) *Khanki type silt excluder* :—

Two undersluices bays adjacent to the regulators were used for the construction of this excluder in which three tunnels running parallel to regulator face were provided in each bay. The tunnel along the face of the regulator is the longest tunnel with u/s end just above the u/s abutment of regulator and the extreme right tunnel in Bay No. 2 is shortest in length. Each tuunel stepped out from the one next to it farther from regulator face and has one opening at its u/s end and openings facing the divide wall in the projection.

(2) *Haveli Canal excluder at Trimmu* :—

The left undersluices of Trimmu barrage which have eight bays have been divided into two portions by a divide wall going far out to give a smooth approach. The four bays between regulator face and divide wall are provided with full slab excluder with top of slab at the crest level of the regulator and extending beyond the regulator face which ensured the separation of escape water before turning into the regulator. High efficiency of silt exclusion was claimed by the designers but considerable turbulance and surging action was noticed in the pocket when the canal and excluder were in operation simultaneously on model.

(3) *Kalabagh type silt excluder* :—

It is a modified Khanki type silt excluder covering only two bays of the undersluices without any additional divide wall. In the design the length of the tunnels decreased in equal steps from left to right and the openings towards the pocket were extinct,

(4) Vortex type silt excluder.

The vortex excluder consists of a pipe of suitable diameter with a silt parallel to the axis of tube at its top placed horizontally across the bottom of the parent channel perpendicular to the currents of flow. As the water passes over the tube a shearing action across the open portion sets up vortex motion within the tube which has sufficient velocity to prevent any deposition of sediment within the tube. In order that the vortex tube be operated at highest efficiency in wide channels the discharge per foot entering the tube along its entire length should be same. The flow entering the vortex tube has to be discharged at one end of tube itself and in this case the discharge end acts as a sluiceway whereas tube is clogged at the other end. It has been found that the efficiency and the performance of the vortex ejector increases considerably if the vortex tube discharges into another exit pipe off-taking from the centre of the tube. Depending upon the conditions of the silt and the design capacity of the excluder the vortex ejector may discharge into two or more than two exit tunnels. This is a subject in which the authors are writing a separate paper and is not dealt with here in detail.

Comparison of Kalabagh and Trimmu Type Silt Excluders.

The relative performance and the efficiency of the following two types of excluder was tested on a model at Malikpur in the year 1941 [23]

(*i*) The Trimmu type of silt excluder with a slab covering the first four bays and a divide wall 600′ long at the fourth pier.

(*ii*) The modified Khanki type covering only two bays of the undersluices without any additional divide wall.

It was noticed from the model that a considerable turbulance and surging action was generated in the pocket fitted with Trimmu type excluder. With improved Khanki-type the conditions of flow were smoothened out and a regular curvature to the canal head was obtained. The silt which passed into the canal with Kalabagh excluder was 41-44% of that which passed the canal with Trimmu type excluder.

The relative merits of different types of excluders when off-taking channels are drawing a considerable proportion of the parent channel discharge.

Silt excluder in left pockect of Taunsa Barrage as originally designed on the pattern of Kalabagh excluder is as shown in Figure (9). The three off-taking canals on the left for which the excluder and the pocket were required to be designed were Muzaffargarh Canal, Hydel Canal and Thal Canal with full supply discharges of 6,549, 34,400 and 2,305 causes respectively.

The preliminary tests showed that for a still pond system the widening of the pocket comprising 7 bays of undersluices to a pocket covering 10 bays of undersluices decreases silt entry into the left canals as wider pocket draws comparatively less solid charge at its intake due to decrease in order of pocket velocities, but when the silt excluder with a full spuply discharge of 28,800 cusecs is running full, the extractor efficiency drops if the pocket is widened from 7-10 bays of undersluices. In all the tests described below a pocket consisting of 7 bays was constructed on the model. The model comprising the barrage with its ancilliary works and the river valley extending out to about 4½ miles above the weir line was constructed on 1/150 horizontal and 1/25 vertical scales. The model river bed in each test was moulded according to the stabilized bed configuration obtained after development of the leading cuts through the barrage on a separate model. Separate silt collecting traps of suitable dimensions for silt collection below the weir, undersluices and three canals were constructed on the model. A discharge equivalent to 3 lac cusecs in the river was run for 3 hours. Sand was injected on the model in the main channel approaching the weir. Equal regulation system was adopted for operating the weir gates. The details of different types of excluders are shown in figure (10 *a*, *b*, *c*,). The results showed that the efficiency of excluder tunnels in the 4th bay was least so in this series of tests the excluder tunnels were confined to Bay No. 1—3.

The silt per cusec per hour drawn into each canal and ejected by excluder tunnels below each undersluices and percentage reduction or increase in silt entry in each canal with respect to sediment entry under still pond system (without any excluder) is given in table III, for different types of excluders. The following inferences can be drawn forth from the results :—

(1) The Orthognal and the Khanki types excluders are almost equal in their performance in minimising the silt entry into the canal intakes. The silt escaped by tunnels of these two types of excluders in undersluices No. 3 is minimum as these are drawing from the outside of curve and if these tunnels are eliminated there will not be marked reduction in the efficiency of silt excluders. The percentage reduction of silt entering Thal Canal as compared to the percentage reduction in Hydel Canal in case of Orthognal type of excluder is poor and the reason for this can be ascribed to the fact that the inlet of tunnels contiguous to regulator face is located within the zone of withdrawal of canal where the increased slope increases the shear at the bed.

The percentage reduction of silt with Orthognal type of excluder with extraction ratio of 50% for Hydel Canal is 50·83 per cent whereas the overall percentage reduction of sediment when all the canals are taken collectively is only of the order of 20 per cent.

(2) In the absence of any silt excluder the solid charge entering the Muzaffargarh Canal was minimum as the canal regulator was located on the outside of the curve fig. (11). All types of silt excluders increased the sediment entry into the Muzaffargarh Canal as with increase in pocket discharge more flow veered round the divide wall nose into the pocket throwing

more silt into suspension as a consequent of increased velocity and turbulance in the vicinity of divide wall.

(3) The proposed excluder was throwing maximum silt into the Muzaffargarh Canal as the u/s corner of excluder slab facing the divide wall was causing churning of flow thereby throwing more silt into suspension and thus increasing the silt charge in Thal Canal and the Excluder tunnels discharging under undersluices Bay No. 3. This is evident from the contours of bed configuration in pocket in Fig. (10 *b-c*).

(4) The Dargai type excluder with ducts at the bed of triangular shaped trough though efficient gets clogged by debris.

The performance of Khanki type excluder in the bays of left pocket of Taunsa Barrage when off taking channel is drawing a small proportion of parent channel discharge.

At advanced stage of construction of Taunsa Barrage, Hydel canal was abandoned and it was proposed to replace it by a Sui Gas Canal with a capacity of 1,200 cusecs. Thus the total discharge of the left bank canals was 10,054 cusecs. As the left pocket consisting of 7 bays had been constructed already the divide wall separating the pocket and the weir was cut short to upstream floor and another divide wall of length $1{\cdot}4 \times L$ (where L is distance of upstream abutment of regulators and the weir line) was raised at end of the 4th bay of the pocket Fig. (11*b*). The crest level of regulator of off off-takes and the top of excluder was kept at 433. In this series of tests the pocket undersluices were kept closed, the gates of excluder tunnels were operated to regulate the flow through the excluder tunnels and the gates of undersluices from bay 5—7 and the weir bays were raised to equal heights from crest level. Four tunnels of size $13{\cdot}5' \times 8{\cdot}0''$ covered one bay of the undersluices.

Having fixed the river discharge at 3 lac cusecs arbitrarily it was desired to test the relative merits of excluder tunnels covering 0 bays, 2 bays and three bays for different extraction ratio :—

$$\left(\frac{\text{Full supply discharge in left canals}}{\text{Total discharge through excluder}} \times 100\right)$$

The efficiency (E) of excluder with respect to still pond against different escapages through the excluder is plotted in fig. (12*a*).

The percentage increase of total sediment that enters the pocket at its intake in relation to the total sediment that enters the pocket without any excluder in the pocket against different escapages through the excluder is also plotted in Fig. (12b).

$$\text{Percentage increase} = \left(\frac{(S_W - S}{S}\right) 100$$

Where S is the total sediment entering pocket with still pond system and S_W is the total sediment entering pocket when excluder is in operation.

The following facts can be discerned from fig. 12.

(1) The maximum reduction of silt entering canal with. 4 tunnel excluder, 8 tunnel excluder and 12 tunnel excluder is 31·5%, 12% and 0% respectively at respective extraction ratios of 72%, 72% & 35%. The discharge of the tunnel in 1 bay when fully open will be about 7,200 cusecs which means 72% extraction ratio in relation to the off-take discharge. The bed and surface currents in the approach channel to the pocket and the pocket itself in case of still pond system and when 4, 8 & 12 tunnel excluder is drawing 72% of the full supply discharge in left canals is shown in Fig. (13 *a,d*). In case of still pond the pocket was drawing bed currents in width of 180·0′ at a distance of 900.0 feet above the weir line but in case when excluder was extracting 72% of canal discharge the pocket was drawing the bed currents in a width of 225.0′ at R. D. 900. Thus with functioning of excluder the zone of withdrawal of bed currents into pocket increases proportional to extra withdrawal of excluder. It is also evident that in case of 4 tunnel excluder the tunnels are drawing from inside of the curve within the pocket but in case of 12 tunnel excluder, about 6—8 tunnels tap their supplies from outside of the curve. Thus the fall in efficiency for a specific discharge of excluder with increase in excluder tunnels is obvious.

(2) The 3 undersluices bays on the weir are quite effective in drawing bed currents in case of still pond system.

(3) As the discharge of extraction increases beyond a critical value the efficiency of the extractor falls, as with increase in pocket discharge more silt is taken into pocket which may not be digested by excluder *intoto* and some of the silt may be thrown into pocket.

(4) At higher escapes of excluder the turbulence generated into the pocket upsets the normal vertical distribution of silt that results in excessive sediment entry into the canals.

Performance of excluder at a very deep intake :—

The floor level of intake of power tunnel of Warsak Dam is at R. L. 1200 (the bed level of the silted reservoir at which the drag force works out to be, ·0214 lb/sq. ft., which is sufficient to move fine silts, the crest level of power tunnel is 1206, the crest level of Dam is 1220 whereas the normal Pond level is 1269 which can drop to R. L. 1250. The full supply discharge of Power tunnel is 24,000 and the incoming discharge in Kabul river varies from 5,000—2,00,000 cusecs. The excluders were tested for full supply discharge in power tunnel and the rivers discharge equal to 100,000 cusecs. As the intake of power tunnel takes off from a deep parent channel (the depth of water at intake is 50-70 feet), the slope of water in reservoir is flat and as is evident from figure 7 (a) the velocity and velocity gradient at the bottom of intake are of low order and as the water way at the month of intake is very large to disturb the regimen of velocity distribution ; it was envisaged that an excluder of ejector type or vortex excluder will be efficient for exclusion of coarse silt from power tunnel. The excluders tried on model discharged in the cistern of Dam through an 26.0′ high access tunnel (bed level at EL, 1170 and top level at 1196) below the crest of extreme right hand bay of dam. The design of ordinary frontal type excluder tried on model is shown in figure (14). The height of tunnel was kept 3.0′ feet only. The area of cross-section of the silt excluder exit at its tightest section is 24 sq. ft. and with reservoir level at 1,269 the discharge of silt excluder as worked out from model is 1,200 cusecs. thus generating a velocity of the order of 50 feet per second at the tightest section. The efficiency of the silt excluder for coarse and medium sand is about 50% whereas the efficiency of the silt excluder for total sediment passing through intake is 37%. The design of vortex silt excluder as tried on model is as shown in Fig. (15). The vortex tube was of 10.0′ dia with 2.0′ top aperture and the two off-taking pipes from the central portion of the two halves of the vortex ejector were merged together in a single pipe of 10.0′ dia above the dam. The discharge per foot run along the axis of each bay and perpendicular to the axisal lines of bay at the mouth of intake as worked out from velocity distribution in the vertical are plotted as vectors in figure (15). The resultant of two vectors immediately above intake are also shown in the same figure The axis of vortex tube was kept perpendicular to the resultant vector at each point.

The velocity distribution for 100,000 cusecs river discharge is shown in figure (16). It is apparent from this figure that velocity distribution at the intake is such that the maximum velocity is near the bed at the mouth of intake. The vortex tube ejector improves the relative distribution of flow in different bays. The efficiency of this excluder is 55 per cent for the coarse silt and 40 per cent for the total silt.

The maximum discharging capacity of vortex type silt excluder is about 4,000 cusecs. When supply is available in summer we can afford to pass more discharge through silt excluder thereby improving the efficiency of the silt excluder. The efficiency of the silt excluder for medium or coarse silt when it is discharging full bore, is more than 80 per cent.

II. **Sediment Deflectors.**

Silt vanes at bed or near the surface in the parent channel aligned suitably with respect to the intake can deflect the heavily silt laden bottom layers away from the off-take towards the middle of the parent channel.

Bed Silt Vanes

In a very interesting paper on silt exclusion from distributories, King[24] has recommended the use of bed vanes and has given specifications also. Silt vanes of height 1/3—1/4 the depth of water in parent channel aligned on a gentle curve with extrados towards the off-take head beyond the influence of "strong draw" of the off-taking canal with U/S end of vanes parallel to centre line of parent channel and D/S end tangential to lines which are at an angle with centre line not less than 2—1 are suited for a case where parent channels are of low velocity (less than 3·5′) and where the off-taking channels are drawing less than 1/3 of the parent channel. The silt vanes, channels between vanes and the approach to vanes are usually made of smooth surface as rough surfaces are likely to create eddies that pick up coarse silt in their cap and throw up towards surface. For proper functioning of silt vanes it is essential that the velocity of water passing over the vanes should not be great enough to suck in heavy silt in between the vanes and so it is usually thought that those will not be very efficient at canal headworks.

Silt vanes in conjunction with curved wing is more effective for silt exclusion as all the surface water cut off by curved wing is forced into off-take and upper layers of water outside the curved wing is also deflected to replace the bottom water deflected by the vanes.

The silt vanes are generally not considered suitable in cases in which discharge of the off-taking channel is more than 1/3rd of the parent channel or where the parent channel has insufficient silt transporting power to digest the extra silt charge added by the silt vanes or where the parent channel is not wide to provide sufficient room for aligning vanes of desired radius or where a very small channel takes off from a deep parent channel.

In case boulders or shingle are carried by the river, the vanes in the pocket guide the coarse detritus away from canal head. The silt vanes were tried successfully on model to exclude shingle and boulder from head of Upper Bari Doab Canal taking off from Madhopur[25].

Surface Vanes.

The surface vanes have been recommended by Russian research workers for sediment deflection away from the intake. The principal is illustrated in figure [17a] where a surfaced vane when introduced obliquely to the flow creates in the current artificial transverse circulation, directing the surface and bed water as shown in the figure. The vanes with the form of segment or form of pontoons has to be held together by a super structure. It has been found from experiments that the best results are obtained with the following characteristics of the guide system of surface vanes, for reference see figure[17b].

$1 = 2{\cdot}5D$ (D is depth of water).

$L = 2{\cdot}5D$ (L length of vane).

$B = 5\ H$

$A = bK + 1{\cdot}5H$

where $K = \dfrac{\text{flow in diversion}}{\text{flow in the flume.}}$

immersion of the vanes 0·33D.

It has been found that in the absence of the surface guide vanes the regulator received 40 to 86% of total bed load but with surface vanes the sediment fell to 1·0 to 4·25%.

TABLE II

Test No.	Shape of Guide Bank	Type of River Approach	Season	Discharge	Silt in left Canal	Silt in Right Canal
				Cusecs	Cuft	Cuft
1 (a)	Both the guide banks Belly shaped.	Left handed approach with left guide bank nose fully under attack.	I	400,000	·32	·66
				600,000	1·0	·59
			II	400,000	·27	·25
				600,000	·405	·24
			III	400,000	·25	·25
				600,000	·38	·26
1 (b)	Do.	Left handed approach with spur placed II to guide bank at their U/S ends	I	400,000	·77	·7
				600,000	·59	·44
			II	400,000	·215	·18
				600,000	·17	·35
			III	400,000	·13	·12
				600,000	·16	·24
1 (c)	Do.	Approach as above but tangential to the nose of left spur	I	400,000	1·36	·23
				600,000	·95	·55
			II	400,000	·20	·10
				600,000	·39	·25
			III	400,000	·14	·067
				600,000	·125	·30

Efficiency of different types of
ICS = Silt per cusec per hour into
ICE = Silt per cusec per hour into

$$\textbf{Percentage efficiency} = \frac{(\text{ICS} - \text{ICE}) \times 100}{\text{ICS.}}$$

Nos.	Off Takes and Excluders.	Discharges. Prote-type.	Discharges. Model.	Still Pond. Silt per cusec per hour (ICS).		Kala Bagh Type. Silt per cusec per hour (ICE).	Kala Bagh Type. Percentage efficiency over still pond.
1.	Thal Canal.	2305	·123	·187		·065	65·2%
2.	Hydel Canal.	34400	1·834	·181		·104	42·54%
3.	Muzaffar Garh Canal.	6549	·350	·123		·568	−361·8%
	Total in pocket.	43254	2·307	·164		·246	−50·0%
	EXCLUDERS. Bay No. 1	7200	·384	...	...	·911	...
	Bay No. 2	,,	,,	...	...	1·034	...
	Bay No. 3	,,	,,	...	...	1·328	...
	Total for Excluders.					1·091	...

TABLE III
excluders over still Pond.
canals with still pond.
canals with excluders.

Improved Kala Bagh Type.		Khanki Type		Orthognal Type		Dargai Type.	
Silt per cusec per hour (ICE).	Percentage efficiency over still pond	Silt per cusec per hour.	Percentage efficiency over still pond.	Silt per cusec per hour.	Percentage efficiency over still pond.	Silt per cusec per hour.	Percentage efficiency over still pond.
·154	17·64%	·106	43·21%	·154	17·64%	·073	60·96%
·10	44·75%	·091	49·72%	·089	50·83%	1·46	19·33%
·257	—108·94%	·194	—57·72%	·153	—24·40%	·189	—53·65%
·170	—3·65%	·130	20·73%	·132	19·51%	·130	20·73%
1·388	...	1·622	...	1·596	...	·789	...
1·508	...	1·367	...	1·596	...	·533	...
·581	...	·630	...	·360	...	1·007	...
1·159	...	1·206	...	1·184	...	·777	...

Effect of Shape of Guide Banks with Different Probable River Approaches on Silt Exclusion into off-Take

TABLE I.

Test No.	Shape of guide bank	Type of River Approach	Discharge	Silt in right bank canals	Silt in left bank canals
1 (a)	Left guide bank Belly shaped of length 7,700′ and right guide bank length. 6706 6700′.	Left handed approach with left guide bank nose fully under attack *i.e.*, Approach No. 1.	4 lac 6 lac Total	·476 ·27 ·38	·415 4·86 1·89
2 (a)	Guide banks as in Test 1	Left handed approach touching the u/s curved part of left guide bank but not fully bringing nose under attack.	4 lac 6 lac Total	·543 ·965 ·62	·218 1·039 ·4915
(b)	Both the banks Belly Shaped.	Approace No. 2.	4 lac 6 lac Total	... ... ·77	... ... ·30
3	Guide banks as in test 1	Right handed approach with right guide bank nose under attack.	4 lac 6 lac Total	8·78 7·5 8·35	·168 ·167 ·167
(a)	Guide banks as in test 1	Straight approach normal to the weir towards	4 lac 6 lac Total	·275 ·508 ·32	·502 ·938 ·647
(b)	Both the banks Belly shaped.	Approach No. 4.	4 lac 6 lac Total	... ... ·38	... ... ·602

BIBLEOGRAPHY

Lane E. W., ... Suspended load control and the problem of channel stabilization, Proe, Hydraulic Conference, Bulletin 20 Iowa.

2. MacDougalls C.H., ... Bed sediment transportation in open channels. Trans ; American Geo physical Union 1933, page 491.

3. Chang, Y. L., ... Laboratory investigation of flume traction and transportation. Trans. Am. S. C. E. Vol. 104, 1939, page 1246—1313.

4. Sheild, A., ... Anwendung der Aehnlichkeitsmechanik und der turbulenz-forschung auf die geschiebe bewegung.

5. Schoklitch A, ... Uber Schleppkraft und geschiebebewegung 1914, page 50.

6. Meyer Peter, ... Neure Veresuchsresultte uber Gescbiebe betrieb Schweisorische bauzeitung No. 103, 1934.

or

7. Obrien M. P., ... Notes on transportation of silt by streams. Transactions A. G. U. Vol , 17, 1236, pp. 431-436.

8. Straub L, G., ... House document 238, 73 d Congress, 2nd Session U. S. Government Printing Office, Washington D.C,1935 1, 1135

9. ——– ... An Introduction to Fluvial Hydraulics by Serge Leliavsky, Page 170.

10. Straub, L, G., ... Loc -- cit.

11. Pettis C. R., ... Discussion of Prof. Lane's paper in Trans. A.S.C.E. Vol. 102, page 149.

12. ——— ... The maximum permissible mean velocity in open channel Hydro-technical construction quoted from introduction to Fluvial Hydraulics by Leliavsky.

13. Mushtaq Ahmad A. R. Chaudhari and S.A. Awan. ... Technical Report No. 80/Hyd/53 Model experiments on the head regulator of Balloki Sulemanki Link and Balloki level Crossing to improve approach conditions.

14. Tariq A. & Sarfraz ... Proceeding West Pakistan Engineering Congress 1958. Paper No. 330.

15. Inglis C. (C.) ... I.A.H.R. 1951 Bombay.

16. John R. Freeman ... Hydraulic Laboratory Practice.

17. Vogel H.D., ... Movement of bed load in Forked Flume Civil Engineering, Vol. IV February 1934.

18. Pir Mohd. Ibrahim and Mushtaq Ahmad ... "On sitting of Distributors and factors affecting sediment Exclusion from canals." Proceedings of the Punjab Engineering Congress 1954. Paper No. 301.

19. Inglis C. C. ... "Report on tests made on a model of a group of regulators at Odereclal" Bombay P. W. D. Technical Paper No. 26.

20. Mushtaq Ahmad ... "Some aspects of design of Headworks to exclude sediment from canals". proceeding I.A.H.R. Bombay 1951.

21. Serge Leliavsky ... Irrigation and Hydraulic Design Vol. II. Page No. 388.

22. F. F. Haigh ... Paper No. 211. "Silt excluders." Proceedings of the Punjab Engineering Congress, 1938.

23. S. I. Mahboob ... Paper No. 251. "The Kalabagh Barrage." Proceedings of the Punjab Engineering Congress, 1842.

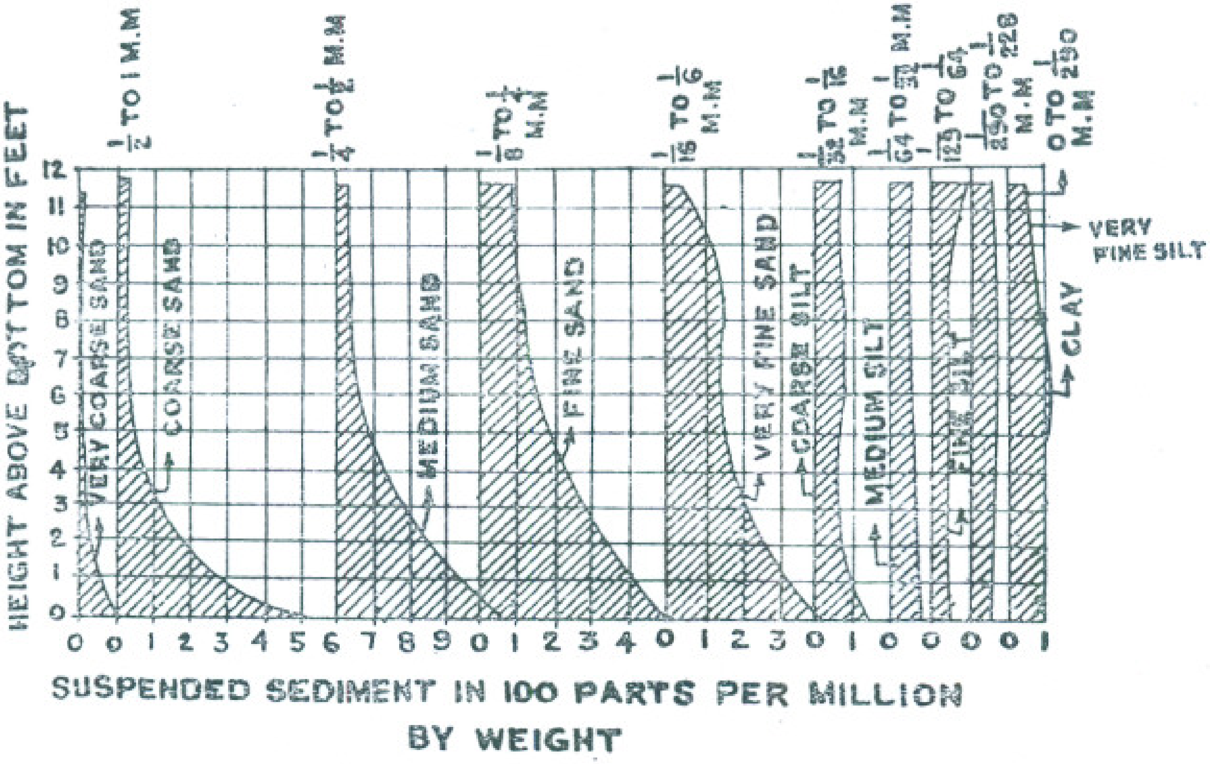
24. H. W. King ... Paper No. 169. "Silt Exclusion from distributories. Proceedings of the Punjab Engineering Congress, 1933.

25. —— ... Punjab Irrigation Research Institute, Report for the year ending April 1942.

PAPER NO. 341

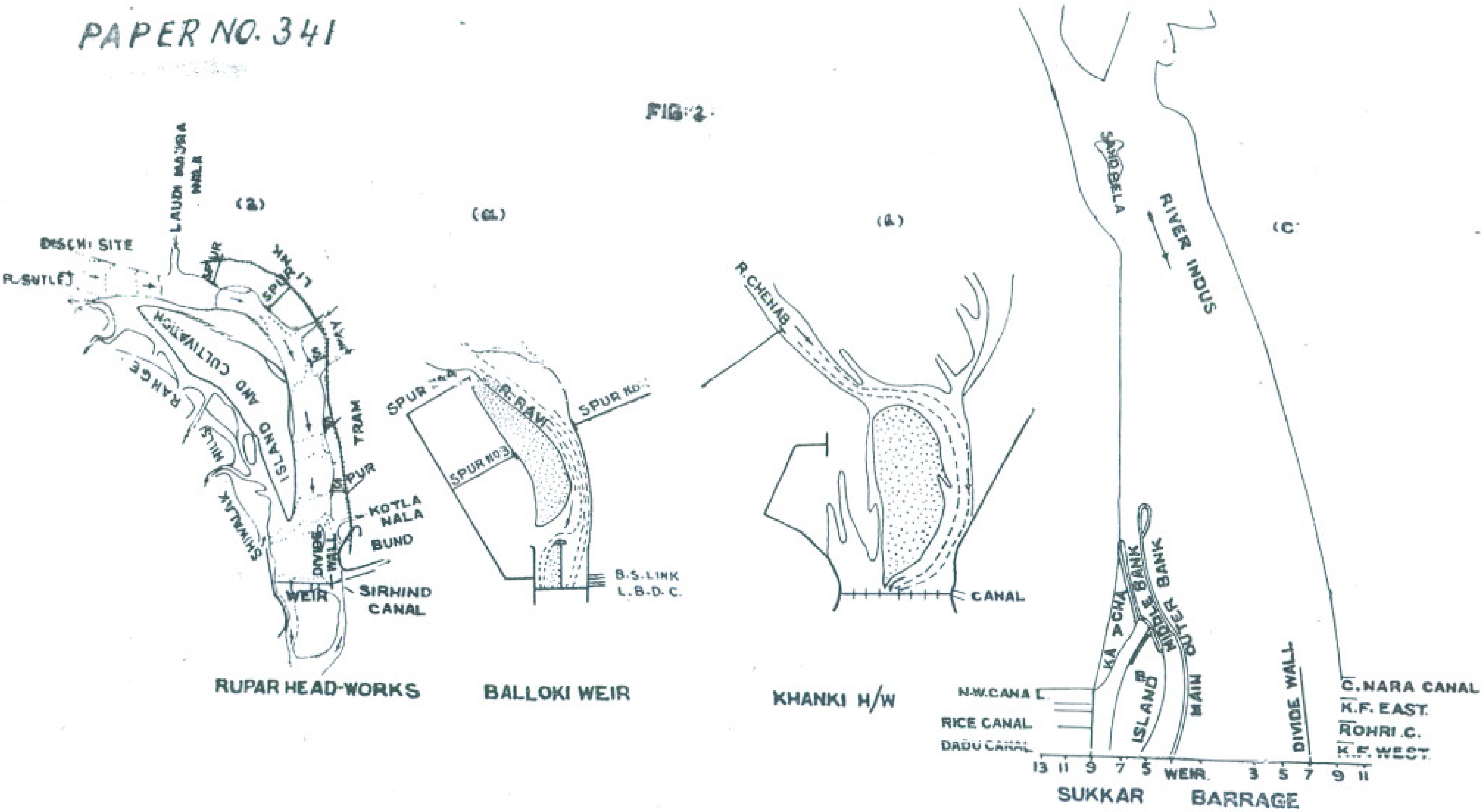
270·59·1

FIG. 1



PAPER NO. 341

FIG: 2.



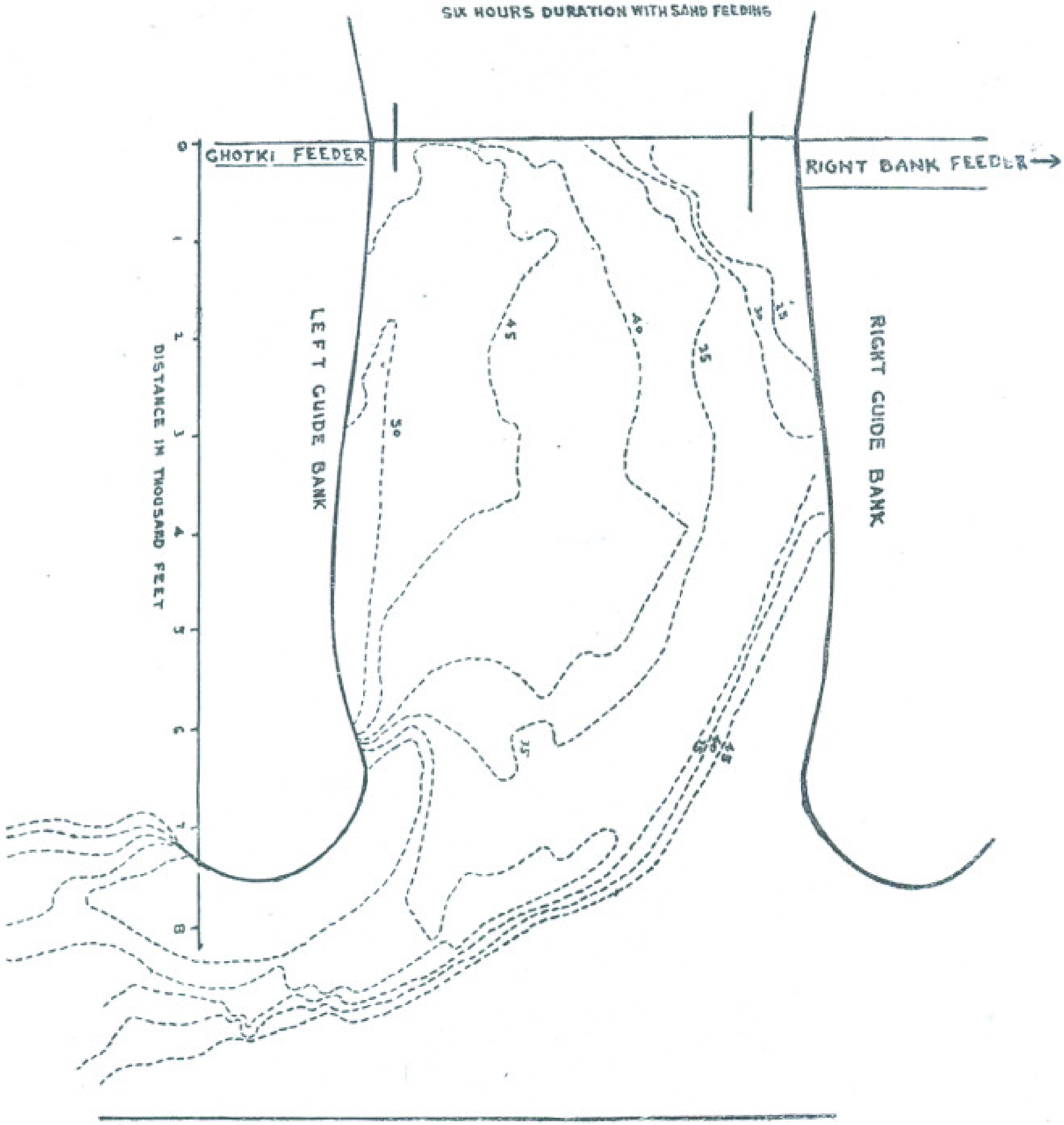
PAPER NO. 341

FIG. 3

MODEL OF RIVER INDUS AT GUDU BARRAGE

61-SD-6

TEST SHOWING BED CONFIGURATION AFTER II SEASON RUN WITH DISCHARGES EQUIVALENT TO 400000 & 600000 CUSECS EACH OF SIX HOURS DURATION WITH SAND FEEDING



PAPER NO. 341

FIG 3(a)

MODEL OF GUDDU BARRAGE 61.59.4

TEST SHOWING BED CONFIGRATION AFTER 1ST SEASON RUN OF *DISCHARGES EQUIVALENT TO 400000 AND 60000 CUSECS WITH SPURS OF LENGTH 2000 PLACED PARALLEL TO GUIDE TO GUIDE BANK AT THEIR U/S ENDS

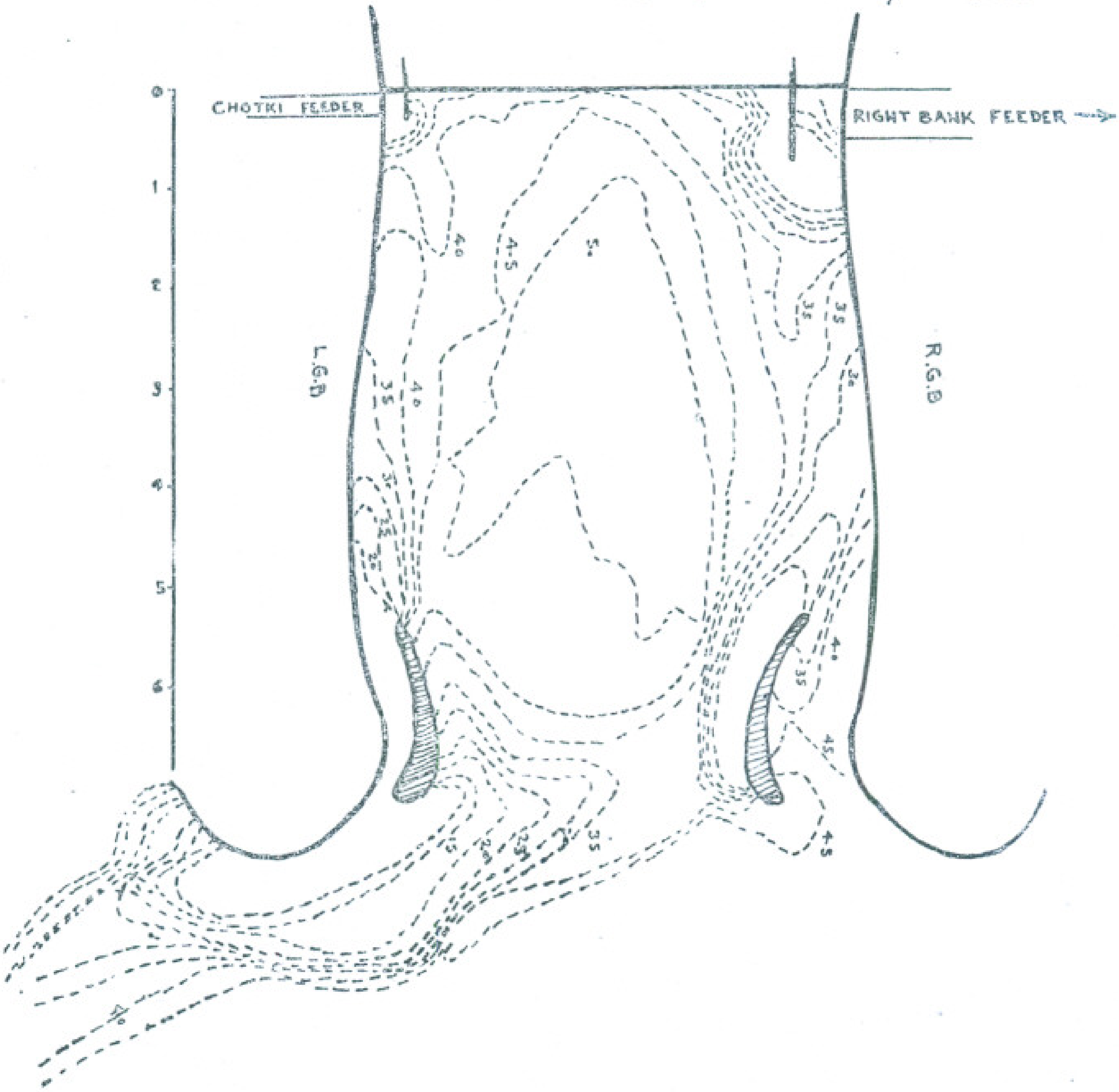
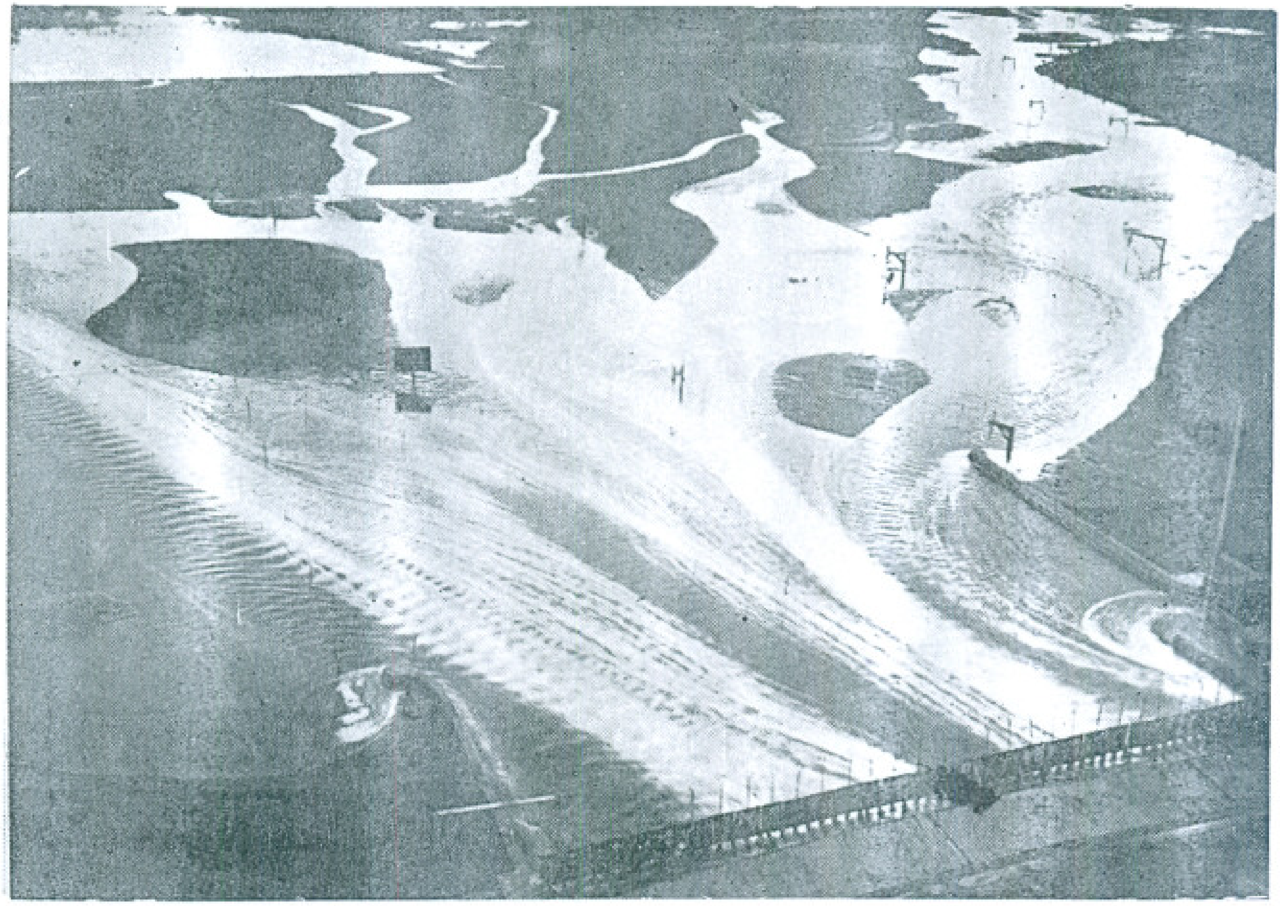


Fig. No. 4.



Pocket is drawing from inside of the curve.

PAPER NO. 341

FIG: 5

272-59-1

MODEL OF RIVER TAWI AND CHENAB AT MARALA HEAD WORKS
BED CONFIGURATION AFTER FIRST SEASON RUN WITH DEVICES

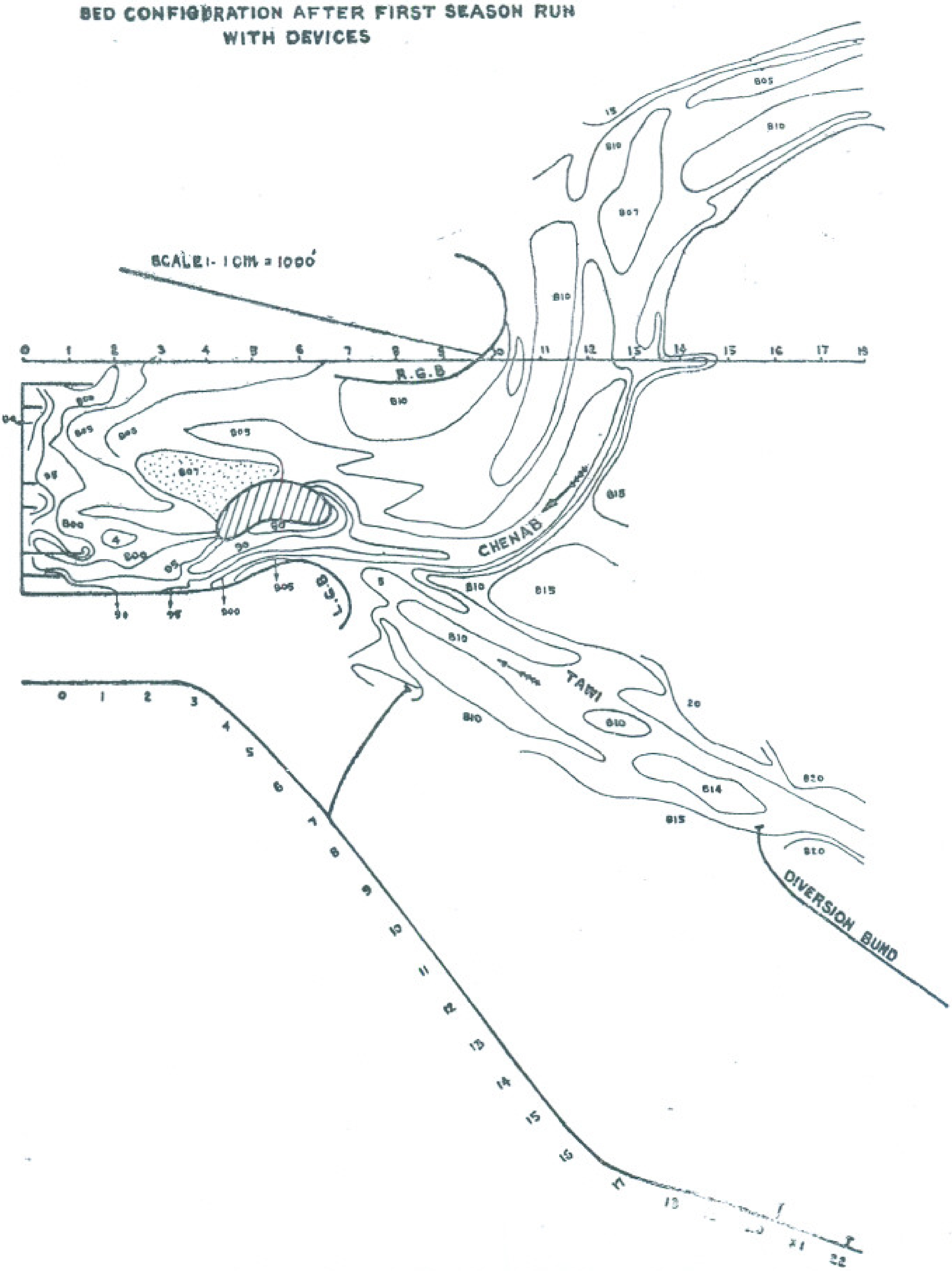
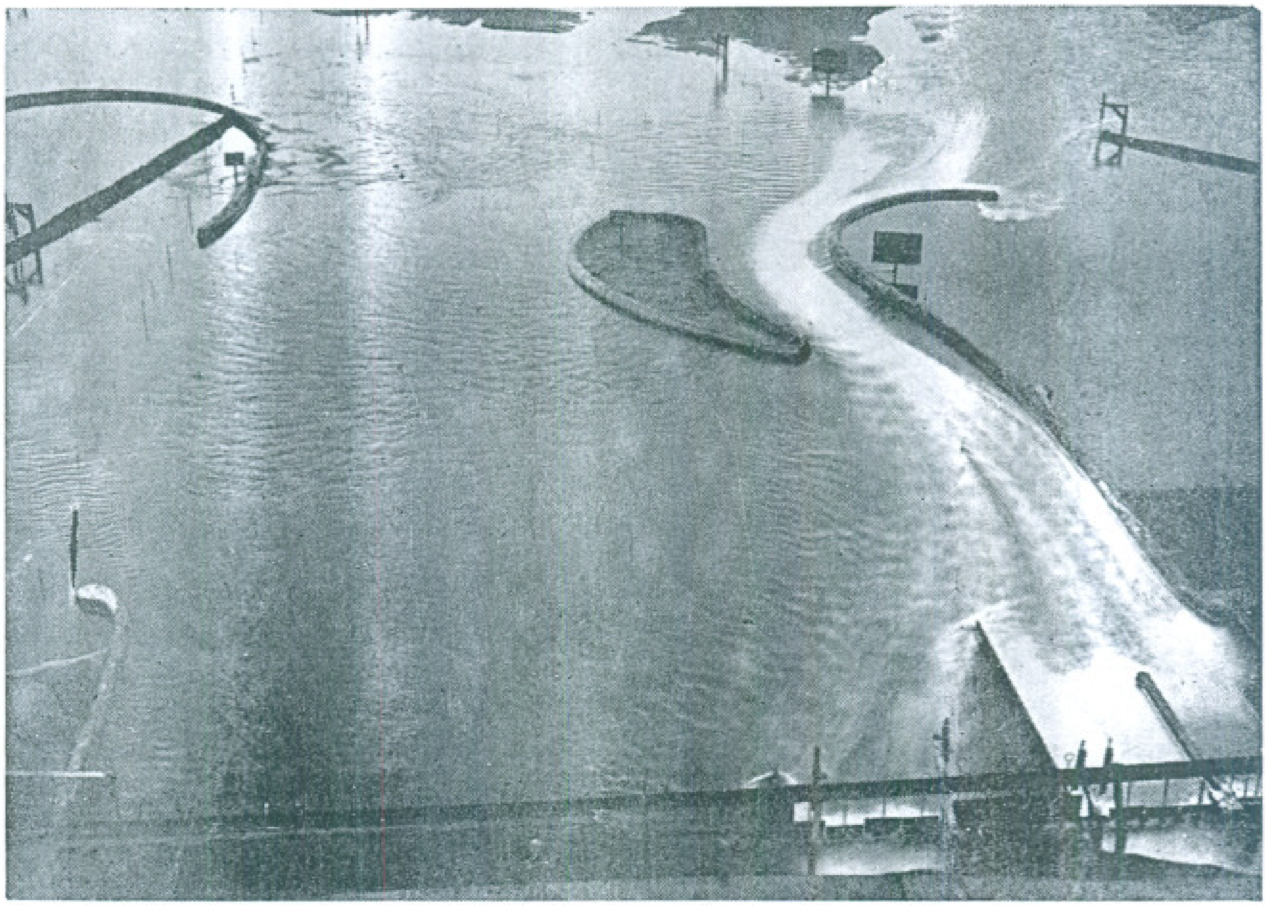


Fig. No. 5-A. PAPER NO. 341.



PAPER NO. 341

FIG: 5(6)

MODEL OF RIVER TAWI AND CHENAB AT MARALA HEAD WORKS TEST SHOWING BED SURFACE CURRENT DIRECTIONS (WITH DEVICES) WHEN TAWI AND CHENAB DRAWING 50000 AND 157200 CUSECS RESPECTIVELY.

SCALE 1 CM = 500'

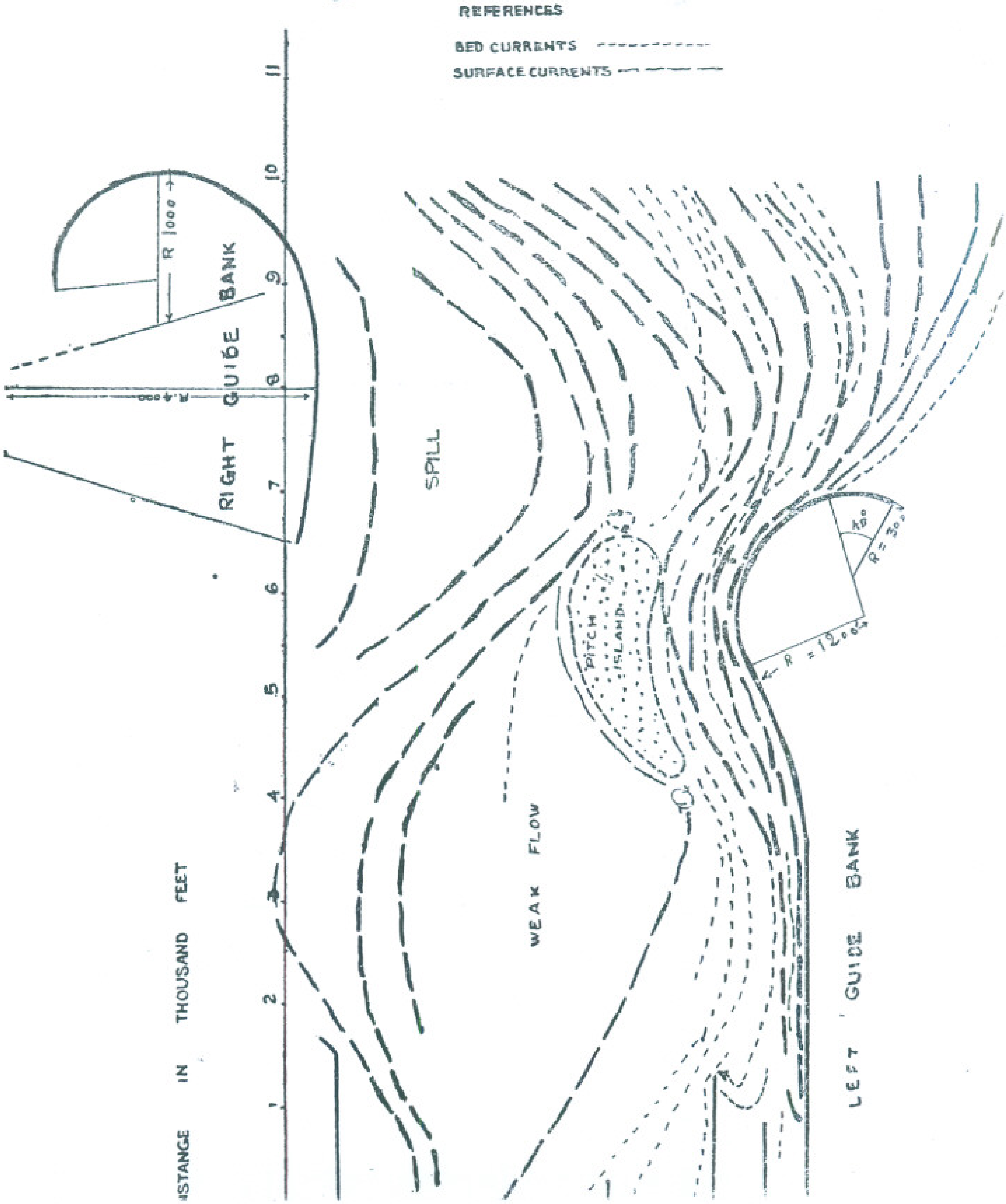
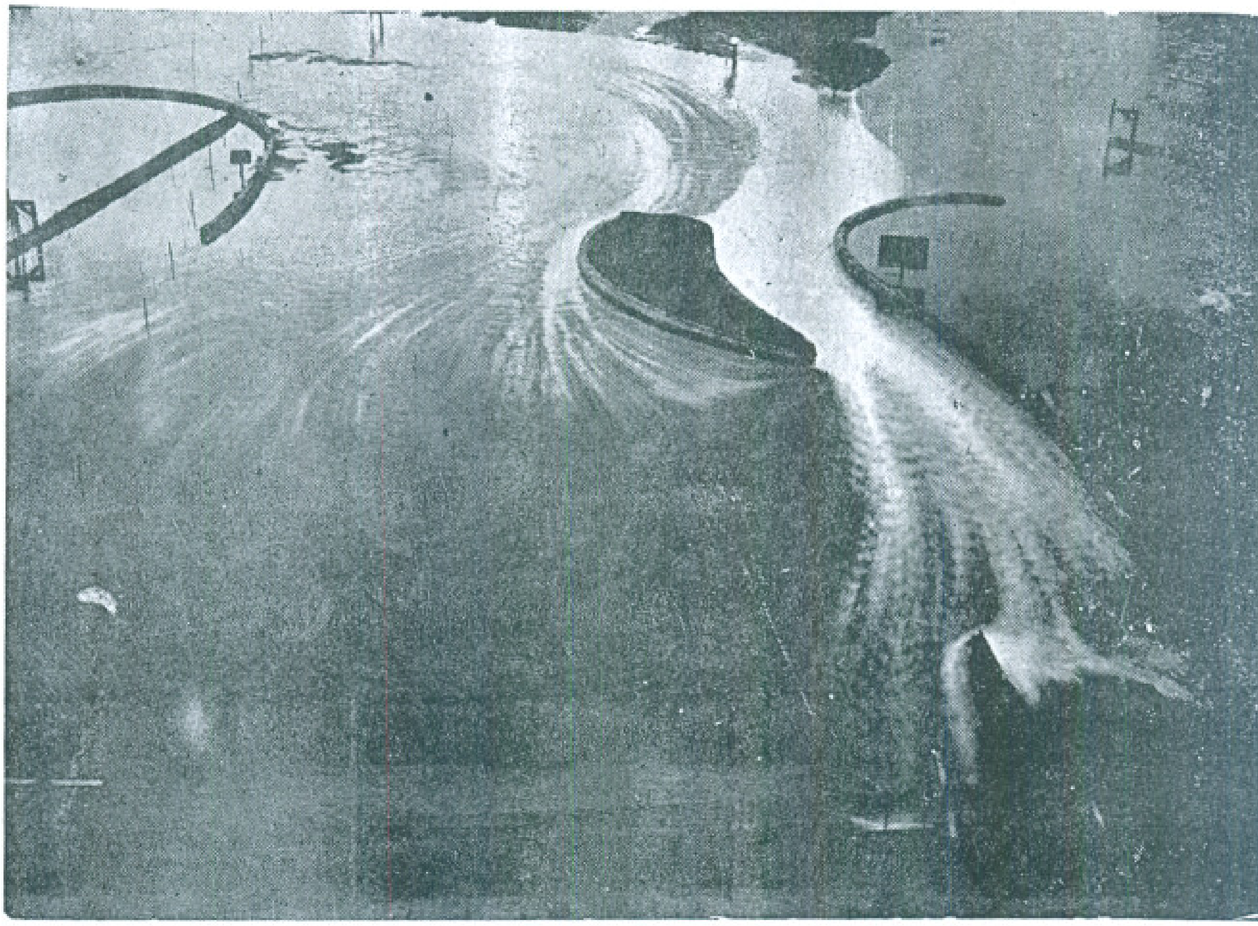
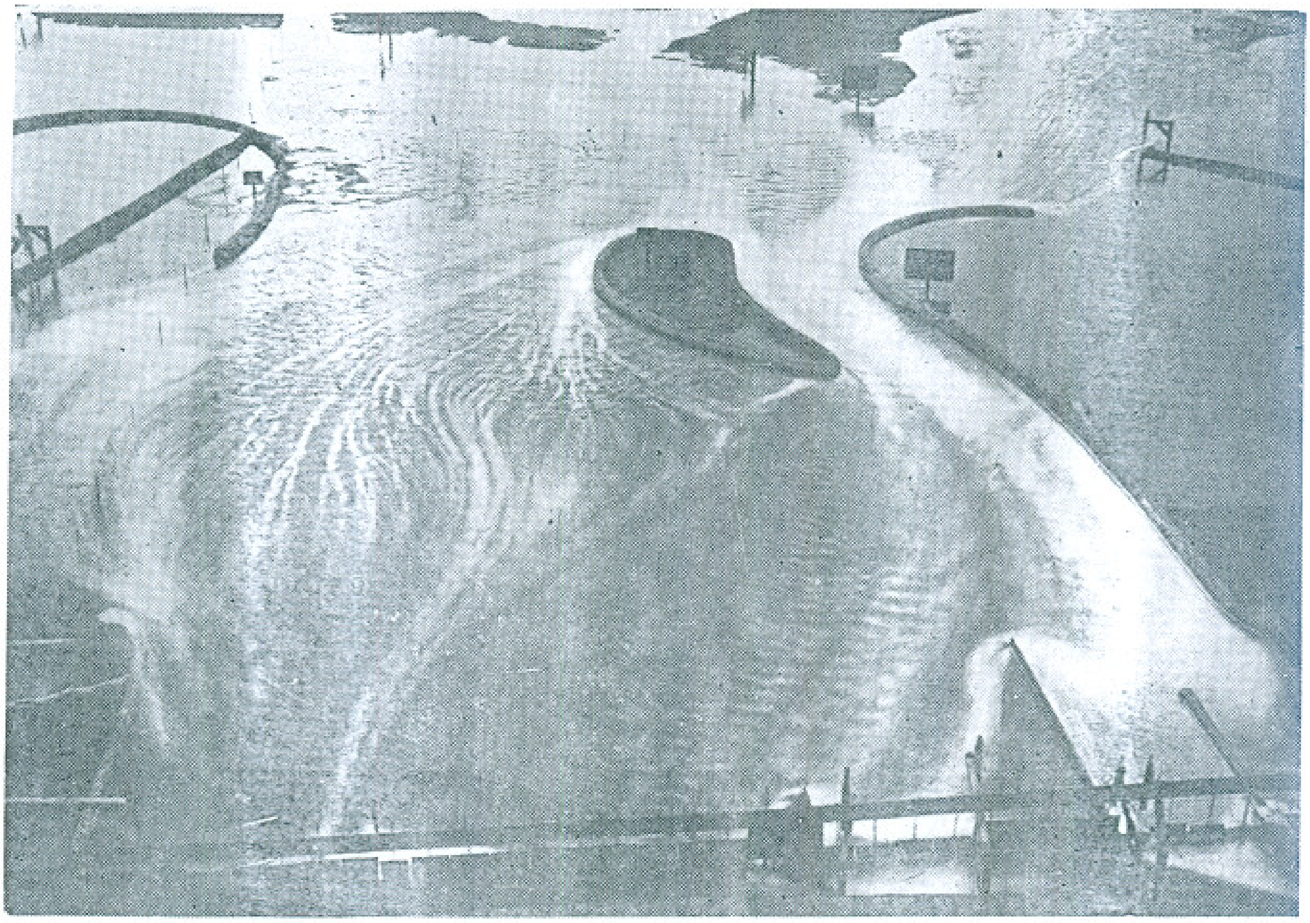


Fig. No. 5-C.



Notice channel flow entoring the pocket.

Fig. No. 5-D.

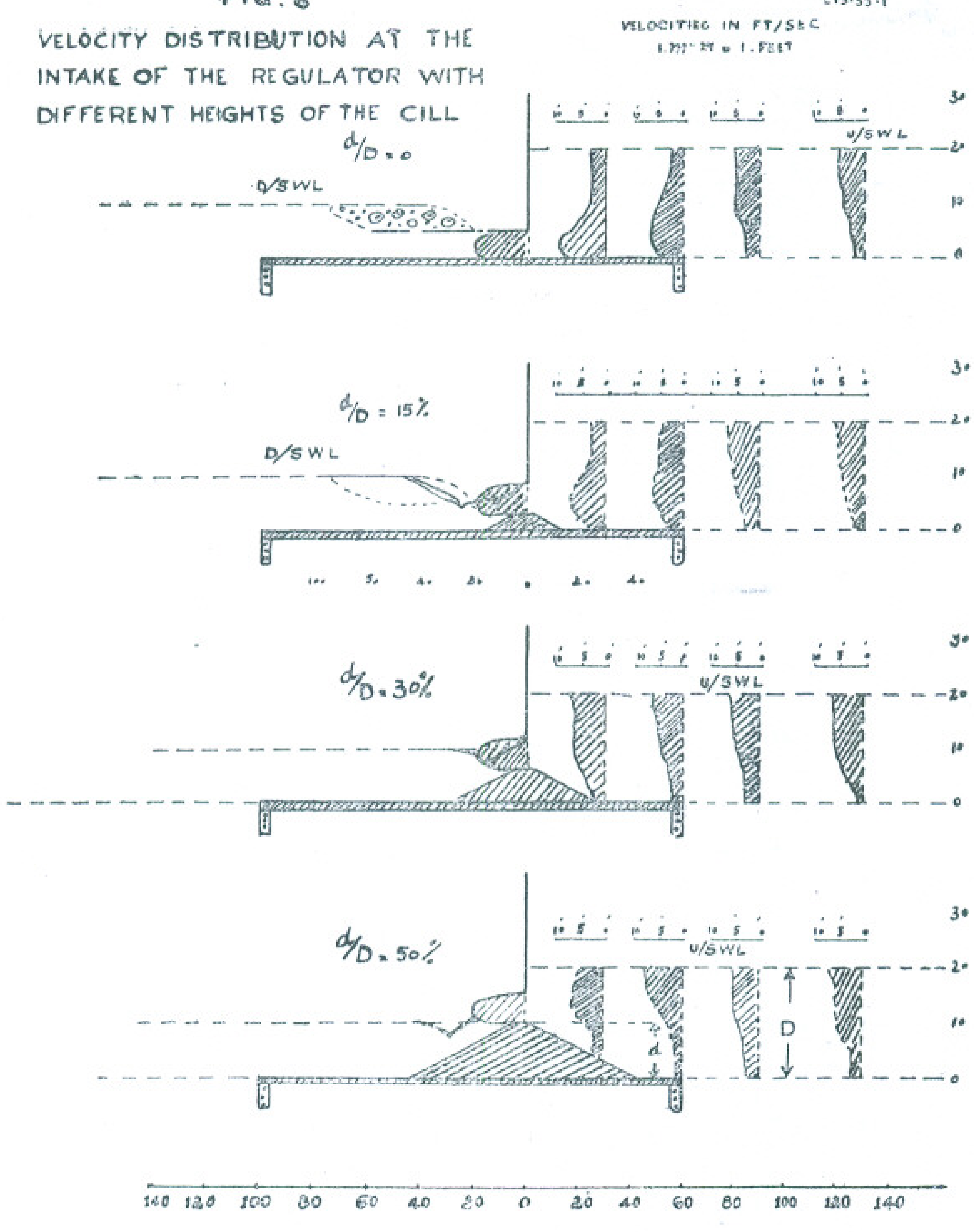


Notice some flow from Tawi is approaching under aluices in bay No. 3.

PAPER NO. 341

FIG: 6

VELOCITY DISTRIBUTION AT THE INTAKE OF THE REGULATOR WITH DIFFERENT HEIGHTS OF THE CILL



Lib 58-3

PAPER NO. 341

FIG: 7 (a)

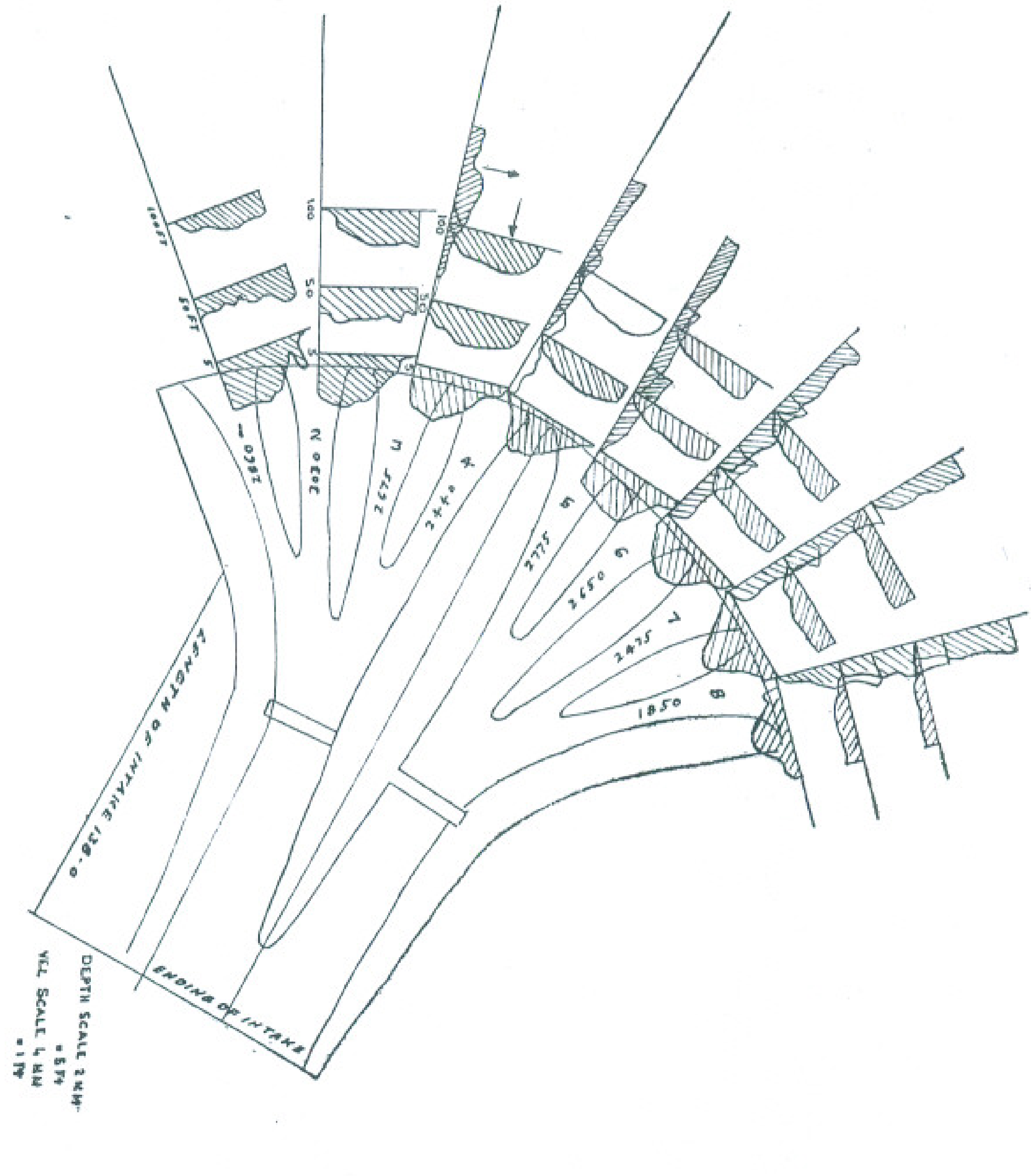
TEST NO. 2

MODEL OF WARSAK DAM

Q = 100,000 CS.

Q TUNNEL = 24000 CS

VELOCITY DISTRIBUTION ALONG AND TANGENTIAL TO INTAKE FLOW

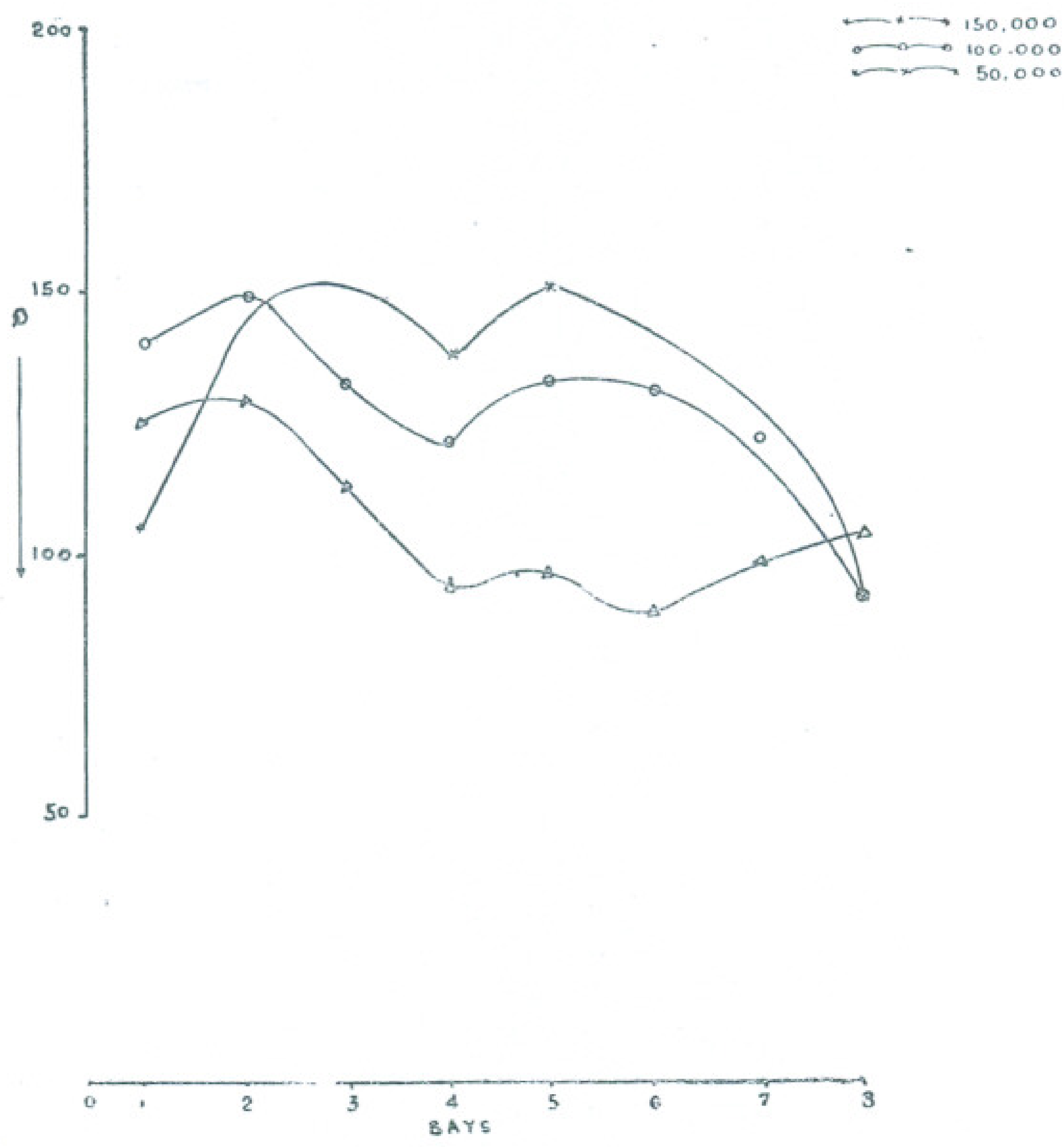


PAPER NO. 341

287-58-1

FIG:-7(b)

MODEL OF WARSAK DAM
DISTRIBUTION OF DISCHARGE PER FOOT RUN
THROUGH DIFFERENT BAYS



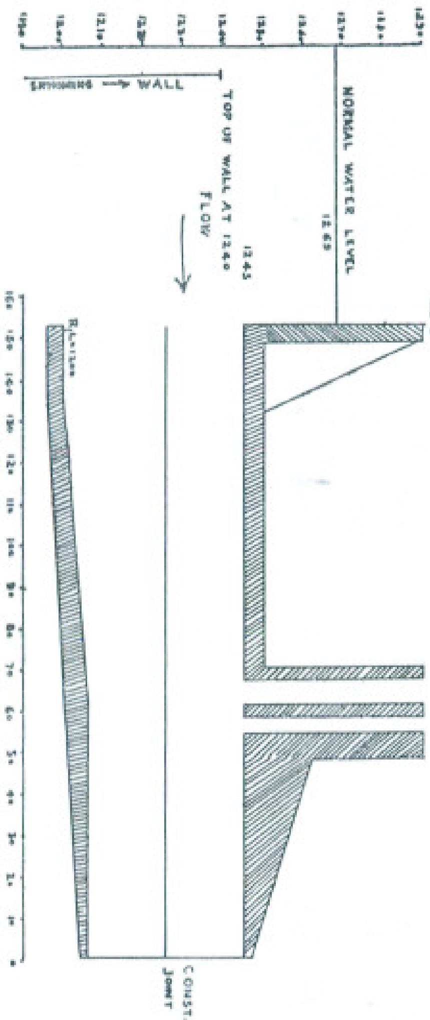
PAPER NO. 341

FIG. 8

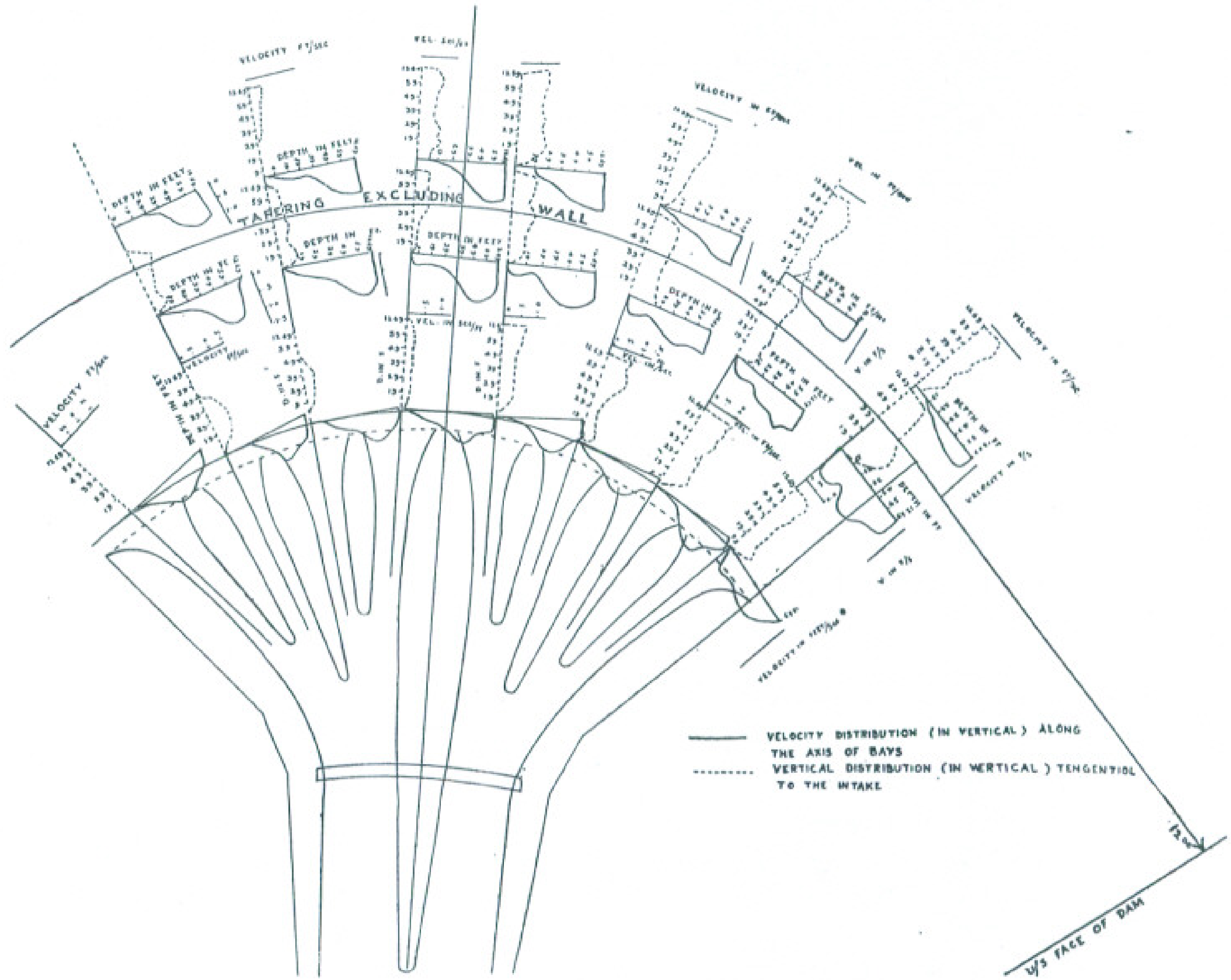
MODEL OF WARSAK DAM

VELOCITY DISTRIBUTION ALONG & TANGENT TO FLOW AT 5 FEET FROM INTAKE AND 10 FEET IN AND OUTSIDE THE EXCLUDER WALL

Q = 100,000 CS



L. SECTION OF INTAKE OF POWER TUNNEL



PAPER NO. 341

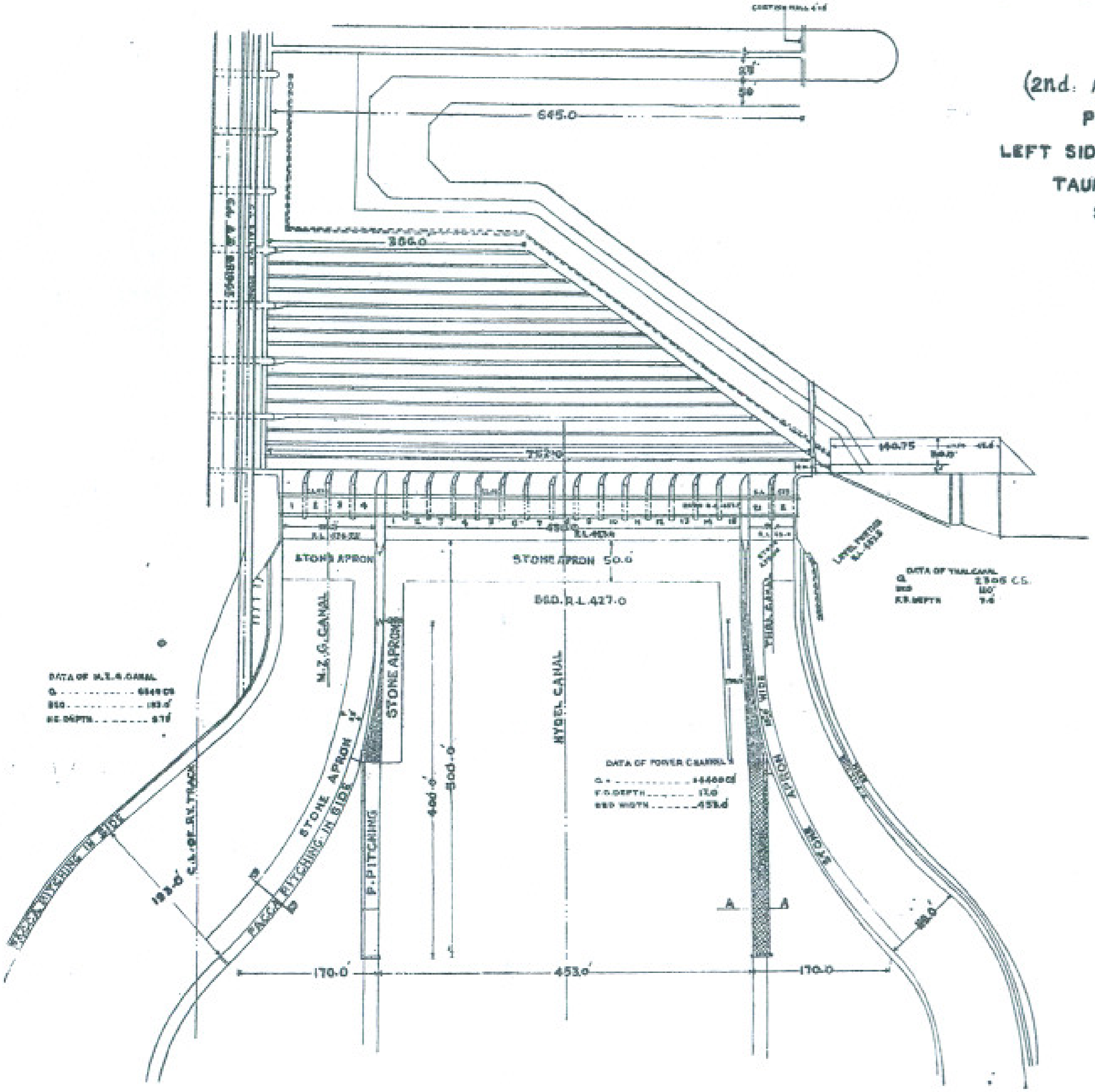


FIG. 9
(2nd. ALTERNATIVE)
PLAN OF
LEFT SIDE REGULATOR
TAUNSA BARRAGE
SCALE = 1/500

PAPER NO. 341

FIG 10(a)

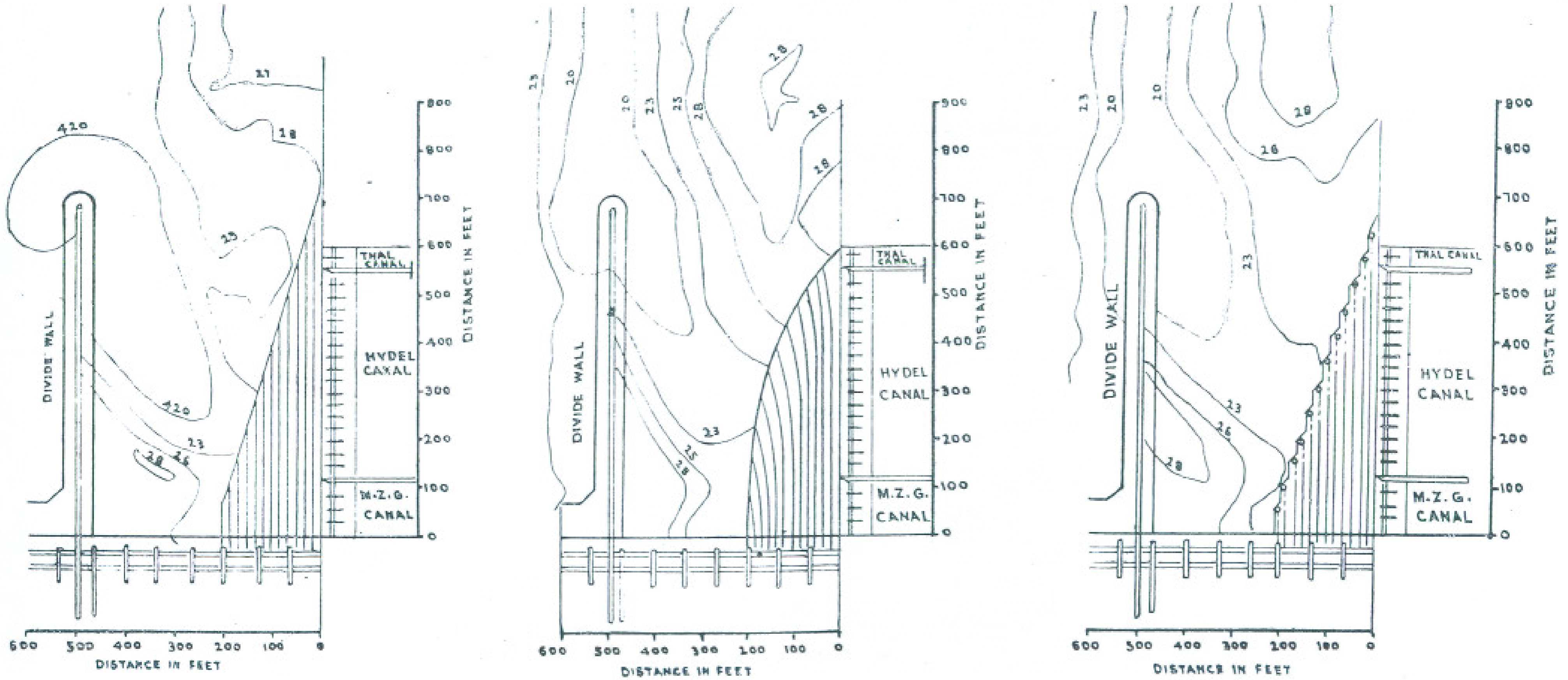
MODEL OF TAUNSA SILT EXCLUDER

167-59-1

ORIGINAL TYPE IMPROVED

ORTHOGNAL TYPE

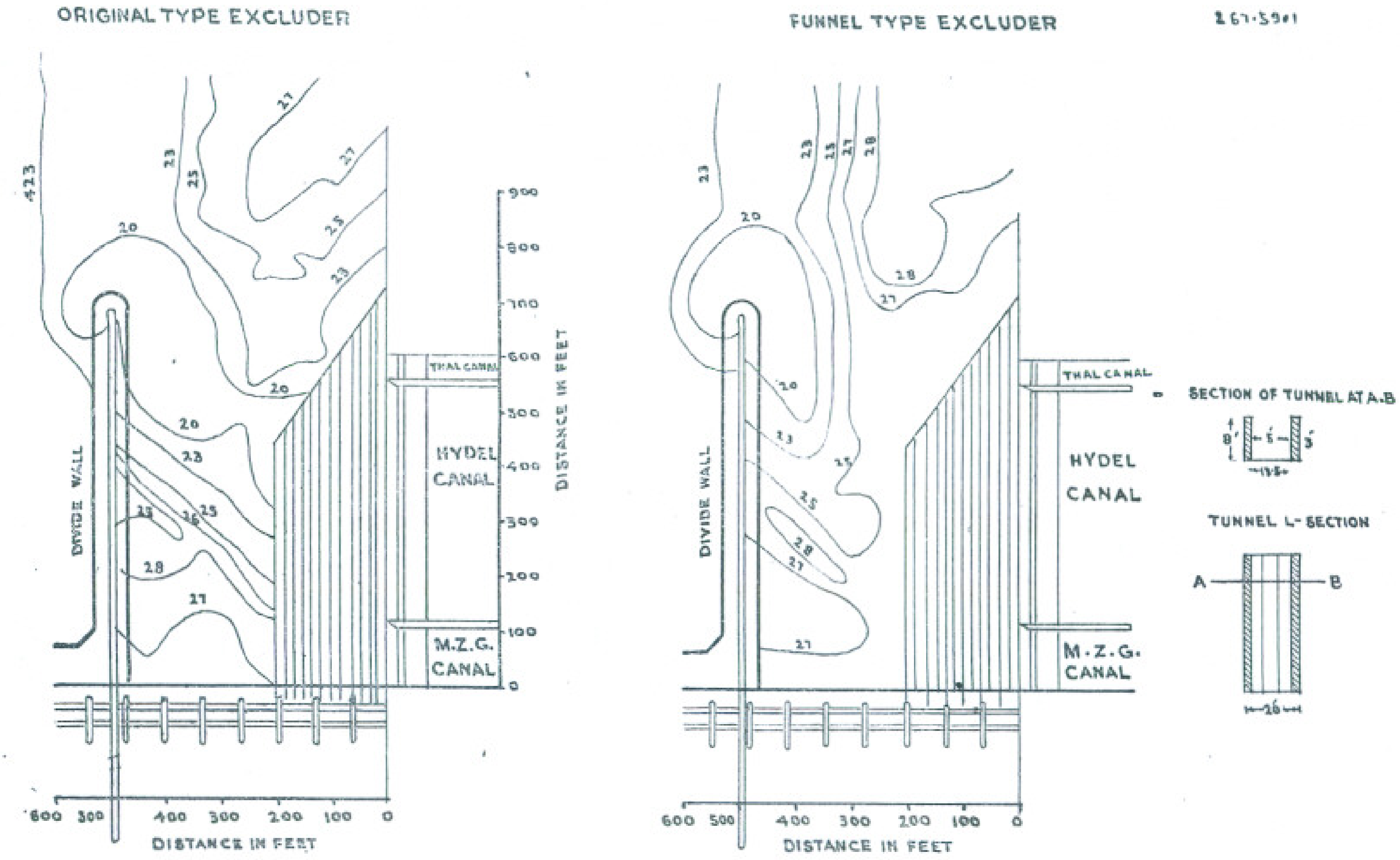
KHANKI TYPE



PAPER NO. 341

FIG 10(b)

MODEL OF TAUNSA SILT EXCLUDER



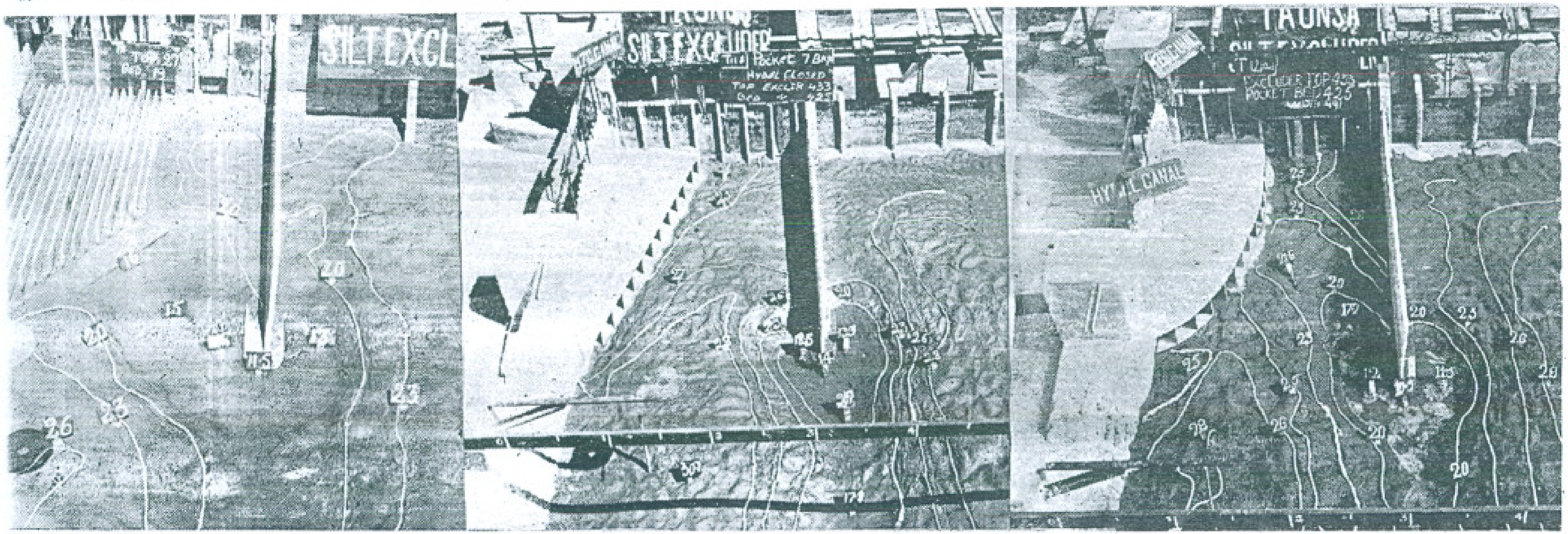
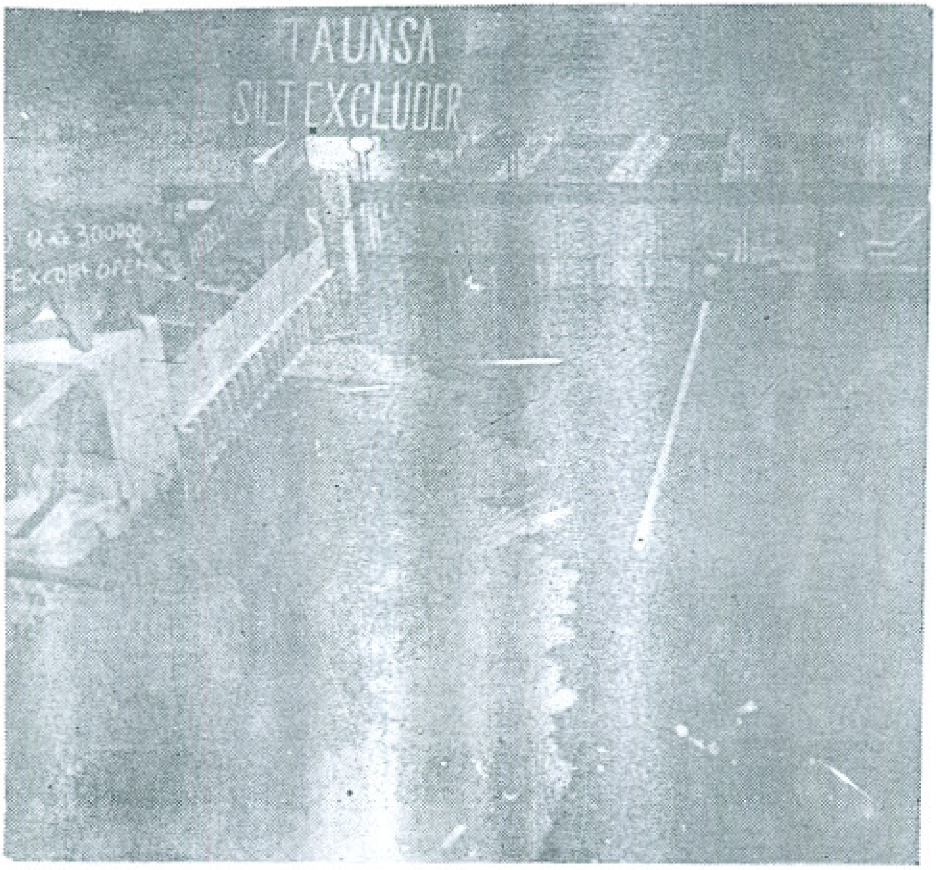

SILT EXCL
SILT EXCLUDER
Pocket 7 Bay
HYDEL CLOSED
TOP EXCLR 433
EXCLUDER TOP 433
POCKET BED 425
HYDEL CANAL

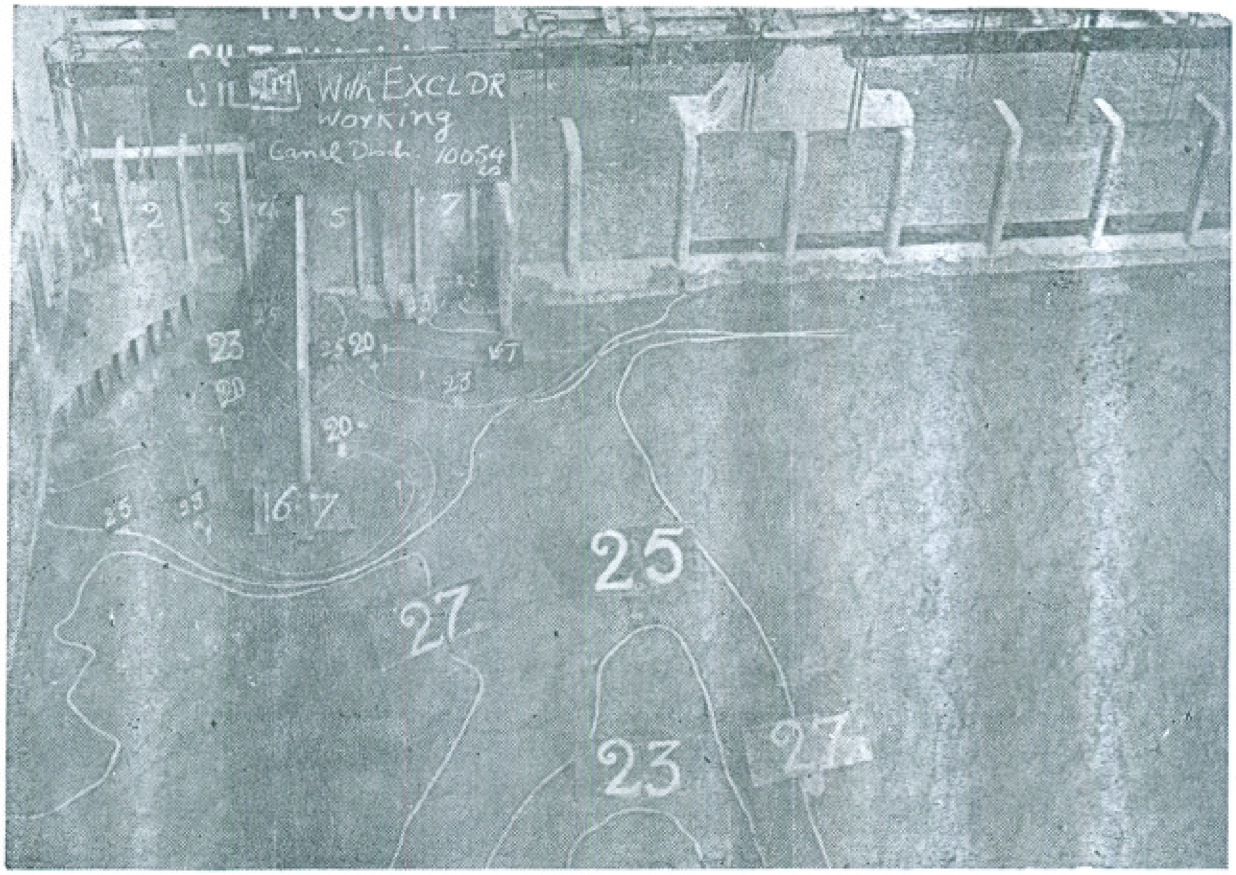
Fig. No. 10 (C)

Fig. No. 11-A. PAPER No. 341.



Notice that Muzaffar Garh Canal is drawing from the outerside of the curve.

Fig. No. 11-B.



PAPER NO. 341

266-59-2

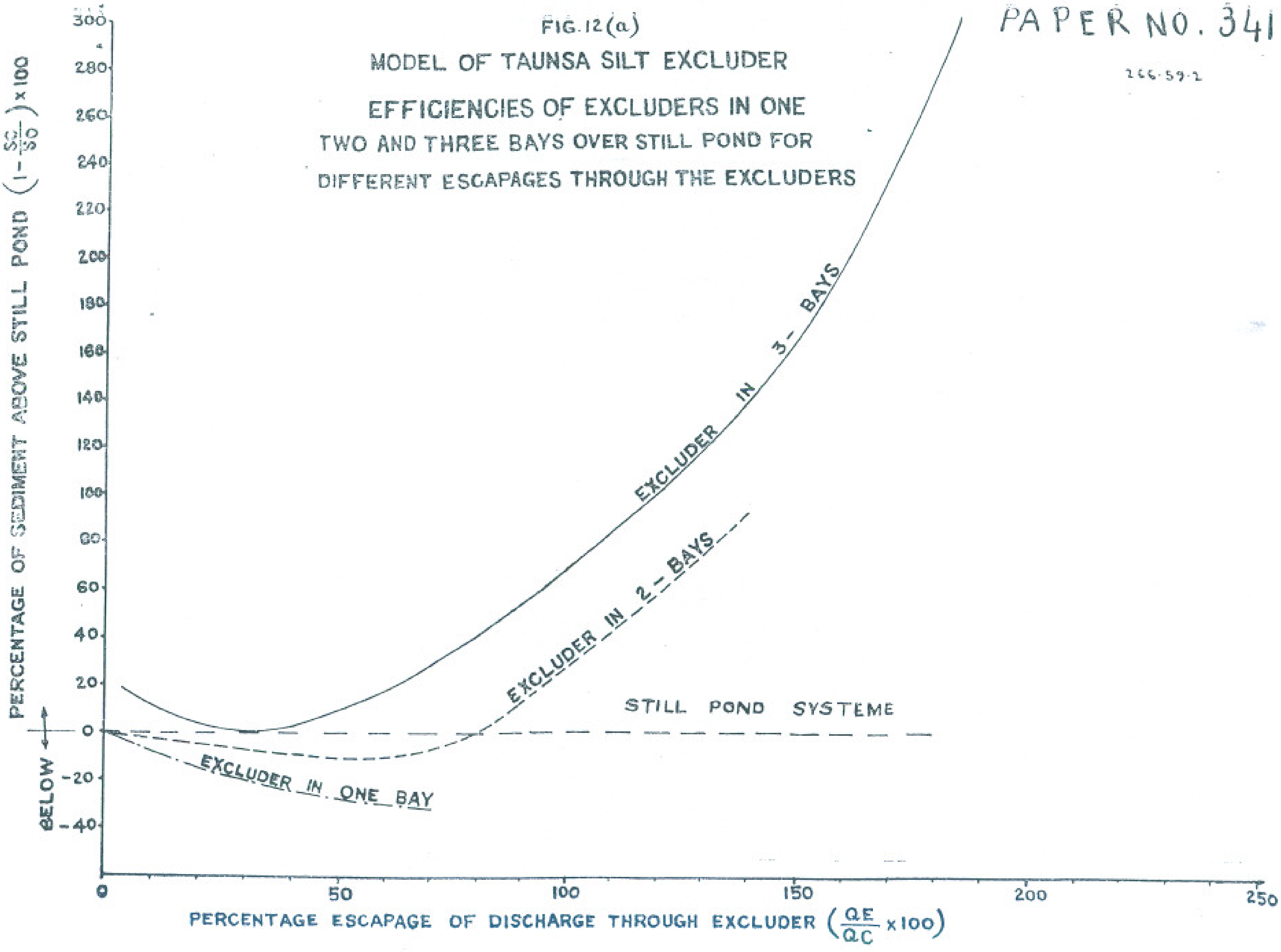


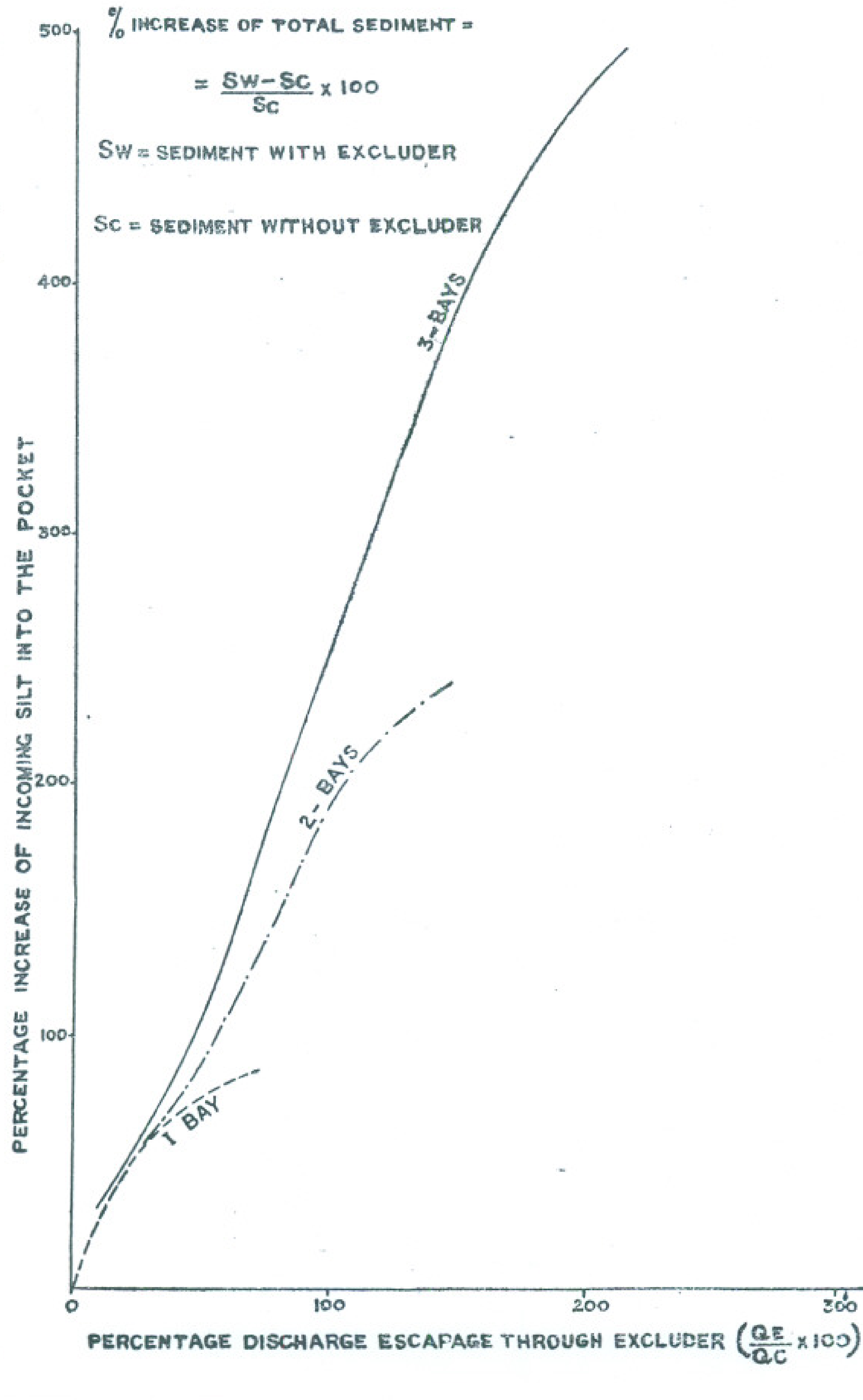
FIG.12(b)

PAPER NO, 341

186-534

MODEL OF TAUNSA SILT EXCLUDER

PERCENTAGE INCREASE OF TOTAL SEDIMENTS INTO THE POCKET WITH EXCLUDERS IN ONE, TWO AND THREE BAYS FOR DIFFERENT DISCHARGES THROUGH THE EXCLUDERS



PAPER NO. 341

FIG 13(a)

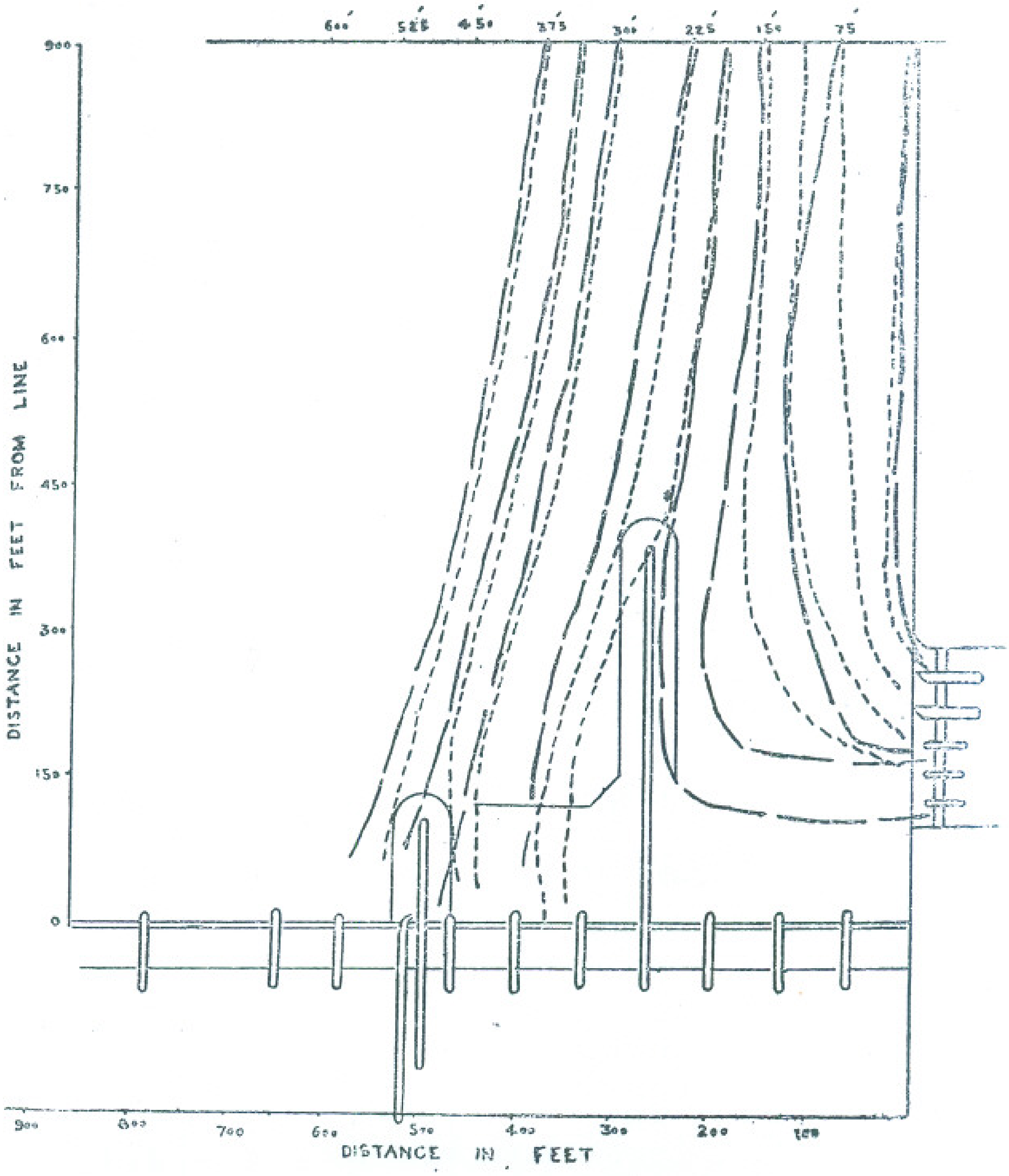
MODEL OF TAUNSA SILT EXCLUDER

SHOWING CURRENT DIRECTIONS WITHOUT EXCLUDER

Q R = 300000 CS.

——— ——— SURFACE CURRENTS

- - - - - - - - BED "



PAPER NO. 341

FIG 13(b)

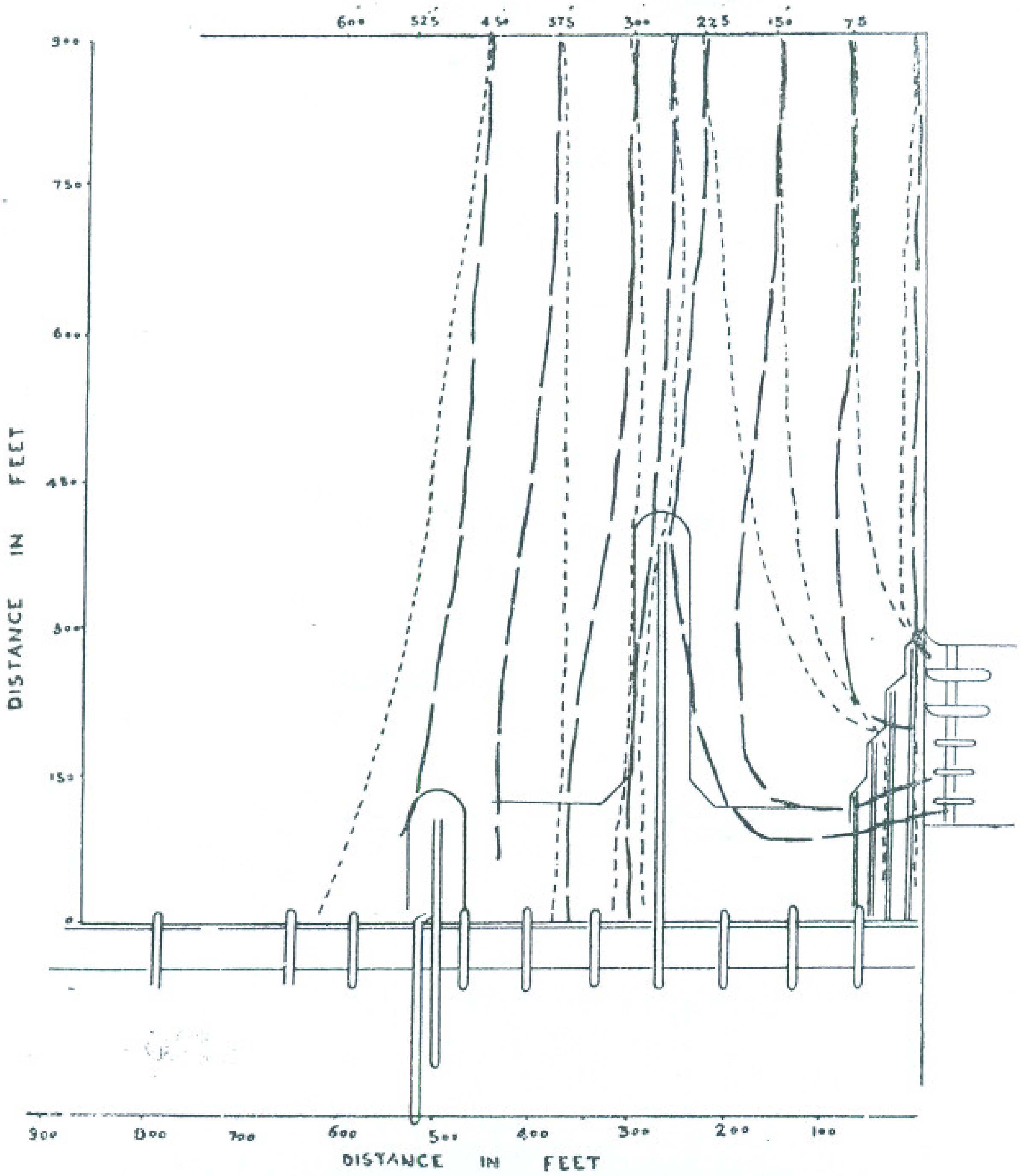
MODEL OF SILT EXCLUDER

SHOWING CURRENT DIRECTIONS WITH EXCLUDER COVERING 1 BAY OF POCKET AND ESCAPAGE 72% OF THE CANAL

Q R = 300000 CS

——→—— SURFACE CURRENTS

- - - → - - - BED "



PAPER NO. 341

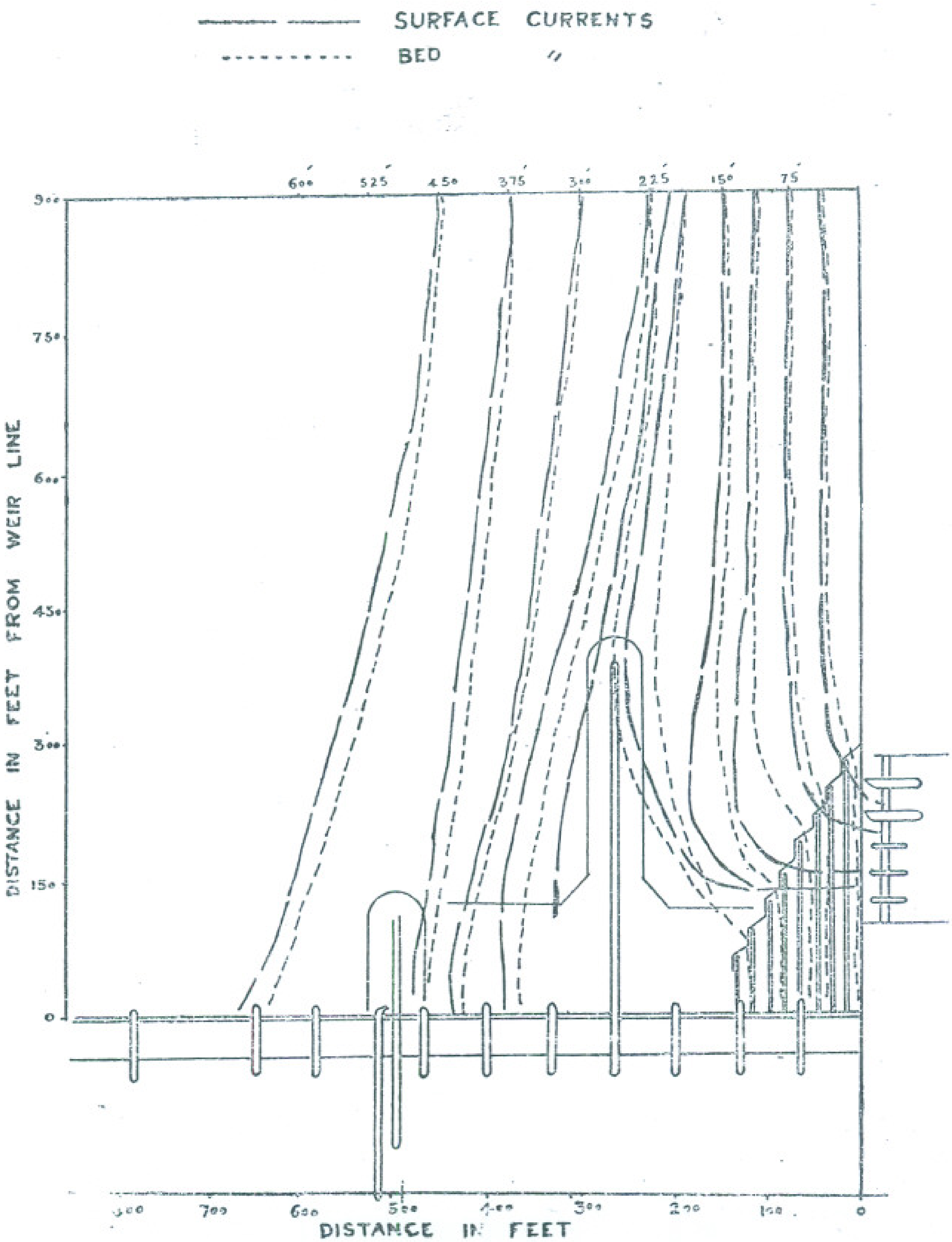
FIG 13(C)

165-59-4

MODEL OF TAUNSA SILT EXCLUDER

SHOWING CURRENT DIRECTIONS WITH EXCLUDER COVERING 2-BAYS OF THE POCKET AND ESCAPE 72% OF THE CANAL.

QR = 300000 CS



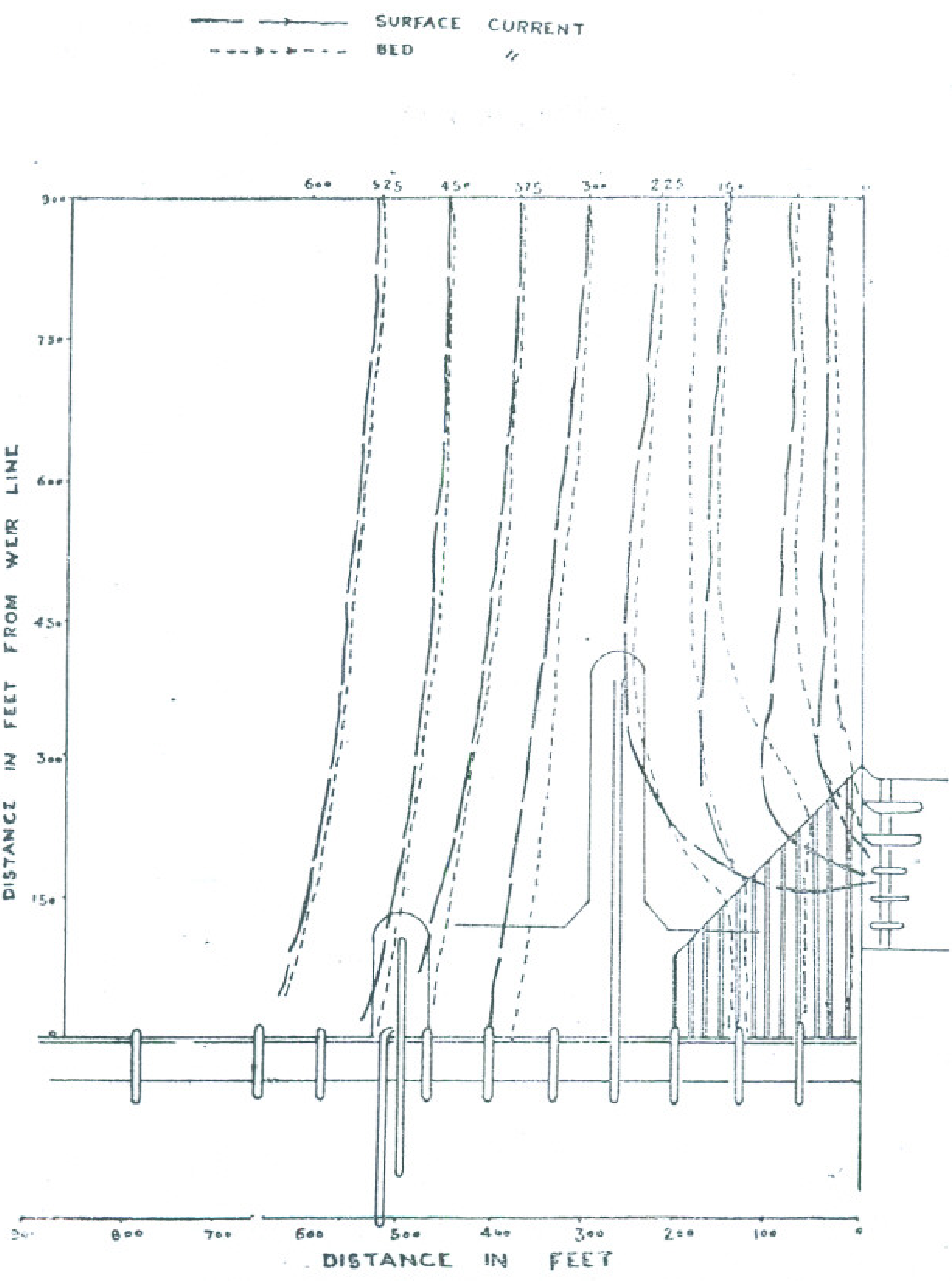
PAPER NO. 34

FIG 13(d)

MODEL OF SILT EXCLUDER

SHOWING CURRENT DIRECTIONS WITH EXCLUDER COVERING 3-BAYS OF THE POCKET AND ESCAPAGE 72% OF THE CANAL.

QR = 300000 CS



PAPER NO. 341

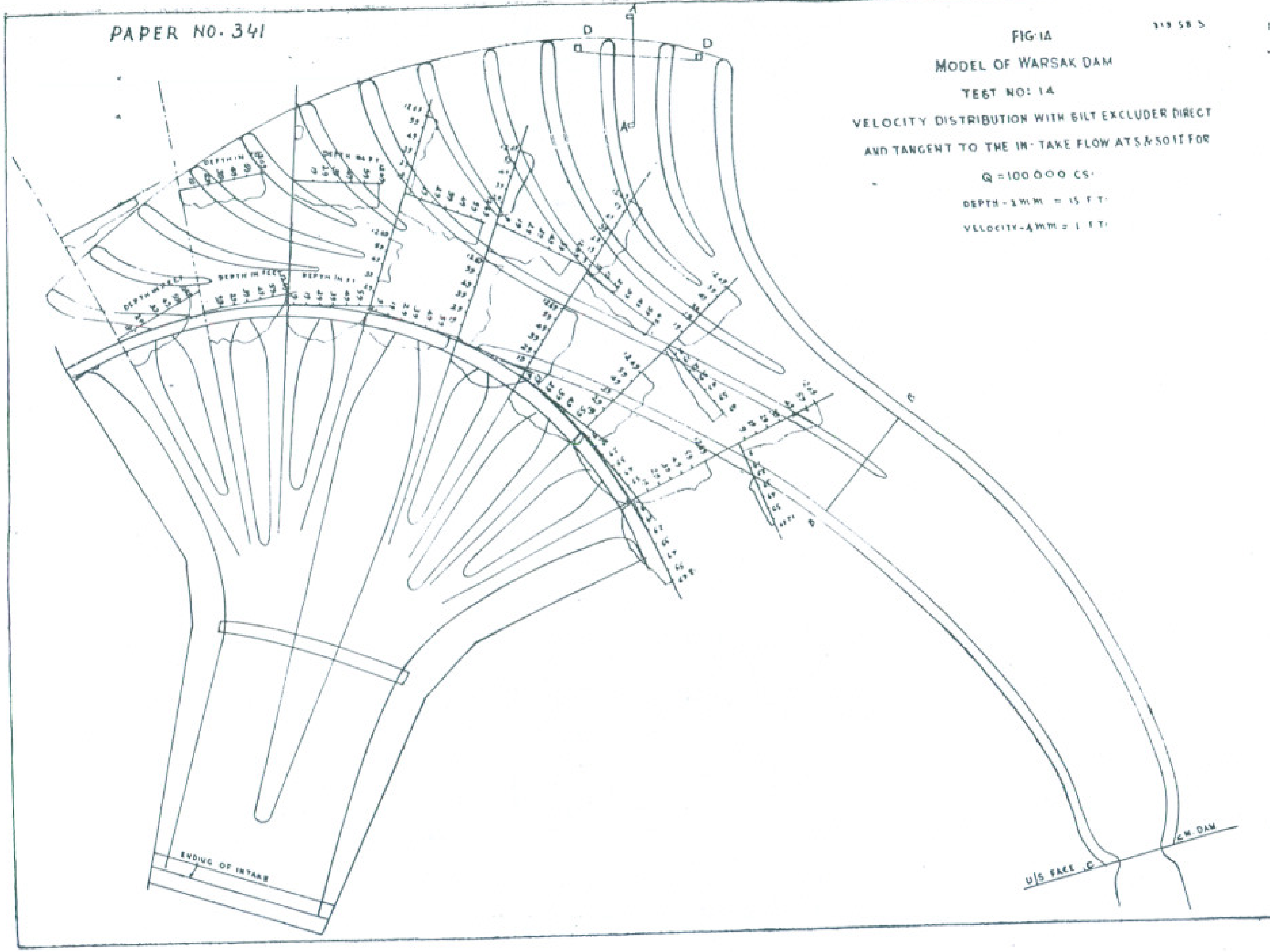


FIG 1A

MODEL OF WARSAK DAM

TEST NO: 14

VELOCITY DISTRIBUTION WITH SILT EXCLUDER DIRECT AND TANGENT TO THE IN-TAKE FLOW AT S.&.501T FOR

Q = 100 000 CS.

DEPTH - 1 mm = 15 FT.

VELOCITY - 4 mm = 1 FT.

PAPER NO. 341

FIG. 1A

MODEL OF WARSAK DAM

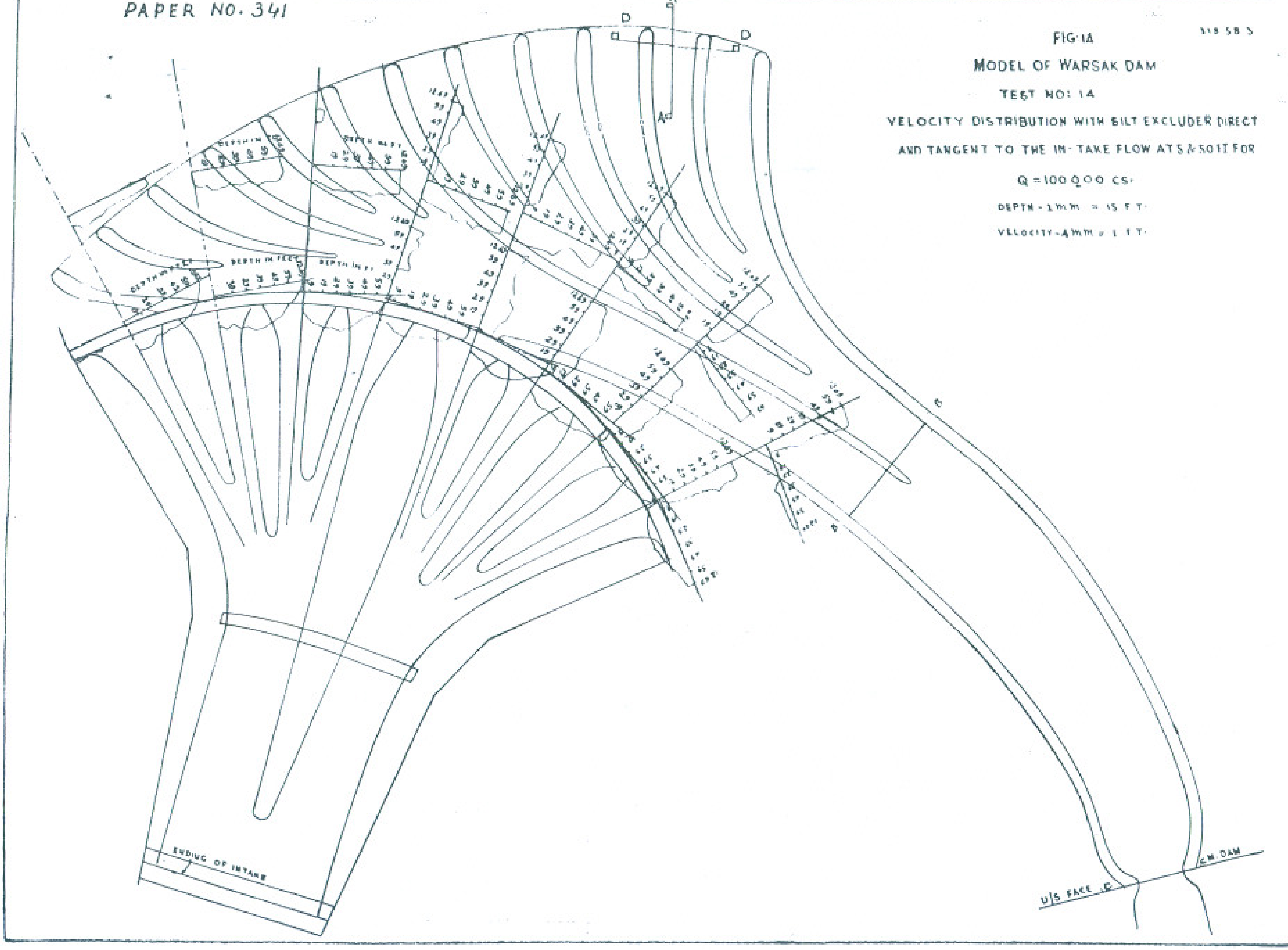
TEST NO: 14

VELOCITY DISTRIBUTION WITH SILT EXCLUDER DIRECT AND TANGENT TO THE IN-TAKE FLOW AT S.&.50 FT FOR

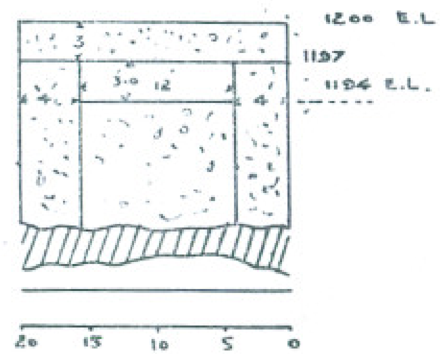
Q = 100,000 CS.

DEPTH - 1 mm = 15 F.T.

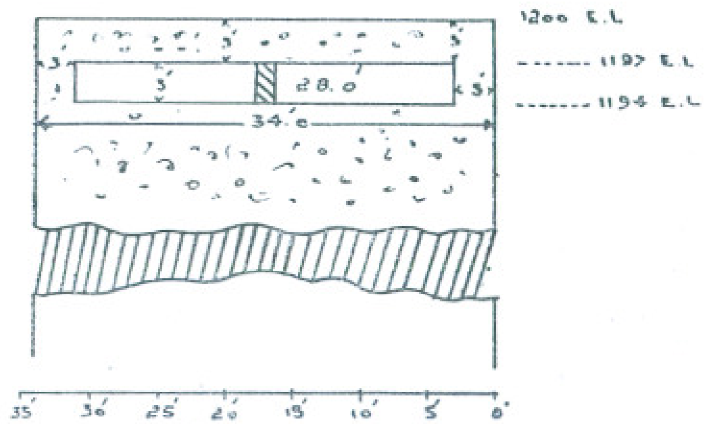
VELOCITY - 4 mm = 1 F.T.



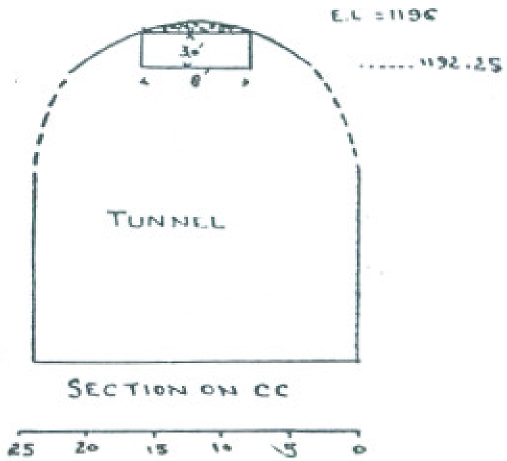
PAPER NO. 3.41



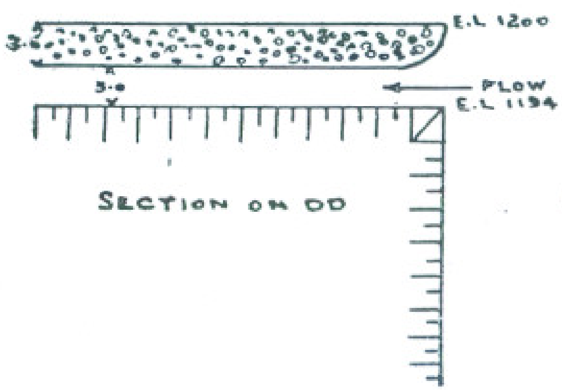
SECTION ON AA



SECTION ON BB



SECTION ON CC



SECTION ON DD

PAPER NO.341

120·58·1

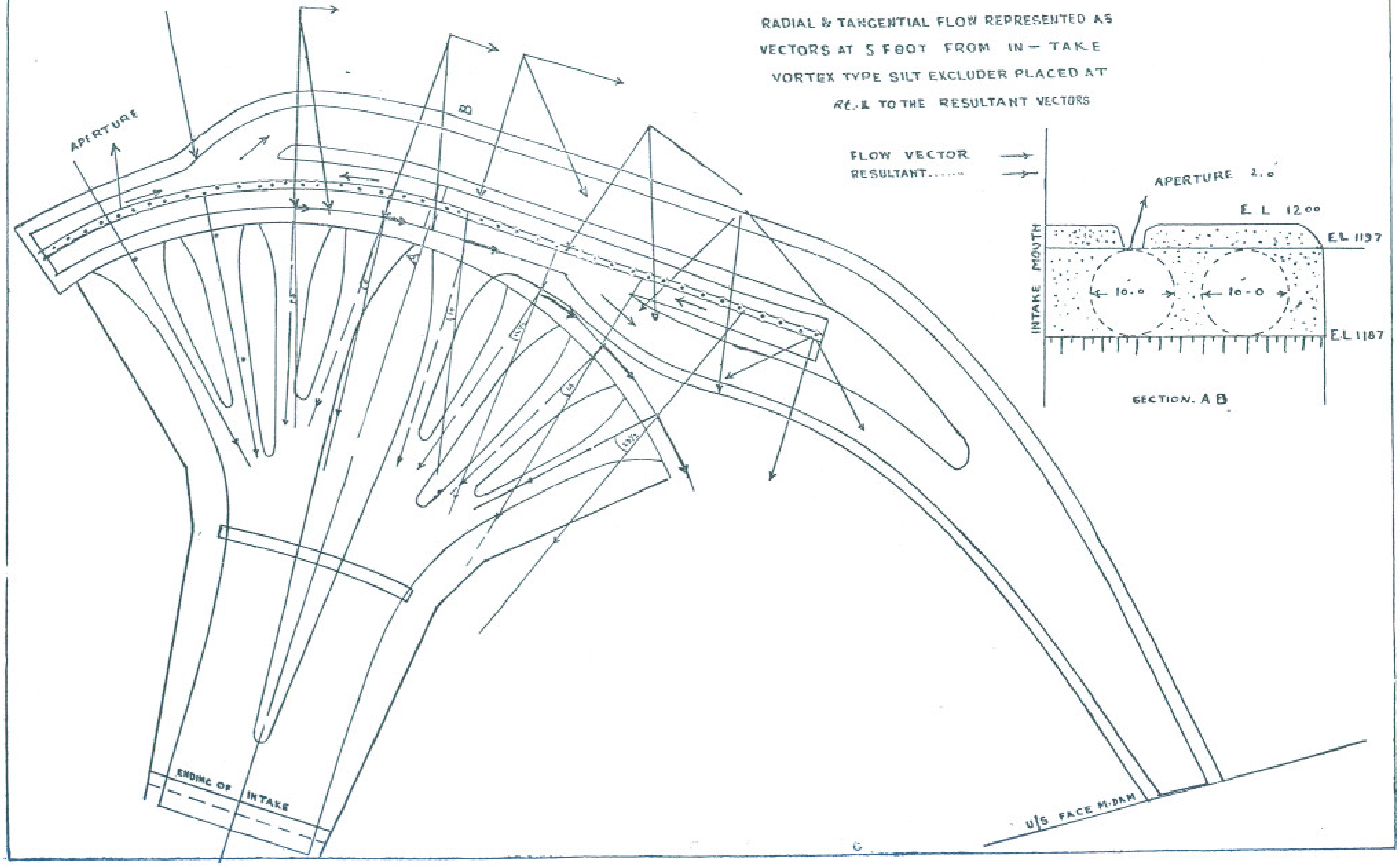
FIG: 15

MODEL OF WARSAK DAM

ORIGINAL TEST

RADIAL & TANGENTIAL FLOW REPRESENTED AS VECTORS AT 5 FOOT FROM IN-TAKE

VORTEX TYPE SILT EXCLUDER PLACED AT Rt.∠ TO THE RESULTANT VECTORS



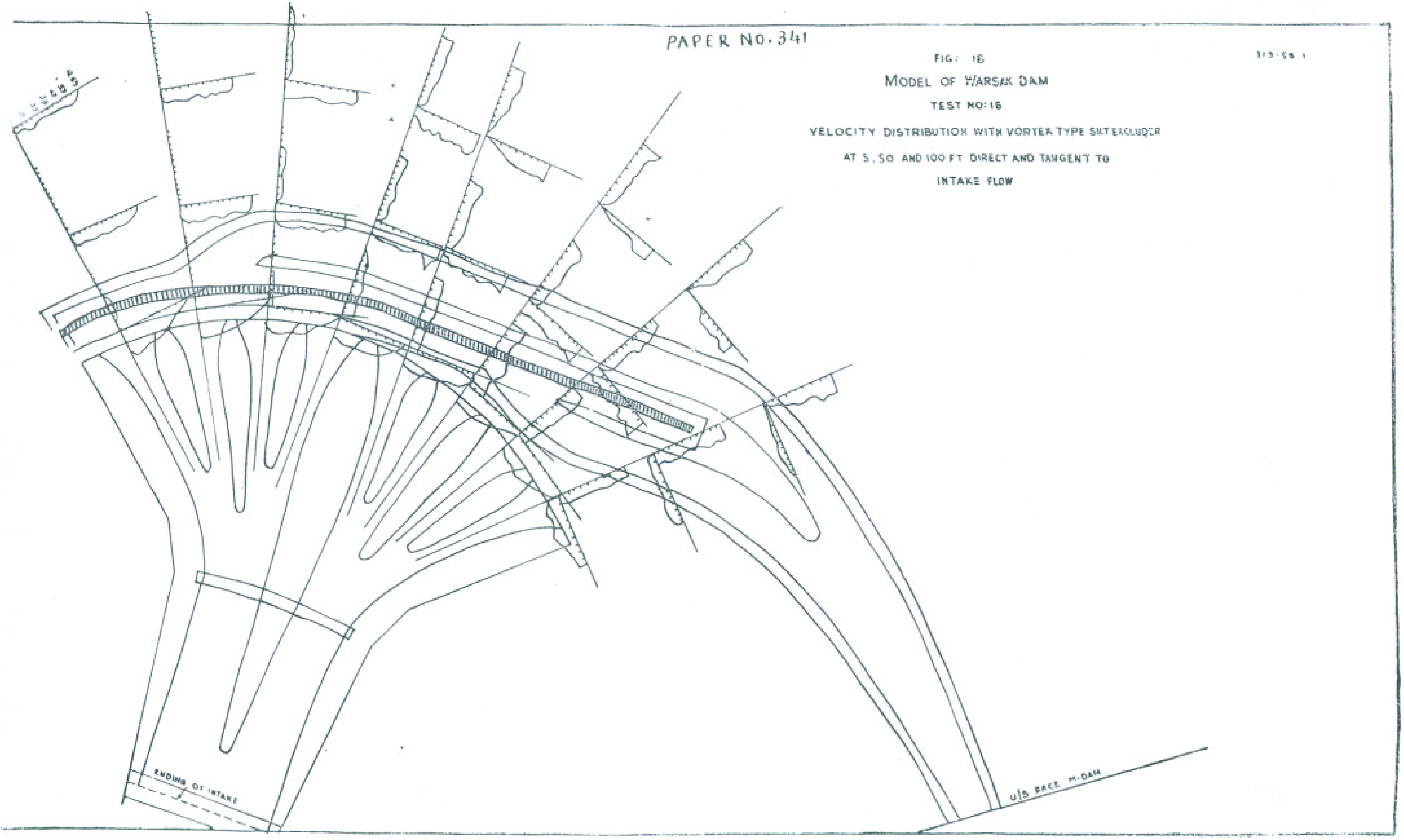
PAPER NO. 341

FIG: 16

MODEL OF WARSAK DAM

TEST NO: 16

VELOCITY DISTRIBUTION WITH VORTEX TYPE SILT EXCLUDER AT 5, 50 AND 100 FT DIRECT AND TANGENT TO INTAKE FLOW



PAPER NO. 341

FIG 17

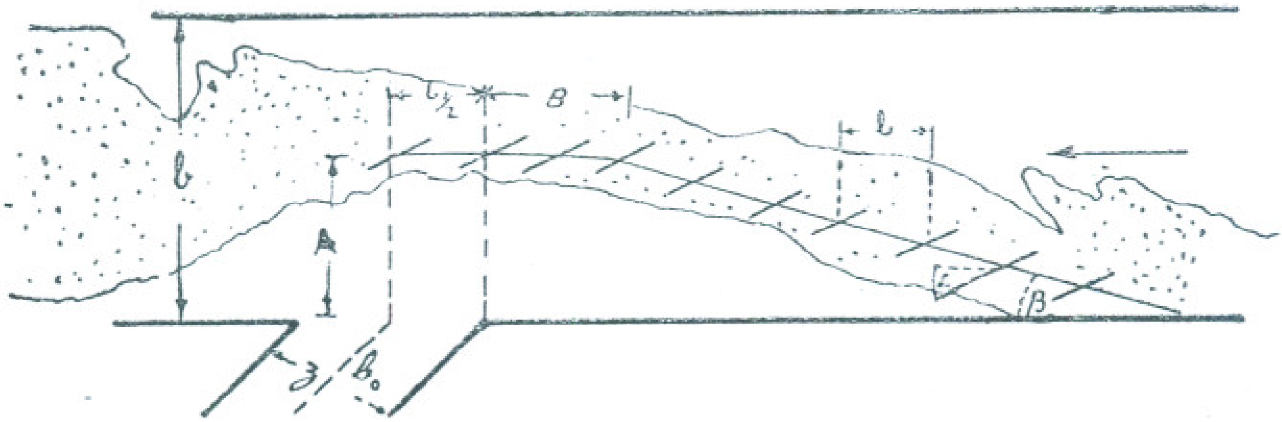
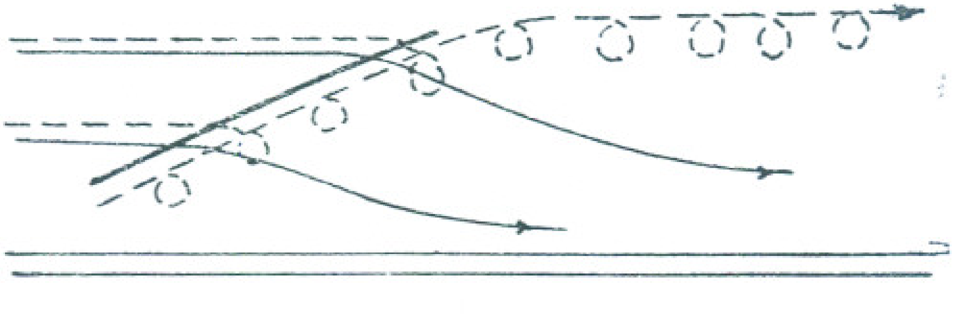


FIG. (b)



SURFACE CURRENTS ———

BED CURRENTS - - - - - -

FIG. (a)