DISTRIBUTARY HEADS AND OTHER CANAL DIVERSION WORKS.

By A. S. GIBB,

Executive Engineer, Punjab Irrigation, Multan.

Diversion works on our irrigation canals are of two classes. First, there are the heads of distributaries taking out of canals. In this class the onward flow of the parent canal is not obstructed, and usually its discharge is greater than that of the distributary. The second class occurs at sites where the whole supply of the parent canal is split up and diverted into two or more branch channels, the regulator heads of which are connected to form a single work occupying the whole width of the parent canal.

This paper is mostly about the first class, but a few remarks and suggestions about the second are also offered. No attempt is made to exhaust either subject, or to lay down final conclusions, rather it is intended to suggest lines along which investigation and experiment will lead to useful results.

Designs for canal works of all kinds require consideration from two points of view. There is first their purely hydraulic aspect, and second, and in the Punjab not less important, the problem of control of silt distribution.

Distributary Heads.

In its simplest form the problem of the distributary head can be stated thus :—It is required to divert a supply of water from a relatively large channel and pass it into a distributary, so as to allow of easy and accurate regulation of the supply drawn off, to involve a minimum loss of head, and to control the silt charge carried into the distributary.

With regard to the last requirement, it is obvious that it is not sufficient simply to design all heads to exclude all heavy silt, since for every cusec bearing less than its due silt charge, drawn off from a canal, another cusec excessively charged must be drawn off somewhere else. It is control of silt charge, then, that is necessary, not simply exclusion of silt.

It is convenient to divide a distributary head into three parts ; (*a*) the intake face presented to the parent channel, including up and down stream wing walls; (*b*) the regulator proper, including regulating gates and bridge, to which the wing walls of the intake face form the approach; (*c*) the delivery, including wing walls, pitching, etc., of the downstream face. These will be considered in the above order.

The Intake Face.

The design of the intake face of a distributary head must largely depend on the condition of flow in the parent channel. It is therefore necessary to discuss this. The first point to notice is that the water in the parent channel is flowing along the intake face past the distributary head. This rather obvious fact has not, as a rule, been allowed to influence designs in the past, as most of our existing distributary heads appear to have been constructed on the assumption that the supply was to be drawn from a still water tank, since they are usually symmetrical about an axis perpendicular to the direction of flow in the parent canal. This feature is shown in Fig. 1, which represents a fairly typical distributary head of the old kind.

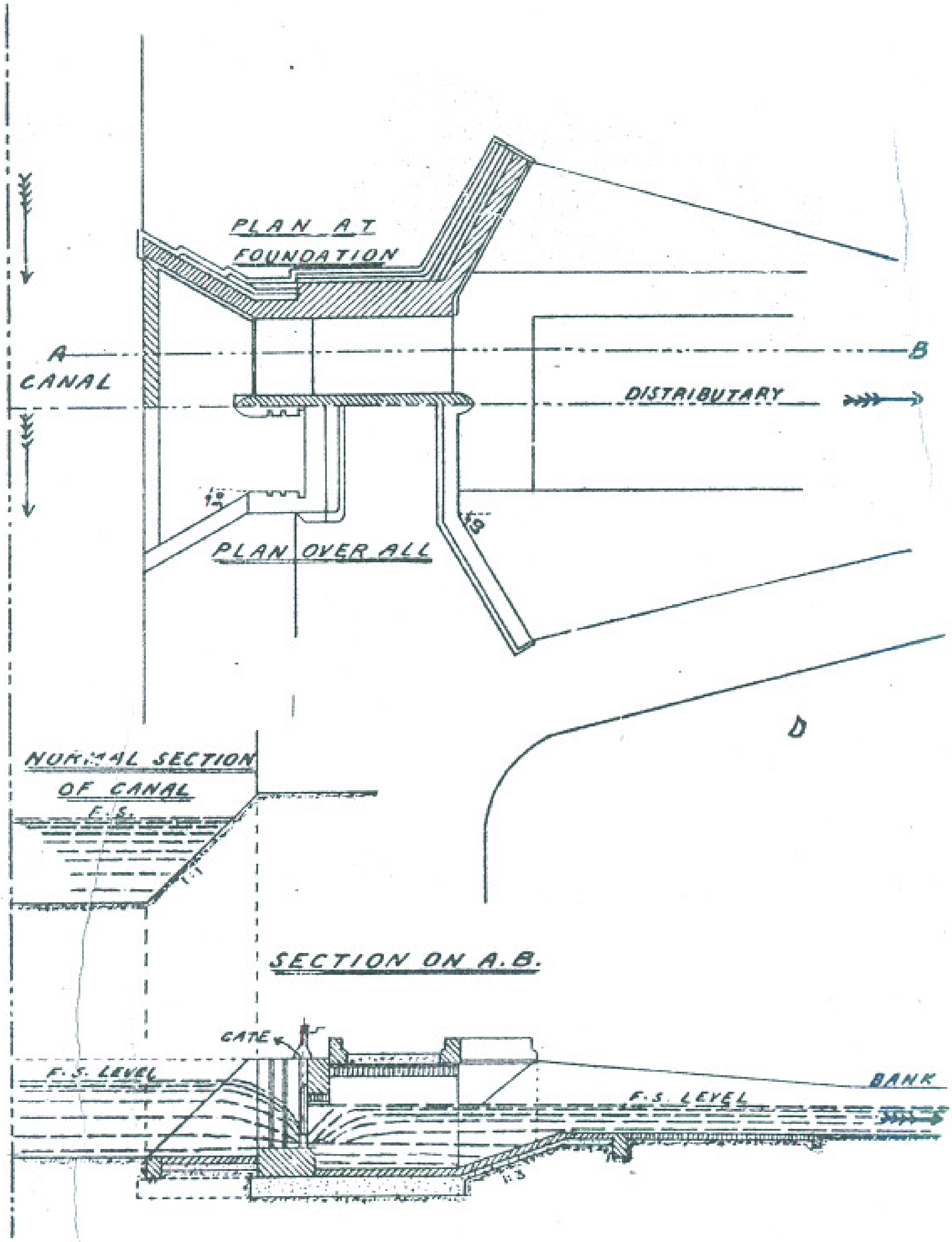
The effect of flow in the parent chann ı :s suggested by the stream line diagrams Figs. 2, 3 and · . In drawing these diagrams a horizontal layer of water of uniform depth is taken and the draw towards the distributary head is represented by radial streams converging towards a point—the conventional "sink" of hydrodynamics, in fact. The angles between the radial stream lines are such that the discharge of all streams is the same; thus the velocity at any point is inversely as the width of the stream. Of course, in a real distributary head the streams converge into a space of finite width and not on a mathematical point, but as the diagrams are only intended to suggest the general nature of the flow and are not to be taken too literally, this objection need not trouble us. Flow in the parent channel is evidently represented in the same way by a system or parallel streams, each of which has the same discharge as the radial streams of the "sink." To determine the width of these streams a velocity diagram has been assumed, giving a velocity zero at the margin, increasing gradually till a maximum is reached some distance out, and then becoming uniform. This is, of course, only a very rough approximation to the velocity distribution in a channel, but it will serve the present purpose. The lines are drawn so as to make the discharge in each stream the same, the widths of the latter being inversely as their velocities. The stream lines resulting from the combination of these two systems

Fig

FIG: I

DISTRIBUTARY HEAD (OLD TYPE)

SCALE 1/450



are obtained by superimposing the two systems and drawing the resultant at each point of crossing so as to form continuous curves. This method of plotting stream lines is explained and justified in Appendix A, which is an extract from Dunkerly's Hydraulics. Diagram Fig. 2 represents approximately the type of stream lines which will be produced by the old class of heads shown in Fig. 1. In this diagram it is assumed that the draw towards the head is not uniformly distributed round the whole semicircle, because the wing walls are so placed as to weaken the draw from the sides and to strengthen it in front of the regulator. It is not possible to estimate this effect exactly, but the principal feature of this class of head, namely that the draw is symmetrical about an axis perpendicular to the direction of flow in the parent channel, can be brought out and its influence indicated.

Diagrams Figs. 3 and 4 represent stream lines drawn in the same way, but in these cases it is assumed that the form of the intake face of the head is such as to draw in the water of the parent channel more from upstream and not at right angles. In diagram Fig. 4 the draw is concentrated within a smaller angle and acts more directly with the stream than in diagram Fig. 3.

There can be no question as to which of these three is most efficient from a purely hydraulic point of view ; the streams shown in Fig. 4 will obviously conserve for future use more of the momentum due to the velocity of approach than those in Fig. 3, while in Fig. 2 the whole of this advantage is lost.

These diagrams will be referred to later in connection with the question of silt control, but before dealing with the effect of special stream forms on silt travel and distribution, it is necessary to discuss the normal conditions in the parent channel with no distributary head present to complicate matters.

The present problem has no particular concern with the question of how the water gets its silt charge, but it is concerned with where it gets it, and with the direction in which the silt travels, and with the distribution of silt in a cross section. Fig. 5 is a typical cross section of a straight canal in which the arrows indicate the direction of the well known circulating cross currents. Fig. 6 is a plan of a marginal strip of the Upper Gugera Branch (Lower Chenab Canal) showing the actual lines of flow * of surface and bottom water as observed by means of floats. (The path of surface floats gave surface lines directly, and rod floats were assumed to follow lines giving a mean between surface and bottom streams. The lines of bottom

* In this diagram the width between the lines has no relation to the forward velocity.

flow were deduced from the observed surface and mean lines). These figures merely illustrate what is well known, namely, that in an ordinary straight canal the bottom water flows from the middle towards the margin, the surface water flows back towards the middle, and there is an upward current in the marginal strip.

Gravitation is the only other known force acting on the silt particles, consequently from these cross circulating currents, allowing for gravity, it is possible to get an idea of the silt's activities in the channel. Sand suspended near the bottom of the canal, as it is carried downstream, will be gradually pushed along on or near the bottom (travelling by saltation as an American experimenter terms it) into the strip of water near the margin, there it will come under the influence of the rising current, and as gravity is acting against the current the ascent will be considerably retarded, with the result that there will be congestion, and the water there will be more densely charged with silt than elsewhere. At last on arriving near the surface the sand is carried away towards the middle of the stream, falling through the water as it goes, its fall being assisted by the ultimate downward tendency of the current. Eventually the sand grains again come under the influence of the bottom current and start off on their rounds again. Heavy particles of silt, it may be assumed, always remain nearer the bottom than light ones, and are thus more under the influence of the bottom current towards the bank. The density of the silt charge in the marginal strips of water will be still further increased, owing to the fact that the forward velocity is less there than it is in the middle, and a given quantity of silt, while going the round above described, must be contained in a smaller volume of water when it is near the margin than when it is near the middle of the stream. It appears, then, that the marginal strip of the parent canal, which is to be drawn off into a distributary, normally contains the most highly silt-charged water in the whole cross section, and tends continually to be fed with a specially selected supply of the heaviest sand available. This is probably the explanation of the fairly generally admitted fact that, with the old type of head, distributaries get more than their just share of silt. So long as this strip of water is accepted in the condition in which the canal offers it to the distributary, no subsequent arrangement of obstacles such as raised or rising sills will probably make much difference. It is the condition of the water in this marginal strip before it reaches the regulator gate that appears to require attention.

If the distribution of silt and its direction of travel in the parent channel is to be controlled, it is obvious that the cross currents which are the cause must be controlled. The next question then, must be, what are the factors which determine the direction of the cross circulating currents in a canal? Appendix B. contains a suggested explanation of these cross circulating currents. But, though this explanation appears to the author to be rational and to cover the known facts adequately, it is not his intention to lay stress on it in this paper. The present purpose can probably be better served by studying such more generally acceptable evidence as is available.

That the current in question results from the presence of the boundaries of the channel cannot be doubted, but that it is not directly caused by the boundaries is also obvious, because water at a little distance from the boundary cannot be assumed to have any independent consciousness of the existence or situation of the boundaries. The influence of a boundary can only be communicated from filament to filament of the stream, and at any point in the stream the only indication of the existence of a boundary will be the fact that a stream filament nearer the boundary will have less velocity than one more remote. A boundary, then, directly affects the distribution of velocity in a direction parallel to itself, but it cannot propagate flow at right angles to its own surface, being itself stationary. It appears, then, that the internal cross currents in a stream must be caused by the distribution of forward velocity, which in its turn is determined by the form of the boundaries. Further evidence on this point is provided by the flow at bends in a stream. The cross currents in a section of a stream at a bend are shown in Fig. 7. Here the symmetry noticeable in a straight channel is no longer maintained, and it is quite evident that the bottom water is flowing, not towards the nearest margin, but away from the region of highest towards the region of lowest forward velocity: similarly the top water is attracted not to the point furthest from both banks, but towards the line of highest forward velocity.

Again, we know in a general way that water flowing with a high velocity lifts and carries more silt than water flowing more slowly, also that the spaces between the spurs in a silting reach, where the water moves slowly, fill up with silt evidently obtained from the more rapidly moving stream in the middle. This silt must have been carried to the side by the bottom current, because surface water tends to be relatively free from silt.

Thus it seems that not only the evidence of the currents themselves, but also the evidence of known movements of silt, which indicate the direction of the currents, go to show that surface water which contains a relatively low silt charge tends towards the region of highest forward velocity, and bottom water, densely charged and containing the heaviest silt, tends to pass towards regions of low forward velocity. This important principle provides a key for the solution of the problem of silt control.* It indicates that, in order to exclude silt from a distributary by selecting top water, the supply should be drawn towards its head at a high velocity.

In view of the fact that this result is directly opposed to very commonly accepted ideas and practice, it will be as well to see what foundation there is for the more popular belief. The opinion is very generally expressed that a distributary must take its water from the parent canal as quietly and gently as possible, and therefore, the flow in towards the regulator must be slow, because rapidly flowing water stirs up silt. There is no suggestion here of any lateral transference of silt across the section of the stream, and if it were true that no such communication exists, then evidently where the silt charge of the stream entering a distributary is reduced by retarding its velocity immediately in front of the head, an ever-growing mountain of silt must be deposited; while, on the other hand, when the silt charge is increased by the local action of rapid flow into the head, then a continually deepening scour hole is bound to result. Obviously there can be no diminution or augmentation of the silt charge without the formation of a corresponding ever-growing deposit or scour hole, unless lateral travel of silt across the direction of mean forward flow takes place, as suggested in this paper. It is no doubt true that of two independent channels the more rapid flowing will stir up and carry on more silt than the other in which the flow is slower, but it does not follow that the same distribution of silt charge will hold good when the rapid flowing and the slow flowing water are neighbouring parts of the same stream. In any case water flowing rapidly into a distri-

* It is necessary to notice that all the evidence of these cross circulating currents is collected from channels which are wide in comparison to their depth and in which, therefore, the influence of the bed predominates over that of the sides. The explanation in Appendix B suggests that in a narrow and deep stream, where there is more side boundary than bed, the direction of cross circulation may be the reverse of that described. It would be interesting to verify this. In the meantime it should be understood that the principal stated above refers only to relatively wide, shallow channels like our canals.

STREAM LINE DIAGRAMS

FIG: 2

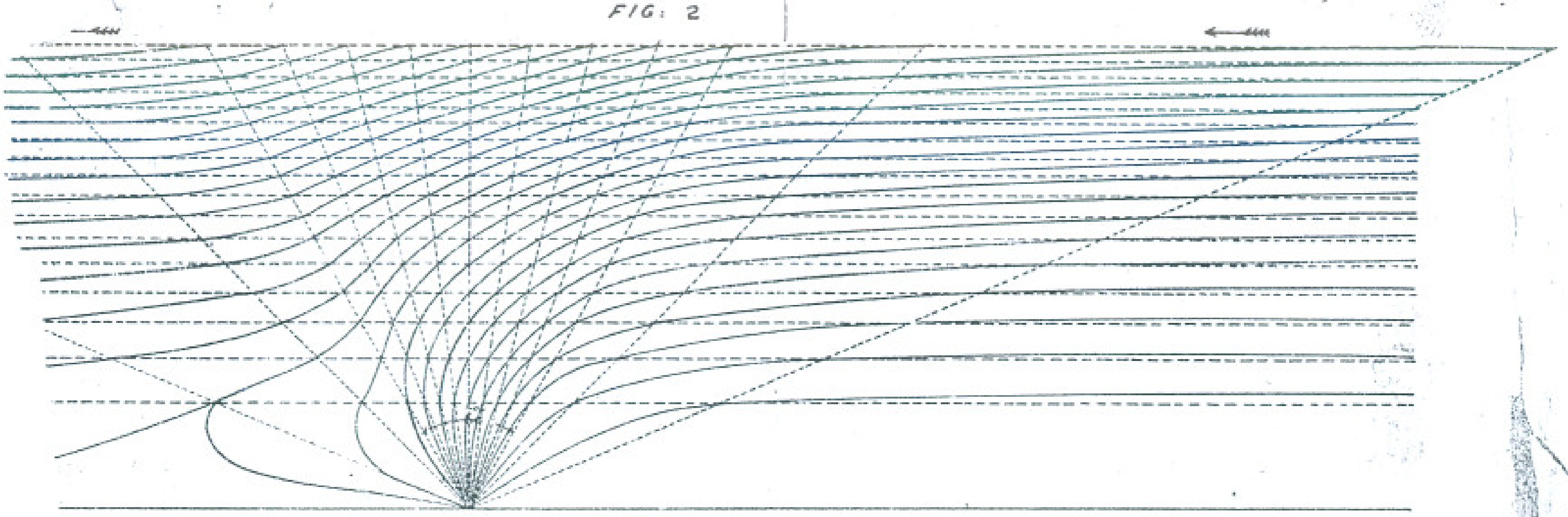


FIG: 3

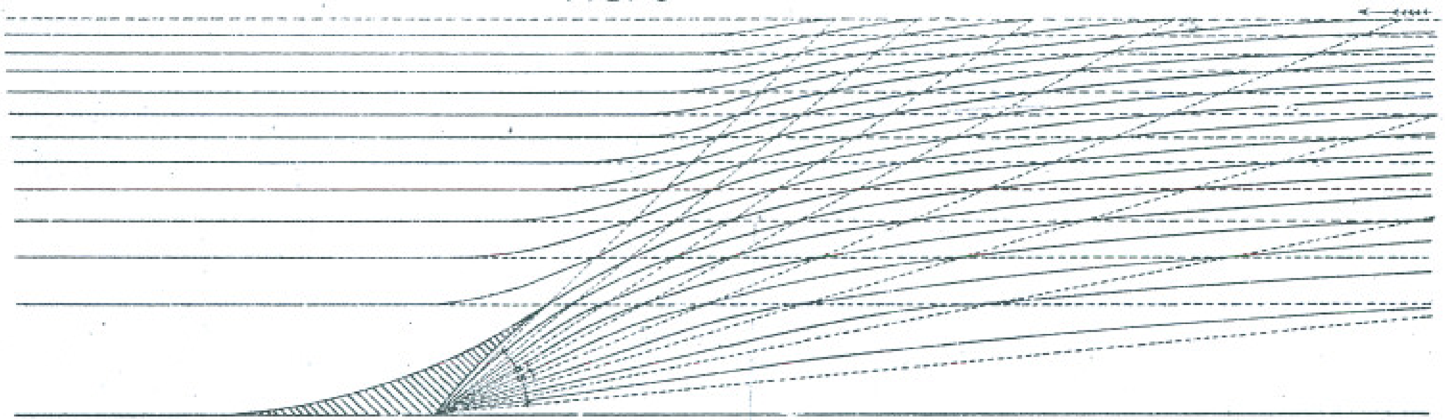


FIG: 4

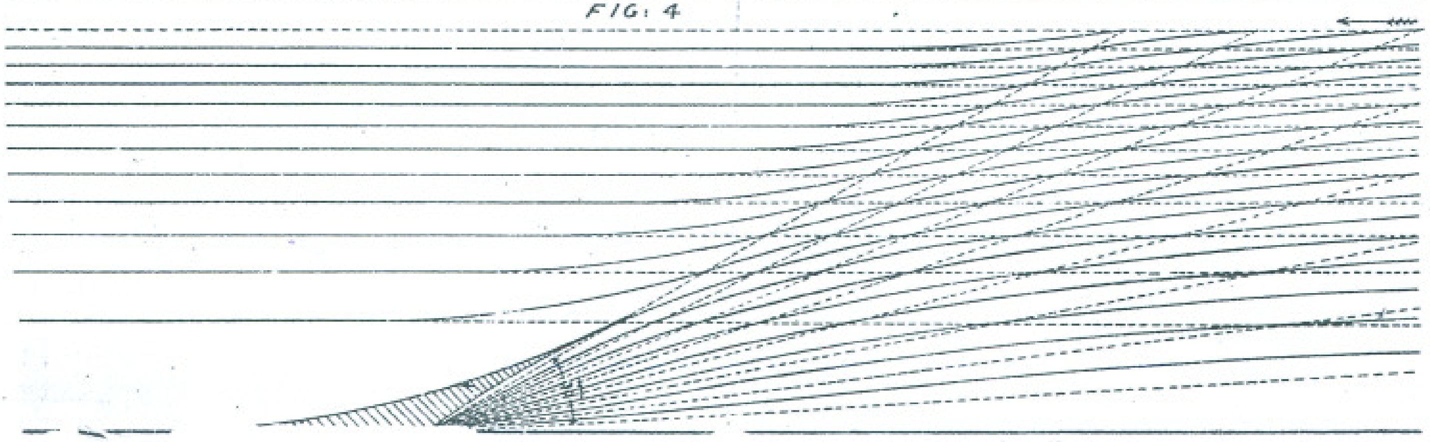


FIG: 6

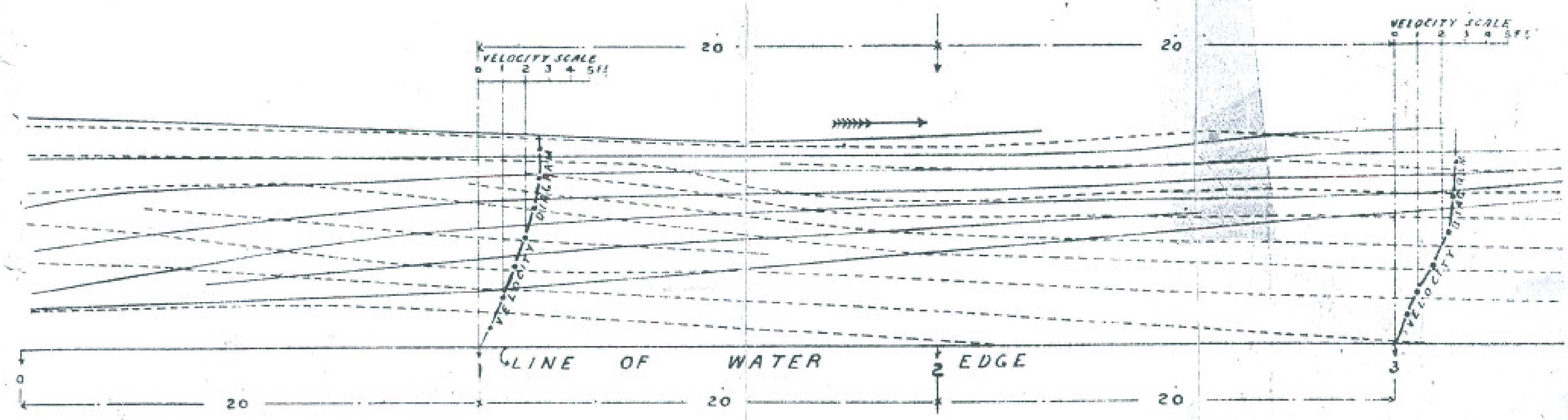
STREAM LINE DIAGRAM

GUGERA BRANCH UPPER AT R.D. 50000

NORMAL FLOW WITHOUT DISTRIBUTARY HEAD

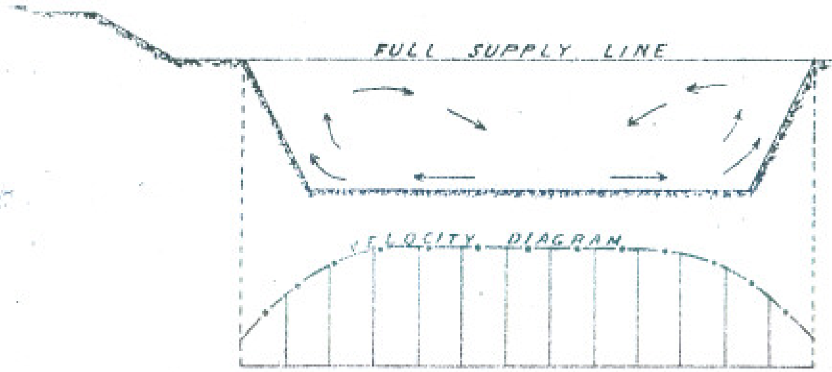
SCALE = 1/112·5

NOTE.
SURFACE STREAM LINES ARE SHOWN BY FULL LINES.
BOTTOM — DO — DO — DO — DOTTED LINES.



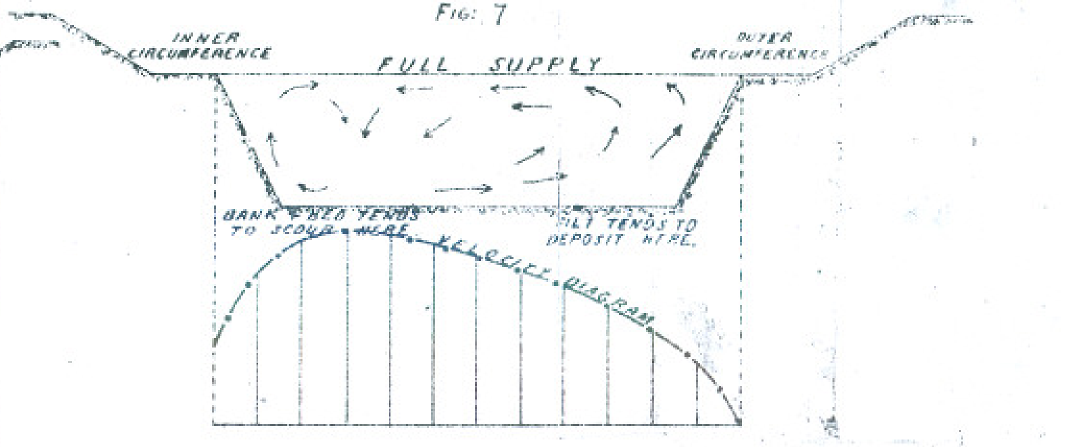
TYPICAL SECTION OF STRAIGHT CHANNEL

FIG: 5



TYPICAL SECTION OF CANAL AT BEND

FIG: 7



butary head can easily be prevented from picking up silt and thereby adding to the charge, by making a brick floor on the part of the bed exposed to it, as is, in fact, usually done.

The opinion is also often expressed that in order to obtain only top water a raised sill is necessary to shut off the bottom water. It is easy, however, to imagine that by drawing the water off over a raised sill of moderate height the already existing upward marginal current might be further stimulated, and therefore the flow of bottom silt laden water towards the side increased. Possibly this is what happens in those cases where raised sills have admittedly failed to effect the exclusion of silt. There can be no doubt, however, that relatively silt free water can be obtained if the crest of the sill over which it flows is so near the surface that the layer of water drawn off is thin enough ; but it is very seldom that the conditions allow of this, and if top water can be got without a raised sill then so much the better.

There appears nothing in the theories just criticised to invalidate the principle arrived at from the study of the cross currents ; it therefore remains to apply that principle for the control of the silt charge drawn into distributary heads. The stream line diagrams Figs. 2, 3 and 4 deal only with the forward components of the velocities and neglect altogether the cross currents, which have been shown to have such an important bearing on the distribution of silt. The diagrams, however, show by the width of the stream the distribution of the forward velocity, which appears to determine the direction of the cross currents. From the diagrams, then, it is easy to determine the direction of travel and distribution of the silt.

Diagram Fig. 2, which represents the flow into the old type of head, shows that along the upstream approach the normal distribution of forward velocity is maintained, that is, low near the bank, and more rapid as the distance from the bank increases. This arrangement was shown to encourage the flow of heavily charged bottom water towards the bank, and the maintenance there of an abnormally high charge of silt in a rising current. In addition to this there is a region of very low velocity near the position of the down stream wing wall of the regulator, in which there will be a strong rising current fed by an inflow of bottom water. As most of this water also finds its way into the regulator, together with the highly charged water from upstream and in front, the supply taken into the distributary will contain a high charge of silt.

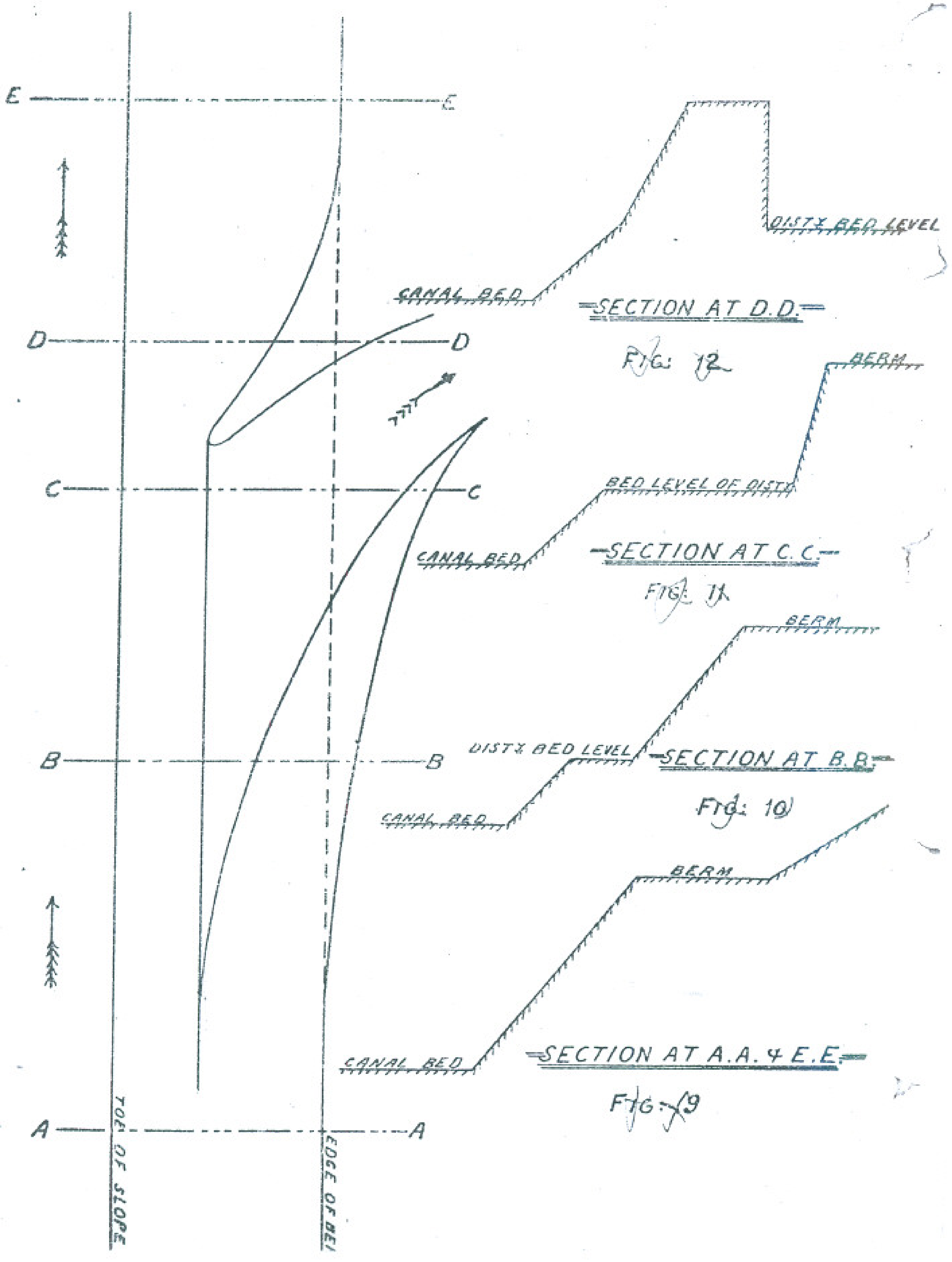
When the draw is concentrated upstream as in diagram Fig. 4, the forward velocity in the whole marginal strip taken into the regulator is seen to be accelerated from a considerable distance, and to become nearly uniform, while outside this strip the water which is to go on down the canal flows more slowly. Application of the principle determining the direction of cross currents to this case indicates that clear top water will flow into the marginal strip destined for the distributary, and bottom water with its silt will flow out into the streams which pass on down the canal. A distributary head built so as to produce flow of this type will evidently draw water carrying a relatively low silt charge.

Diagram Fig. 3 shows stream lines of an intermediate type, in which the draw, though still from upstream, is not so concentrated as in Fig. 4. It shows the same features as Fig. 4, but they are less marked. A distributary head designed so as to give stream lines like these, would draw water more heavily silt charged than one based on Fig. 4, but considerably less than the old type of head represented in Fig. 2.

Expressing these results generally, it appears that the more the draw towards the head is concentrated from an upstream direction, the lower will be the charge of silt drawn into a distributary, and conversely, retardation of the water approaching from upstream, and draw from down stream, tends to send an abnormally high silt charge through the regulator. It is, of course, impossible at this stage of the enquiry to suggest anything in the way of quantitative results, but a principle, by the aid of which, the relative action of different works can be foretold, will not be without value. It will at least suggest the differences between the heads of a silting tank, a distributary with a steep slope and good command, and a distributary of flat gradient serving high land.

In the stream line diagrams the draw is assumed to be towards a single point, whereas in a distributary head the draw is more or less uniformly distributed over a finite width, so these diagrams cannot be used directly for plotting the form of the intake face of any particular distributary head. Suggestions of what the general form of the intake face should be, can, however, be obtained from them. The curve of the stream lines approaching from upstream suggests the form of the upstream portion of the face work, while the triangular area of dead water on the downstream side, shown shaded in the diagrams

FORM OF INTAKE FACE FOR DRAWING OFF MODERATELY LOW SILT CHARGE



Figs. 3 and 4, suggests that a projecting nose of this shape in combination with the correct upstream form will concentrate the draw in the direction required and produce the required system of stream lines.

There is only one other point in connection with the intake face to which attention need be directed. In the old type of head, the floor of the space between the wing walls was usually laid at bed level of the parent canal, and this low level was carried back almost to the gate. There is no evident advantage in keeping this floor so low, and it has the serious disadvantage of providing a deep recess into which bottom silt is pushed just as it is into the space between spurs in a silting reach. The floor in this space need not be lower than the distributary bed, and in order to avoid disturbance of the flow along the face, the normal slope of the canal bank should be maintained between the canal bed and the higher floor level of the intake.

Figs. 8 to 12 show roughly the form of intake face recommended for a distributary head into which it is desired to draw a supply carrying a moderately low silt charge. The side slopes should be pitched for quite a long distance upstream, so as to get the approaching water into as efficient a condition of flow as possible. Then, starting from the point where the curved approach begins, the side slope gradually becomes steeper and steeper, until eventually at the regulator gate the wall is vertical ; but this gradual steepening of the slope affects only that portion of the side which is above the floor level, that is above the distributary bed. Similarly the point of the nose on the downstream side is vertical, but below this point the slope gradually flattens until eventually the normal condition is again reached.

The Regulator.

The form of intake face arrived at above has features directly affecting the design of the regulator proper, which is the next part of the work to be considered. For instance, in the case of distributaries requiring a low silt charge, the water reaching the regulator must be flowing with a high velocity, and therefore the space into which it flows must be narrow. It will be better, however, to deal with the regulator itself independently, and decide what are the factors in design that make for its efficiency.

Regulation over an adjustable sill, which closes by rising from below out of a hole in the floor, involves obvious objectionable features, and is only to be justified by a definite gain of some kind. There is evidently no direct hydraulic advantage gained by the use of such a regulator, nor is any higher degree of accuracy attainable than with other forms. Its only claim, then, is based on its use as a means of controlling the silt charge. This has already been discussed to some extent, but there is another aspect of the subject remaining to be dealt with.

The ordinary gate which closes by being lowered from above is structurely simple and easy to work and maintain ; the only objection that can be brought against it is that it takes the water at a relatively low level and therefore may tend to draw silt, but this tendency is probably not so serious as is often supposed.

The question involved arises in a more direct form in connection with diversion works of the second class mentioned at the beginning of this paper, but it will be better to dispose of it here before going any further.

Under ordinary circumstances the supply discharged through an opening is collected from the immediate neighbourhood more or less uniformly in all possible directions, and judging from ordinary everyday experience outside canals, one would expect to find that, even at a comparatively short distance away, there was no very definite concentration of the draw along any particular direction. On the other hand, in the case of a regulator across a canal, the channel upstream can be made to scour by taking the water through low level orifices instead of over a raised sill of "karries." But we also know that at bifurcations, where the heads of both branches consist of drowned orifices, the head of the branch into which there is the greater fall, while taking less silt, will tend to scour the bed of the parent channel on its own side for some distance upstream, and the other with less fall will tend to draw off a high silt charge, but at the same time silt will tend to deposit on the side of the parent channel upstream of it. There are many cases of bifurcations on Punjab canals which act like this, and they appear to indicate that there may be as much difference between two orifices working under different heads as between an orifice and a sill.

The explanation of this seems to rest on the fact that the water is not being taken from a tank, but approaches the regulator in a restricted channel. Taking the case of two similarly situated drowned orifices of equal discharge, there is evidently more kinetic energy in the stream passing through that which has the greatest head. In the case of discharge from an orifice in the side of a tank, this kinetic energy is generated along streams radiating in all directions, and the effect being quickly dispersed, the surface may remain undisturbed ; but when the supply is brought to the orifice in a restricted channel, the kinetic energy can be generated in one direction only, and since in water the change from pressure head to velocity head takes place more or less gradually, the result is that for a considerable distance upstream of the orifice the water has more kinetic energy than would normally be produced by the gradient of the channel. In fact, energy is added to the stream above by the fall at the orifice just as it would be if we were to push the water on with paddles. Or to put it all into more popular language, there is a stronger draw towards the greater head. This excess of kinetic energy in the water approaching a canal regulator will evidently be greatest when the kinetic energy at the regulator itself is greatest ; so that in the case of drowned orifices, when other things are equal, there actually will be a greater velocity of approach, with a correspondingly lower surface level in the flow, towards that, through which, there is the greatest head. And since for the same head and discharge the mean velocity and therefore the total kinetic energy is less for a discharge over a sill than in flow through an orifice, the velocity of approach will be less towards the sill than towards the orifice.

These results will be referred to again later in connection with the second class of diversion works. Meanwhile, it is sufficient to notice that the greater scouring effect of a regulator consisting of orifices is due in large part to an induced increase in the velocity of approach of the whole of the supply, and only very slightly, if at all, to the low situation.

Fig. 13 is a stream line diagram drawn in accordance with the principles applied in the diagrams Figs. 2, 3 and 4, and shows in vertical section the streams produced by the combination of a "sink" at bed level and a supply flowing horizontally towards it. A distribution of velocity in the horizontal stream, zero at bed, and increasing towards the surface, is assumed. Fig. 14 is a similar diagram in which the "sink" is situated on the surface. These diagrams show that it is only necessary to set the regulator a short way back from the canal for the silt charge drawn in to be independent of the level at which the water is taken, so that there will be no harm done by regulating at a distributary head with a gate closing from above.

From a purely hydraulic point of view a smooth horizontal floor and vertical side walls are efficient, but the lower edge of a gate is bound to cause considerable loss of head in the stream passing under it, which must undergo sudden contraction, followed by sudden expansion of sectional area, the latter change being especially wasteful of energy. Evidently the less there is of this lower edge of the gate the better, hence a narrow and high opening will waste less energy than a wide, flat one. Accuracy of regulation also recommends a comparatively narrow, high opening in preference to a wide, flat one, because in the former a relatively large change in the position of the gate will cause a relatively small change in the discharge. The narrow gate also scores by being lighter and therefore easier to manipulate than a wide one.

In the case of works designed to take a low silt charge, that is those based on the stream line diagrams Figs. 3 and 4, the gate will be placed skew so as to face more or less upstream, but this need not affect the alignment of the bridge or of the distributary head reach. On its exit from under the gate, the supply is contained in a narrow masonry passage, and can be turned round quite a sharp curve without harm being done. It will obviously be better to turn the water here where it is confined between walls and where its energy can be conserved, than to make it alter its course out in front in the parent channel, where its energy due to forward flow will be dissipated.

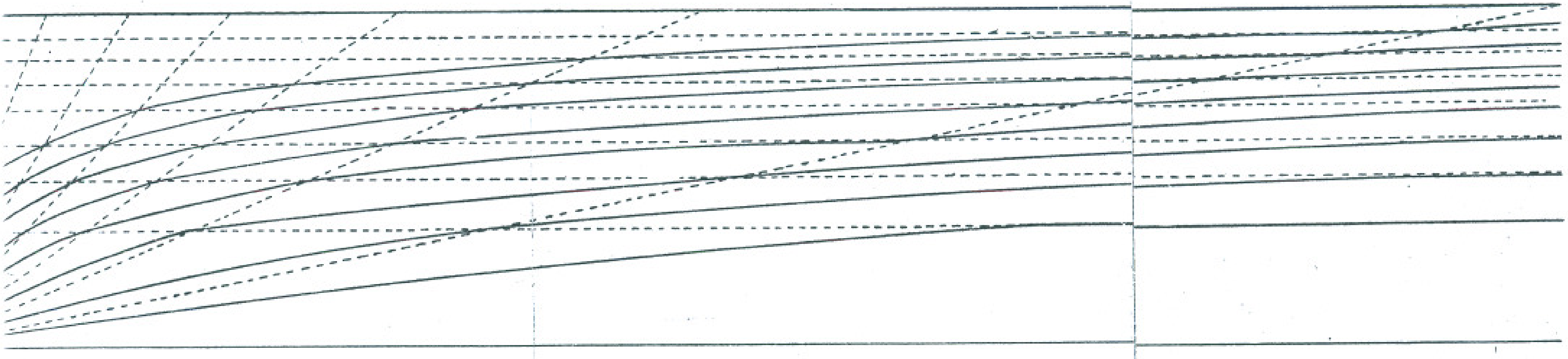
The only other structural points to notice in connection with this part of the work are obvious, but they are mentioned because existing distributary heads are often objectionable on their account. One large opening is hydraulicly more efficient than a number of small ones, because the less boundary surface exposed to the flow the better, and because the loss of head which occurs at the downstream end of piers is considerable. A cistern in the floor of the bridge serves no useful purpose, as the resultant of the momentum of flow under a gate is practically horizontal. Such a cistern, however, does undoubtedly cause needless loss of energy.

The possible dimensions of the gate opening, and the width of the strip of water in the parent canal to be drawn in, depend on the depths of water being dealt with. The variations of depth in canals and branches are often considerable, but they are always more or less periodic, and the relative duration of the periods of low and high level supply is fairly definitely ascertainable. The intake face is designed to deal with a strip of

STREAM LINE DIAGRAM

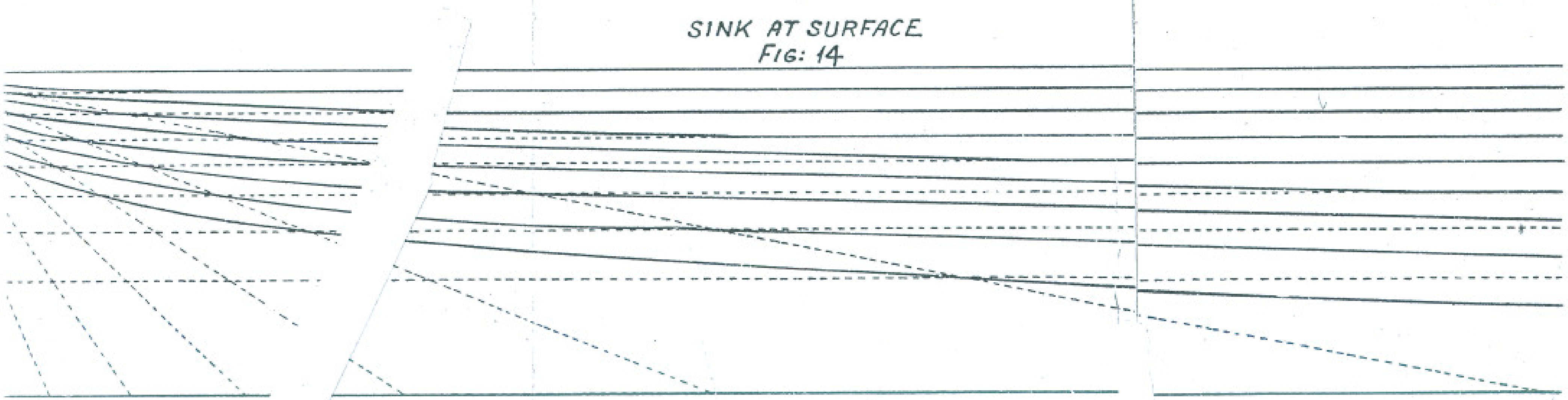
SINK AT BED LEVEL

FIG: 13



SINK AT SURFACE

FIG: 14



approaching water of a certain width. If, as the result of an increase of depth, a narrower strip is sufficient, then the acceleration in the approaching stream will be less than was intended, and the silt charge will be slightly more. On the other hand, however, when the depth is less than that anticipated in the design, the water will flow towards the head more rapidly than was intended, and will therefore carry in less silt. There should, however, be little difficulty in arriving at a compromise which will result in balancing the effects of high and low supplies in the canal.

The width of the gate opening must evidently always be sufficient to pass full discharge into a distributary with the lowest supply level in the canal, and with the lower edge of the gate just dipping sufficiently below the surface of the stream flowing under it to ensure control of the discharge.

Delivery.

The supply for the distributary has now been definitely drawn off from the parent canal. Its amount has been determined at the regulator, and its silt charge by the form of the intake face, and neither of these quantities can be altered henceforth. It only remains to deliver this supply into the head reach of the distributary with as little loss of head as possible, and in such a way as to maintain the silt in suspension.

The water issues from under the gate at a relatively high velocity, but in the old class of head almost the whole of the kinetic energy is dissipated by sudden expansions of the sectional area of the flow. Much energy is often wasted immediately downstream of the gates, where, owing to the use of extravagantly wide gates, the waterway of the bridge is very large as compared with the area of the opening under the gates; but even where the water issues from the bridge with a velocity bearing a reasonable relation to that under the gate, the immediate expansion to a sectional area of flow, often considerably in excess of that in the distributary channel, effectually disposes of nearly all the energy. And it must be remembered that this energy represents command, and that miles of main line channel have been dug for no other reason than to obtain the command which is now being so extravagantly wasted. Moreover for a majority of distributaries there are critical times when the supply in the parent canal is low, and a full discharge is urgently required in the distributary. To be able to draw an adequate supply at such times may make a very great difference in the efficiency of the system. Of course it is only a matter of inches of head, but it is inches that count in this matter.

Fig. 1 shows these objectionable features in the old class of head. The gateway is too wide, and the opening under it is small, compared with the water-way of the bridge ; the result is loss of head owing to the sudden expansion of the sectional area. Below the bridge the sectional area opens out at once to the full width of the distributary (in many cases this width is exceeded), while the depth is still in excess of what it is to be in the channel. The mean forward velocity at this large section must actually be lower than in the distributary, so that, not only has nearly all the initial kinetic energy been wasted, but fresh potential energy, that is command, has to be sacrificed in again accelerating the supply. The effect of this is not, however, confined to the loss of a small fraction of an inch of command ; the acceleration of the supply in an earthen channel is a gradual process, and until it is complete the silt transporting capacity of the water is below normal ; hence the very common phenomenon of a silt bank immediately downstream of the head is produced. This bank of silt is required to provide the increased slope necessary to accelerate the flow ; but it often grows into a serious obstruction.

These objectionable features of the old type of head themselves indicate the cure. The head gate should be, as already indicated, as narrow as other conditions will allow. The rapidly flowing discharge from under the gate must be dealt with sympathetically, and its velocity very gradually reduced in a gradually diverging channel, like the tube of a Venturi meter, until it arrives at the full distributary section in the right condition to continue its flow down the channel carrying its full complement of silt. The delivery end of a distributary head should not then consist of a face wall with two widely divergent wings, but should be continued on, so as to confine the stream between two walls diverging at a small angle (of about 1 in 10) until the width of the distributary is reached.

A gauge, indicating the surface level in this diverging flume, will be more reliable as a means of estimating the discharge, than a gauge whose readings are liable to be affected by changes in the unstable local silt bank produced by the old type of work.

It is interesting to notice that throughout this discussion of distributary head design a low silt charge and a high degree of hydraulic efficiency have always gone together, while a high charge of silt has accompanied waste of energy. This is a highly convenient result, because it is just these distributaries with poor command, flat gradients, and in which silt is therefore undesirable, that conservation of head is most necessary. Whereas distributaries with plenty of command, steep slopes and a high silt-transporting capacity, are just those in which there is ample head to spare and to waste, if necessary.

While the author was engaged in making observations in connection with the study of this subject some five or six years ago, alterations were made in several existing works and the lines of stream flow observed. Figs. 15 and 16 show the head of the Gajiana distributary on the Upper Gugera Branch of the Lower Chenab Canal before and after it was altered, and the directions of flow of surface and bottom water into it in both conditions.* The altered design is simply an early and rather crude attempt to carry out the principles indicated in this paper for drawing off a low silt charge, and was built before the graphic method of suggesting the stream line form used in this paper had been applied to the subject. In the light of the suggestions provided by diagrams Figs. 2, 3 and 4, it is evident that the downstream nose projects much too far into the canal and intercepts too wide a marginal strip ; moreover, it separates the stream along part of the line, where bottom water is being pushed away from the regulator, into the stream flowing on down the canal. Nevertheless, this alteration effected a marked change in the silt charge taken into the distributary, as was evidenced by the fact that, while previously the distributary required periodical silt clearance, after the alteration of the head it scoured out and maintained a considerably flatter bed than it had ever run with before. The reason of this change is evident from the observed lines of bottom and surface flow plotted on the diagrams, Figs. 15 and 16. With the head, as originally built, the lines of bottom flow entering the regulator come from farther out in the canal than the surface lines which they crossed, and it is clear that there was more bottom than surface water entering the distributary. After alteration this condition no longer existed, and the distributary now takes top and bottom water more or less equally.

Several other distributary heads were altered with more or less success, and a considerable mass of observation collected. As a rule the downstream nose of the face was made to project

*In these diagrams the width between the lines has no definite relation to the forward velocity.

farther than now seems advisable. These attempts are mentioned here only to indicate that the views expressed in this paper are based on a collection of observed facts, and are not merely armchair conjecture.

In concluding this part of the paper, attention is drawn to the fact that no type design for distributary heads is offered. The reason is that a type design which can be applied blindly to all sites under all conditions is not possible for works of this kind, each of which must be considered intelligently, and the individual features of each site taken into account.

Diversion Works where the whole of the Supply in the Parent Canal is regulated.

The principles which have been explained in connection with distributary heads will apply also to diversion works of the second class. The cross circulating currents, which control the distribution and transverse travel of silt, are governed by the same influences here as elsewhere, so that the distribution of forward velocity upstream of the regulators must be studied and adjusted to suit the requirements of each case.

While discussing the relative effects of regulators working with different heights of fall through them, it was shown that the velocity of approach was appreciably affected by the fall, the more rapid flow accompanied by a corresponding depression of surface being towards the greater fall. Applying the principle that bottom water flows towards the region of low forward velocity, and top water towards the region of high forward velocity, it is evident that other things being equal, most silt will tend to flow towards the head of the branch into which there is least fall, and the lowest charge will go to that into which there is the greatest fall. Though this is very often what actually happens, it is, as a rule, the opposite of what is desired. If then, silt is to be distributed uniformly among the branches taking off at such a site, it is evidently not sufficient just to make the discharge per foot run uniform across the whole work ; the distribution of kinetic energy must also be made uniform. Or, where an unequal distribution of silt is required, the distribution of both kinetic energy and discharge across the canal must be made accordingly.

In building a new work, it will probably be possible to arrive at a compromise, by making the regulator, which has a high fall, of such extra width as will balance the excess of kinetic energy by a reduced discharge per foot run. In existing works, however, where it is desired to alter the present unfair distribution of silt

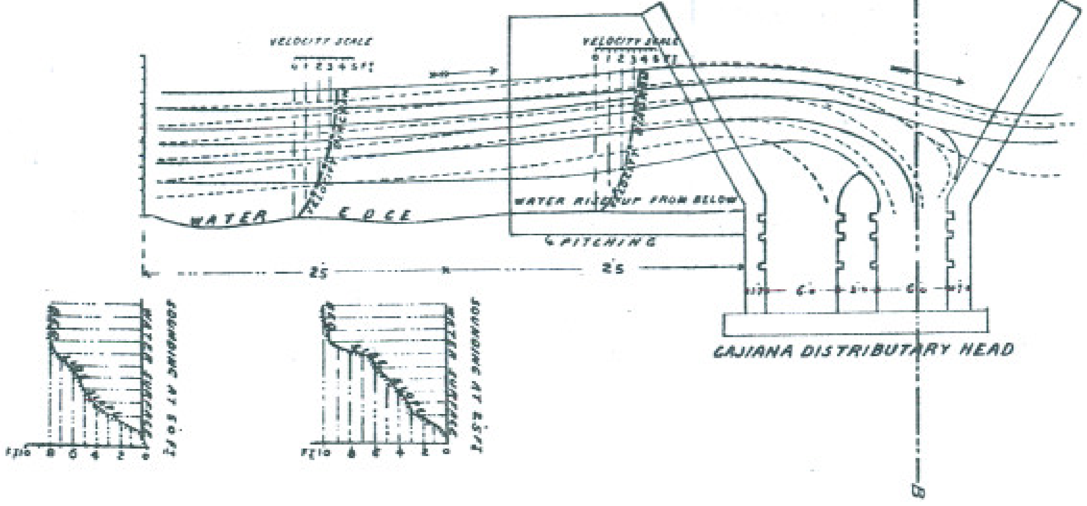
Fig: 15

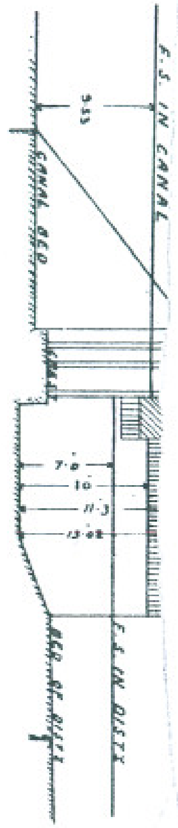
—STREAM LINE DIAGRAMS—

—IN GUGERA BRANCH UPPER AT GAJIANA DISTY HEAD—

—SCALE. 1/225

WITH HEAD AS ORIGINALLY BUILT.





SECTION ON A.B.

DATA WITH HEAD AS ORIGINALLY BUILT.

CANAL	R. L. F. S.	692·05
	R. L. BED	682·53
	R. L. CREST WALL	683·53
DISTRIBUTARY	R. L. F. S.	688·53
	R. L. BED.	683·53
	DISCHARGE	117 CUSECS

NOTE.

SURFACE STREAM LINES ARE SHOWN IN FULL LINES.
BOTTOM — DO — DO — DO — DOTTED LINES.

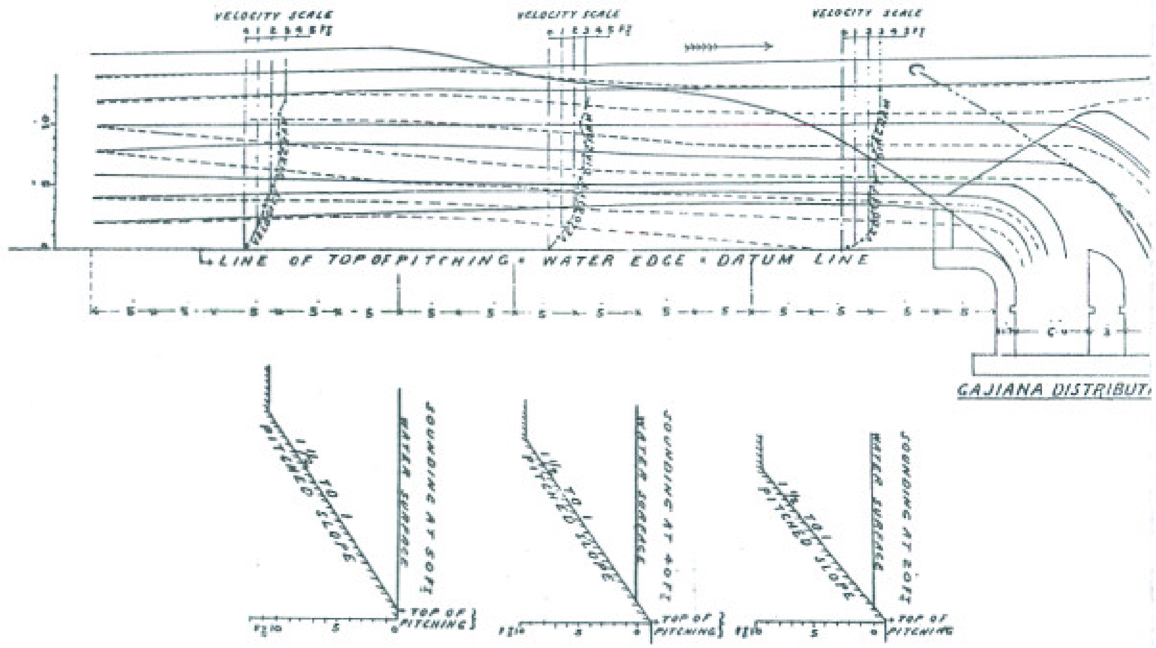
FIG: 16

–STREAM LINE DIAGRAM–

–IN GUGERA BRANCH UPPER AT GAJIANA DISTY HEAD–

–SCALE = 1/225–

HEAD ALTERED IN FEBRUARY 1911
WITH OBSERVED DISCHARGE = 162 CUSECS



NOTE.

SURFACE STREAM LINES ARE SHOWN IN FULL LINES.
BOTTOM —— DO —— DO —— DO —— DOTTED LINES.

whereby the high level branch gets the heaviest charge, it will be necessary to devise means of reducing the draw towards the greater fall, either by means of a subsidiary regulator downstream arranged to head back the supply in the branch, so as to reduce the initial fall into it, or by extending the upstream ends of the piers and making the existing work into a double regulator in which the total fall is divided into two adjustable steps.

If double regulators of this kind were provided at this class of diversion works, and the work constructed so as to give a uniform distribution of discharge per foot run, then a considerable degree of control over the distribution of silt among the branches would be obtained, and it would be possible to alter the share of silt taken by each branch to a certain extent from time to time as circumstances required.

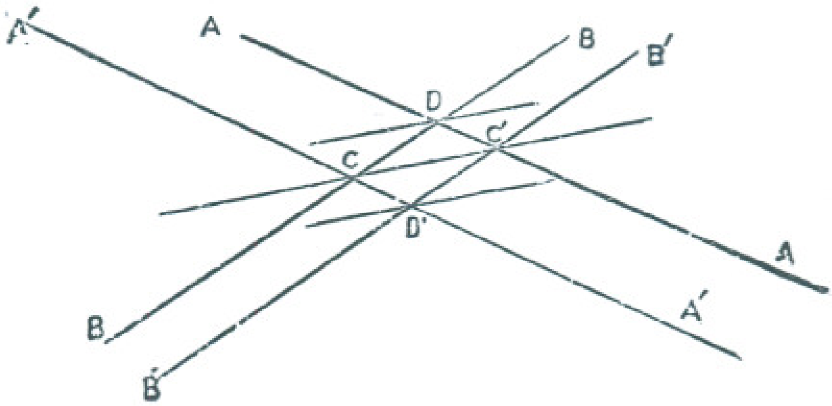
Canal headworks are, of course, only magnified and glorified examples of this class of diversion work, to which the same principles apply, but they do not come within the scope of this paper.

APPENDIX A.*

Composition of Elementary Streams.—If a layer of liquid is acted upon, at the same time, by two sets of forces, which, if acting separately, produce currents consisting of two different sets of streams, the combined action of these two sets of forces will produce currents consisting of a third set of elementary streams, which may be regarded as the resultants of the two former sets. The stream lines marking the boundaries of the first two sets of elementary streams may be called the *component* stream lines; and those marking the boundaries of the third set, the *resultant* stream lines. The principle which connects the resultant streams with the component streams is as follows:—

The resultant stream lines pass diagonally through all the angles of the net work formed by the component stream lines.

Let AA, A′ A′ be a pair of stream lines belonging to one set, and BB, B′ B′ a pair belonging to the other set; the flow along them is the same. The line CC′ drawn through two of the intersections is one set of the resultant stream lines; and the lines parallel too CC′, drawn through DD′ are two more.



For CC′ may be considered a section of the stream AA′, and the velocity perpendicular to CC′ is the flow divided by the area CC′. Similarly, it is a section of the stream BB′, and the velocity across it is the flow divided by CC′ which is the same as the flow in the first stream. Since they act in opposite directions, there is no flow across CC′. Similarly the flow across DD′ due to each stream is the flow divided by the area DD′, and the forces producing the two streams tend to send a double volume per second through DD′.

Hence, between DD′ there are two resultant elementary streams, so that each of the points D,D′ is traversed by one of the resultant stream lines.

The velocity of the stream in AA′: that in BB′: that in CC′ as D′ C′: DC: CC′.

* Extract from Dunkerly's Hydraulics, Vol. 2, Chap. 1, para. 5.

The simple types of motion satisfying the condition already laid down are—

(1) Motion in parallel straight lines. Here $\rho = \infty y$, $dv = 0$ and $dt = 0$, so that the velocity is the same in all the stream tubes, and the distance apart of the stream line is invariable.

(2) Motion in straight lines converging towards, or diverging from an axis, to which they are all perpendicular.

In this case, considering a layer of uniform thickness the elementary streams are of the form of wedges, separated from each other by planes radiating from the axis, and making equal angles with each other. The velocity varies inversely as the distance from the centre, and at the centre is infinite. Thus there is a *source* by which liquid is perpetually flowing out in all directions, or a *sink* down which it is perpetually flowing, according as the velocity is from or towards the axis. The continued existence of a sour e or sink would postulate a continual creation or annihilation of fluid at the point in question.

APPENDIX B.

The normal condition of flow in canals is more or less turbulent. Professor Osborne Reynolds has shown that true stream line motion, in which neighbouring parallel filaments at different velocities slide along each other without disturbance, only occurs under certain favourable conditions; and one of these conditions is, that the rate of change of velocity across the streams must be small, so small indeed, that we may take it that in practically all hydraulic works the flow is more or less turbulent. This does not mean that the principles of stream line motion are not applicable in ordinary practice; the general resultant directions will still be governed by these principles; but an added internal turbulence also obtains.

When it is considered that this turbulence is caused when the relative velocity between neighbouring filaments exceeds that allowed by the viscosity of the liquid, then it is difficult to imagine that the new motion introduced is other than a rolling motion; because, unless rolling motion is introduced between filaments, there seems no way in which the relative velocity can ever exceed that at which true stream line flow ceases to be possible.

Of course, hydrodynamics says that rotational motion cannot be created, and adds, that if such rotation ever existed, it could never be stopped. But hydrodynamics deals with an ideal, "perfect", non-viscous fluid which bears very little resemblance to water, and Osborne Reynolds, who, besides experimenting with water, also made valuable contributions to hydrodynamics, himself warns us against the unintelligent application of hydrodynamic theory to hydraulics.

There can be no doubt of the existence of rotational motion in the water near the margins of our canals, and the direction of rotation in the strings of small eddies there visible indicates that the rotation owes its existence to the fact that the velocity increases rapidly from the bank outwards. There is every reason for supposing that the increase of velocity from the bed upwards also causes rotational motion of some kind But the fact that eddies of the true free vortex type can only exist when independent of gravity, that is, with a vertical axis, suggests that the rotation about horizontal axes caused by the vertical velocity gradient will be of some other, possibly less regular, form. The wave and ripple marks made on the sand beds of our canals seem to indicate a wave motion of some kind, and waves as we know them on water are rotational in character, though hydrodynamic theoretical waves may not be.

Granting, then, that cross velocity gradients involve rotation about axes at right angles to the direction of flow, a new kind of momentum is introduced into flowing water. The theory of the gyroscope explains the various manifestations of the angular momentum due to rotation. From this we know that if a couple is applied to the axle, about which a mass is spinning, tending to turn it about a second axis at right angles to it, then the spinning system will actually turn, or precess, as it is called, about a third axis perpendicular to both; and the direction will be such that the precession of the axle of spin tends to convert the existing spin into a spin about the axis of the applied couple, so that the spin would become in the direction required by the couple.

Now in a channel the ends of the horizontal axes of the rotation caused by the vertical velocity gradient are continually being bent backwards by the slower flowing water near the margin. This retardation at the sides acts as a horizontal couple pulling the ends of the axle of spin back while the portion in the middle is pressed forward. The resulting precession is in a vertical plane, and turns the axle of spin up at the margin and down in the middle. That the axles of spin are not continuous across the stream, but more probably short and irregular, does not alter the final result, which is to produce a rising current all along the region of low velocity, and a downward tendency in the streams in the region of high forward velocity. These currents inevitably induce flow along the bottom from the high to the low forward velocity, and surface flow in the opposite direction.

The vertical eddies which exhibit rotation produced by the horizontal velocity gradient also come under the action of a couple; the bottom velocity is lower than that near the surface, hence the vertical axes are pulled back at their lower ends and pushed forward at the top. Applying the rule for the direction of precession as before, the result will tend to cause flow along the bottom from the region of low to that of high forward velocity, and in the opposite direction near the surface, which will induce downward motion at the low forward velocity and upward at the high.

It appears, then, that the cross circulating current produced by the vertical velocity gradient, is opposed by the tendency of the horizontal velocity gradient to produce a similar current in exactly the opposite direction. But in ordinary earthen channels the velocity distribution is much more influenced by the bed than the side, simply because there is much more bed than sides ; therefore the resultant current is in the direction caused by precession resulting from rotation about horizontal cross axes retarded in regions of low forward velocity.