PAPER No. 169.

SILT EXCLUSION FROM DISTRIBUTARIES.

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Introductory.

I. It is no exaggeration to state that nearly all the difficulties which confront the Irrigation Canal Engineer are either directly or indirectly due to the silt which is brought down in the rivers and enter irrigation channels ; the success of a canal system depends on the degree in which the ill-effects of that silt can be overcome or obviated.

There are two distinct and separate branches of the science of Silt Control : the object of the first branch being to evolve some formula which would give the measure of the silt-carrying capacity of flowing water under various conditions, in order to enable engineers to design channels such as will carry in supension all the silt that they may be called upon to deal with, and will not, on the other hand, erode the bed and sides of the channel. The object of the second branch is the control or adjustment of the quantity of silt entering a stream, or the complete exclusion of all silt liable to deposit on the bed.

The researches of investigators hitherto have been chiefly confined to the first of these : and various formulae have been evolved by Dupuit, Kennedy, Lacey and others which have proved of immense practical value ; but experience has shown that more is required than merely the knowledge of how much silt a stream can carry, or what the design of a channel should be to enable it to carry a given silt charge. The physical conditions of the country often make it impossible to design any channel which will carry in suspension *all* the silt contained in the only water available for it, and it is often necessary to reduce the silt charge in the water available before it can be carried in any channel even if designed in accordance with the best known principles.

The present paper deals solely with the second object above mentioned : the exclusion or adjustment of the silt entry into a channel ; and is not directly concerned with the intricacies of the silt-carrying capacity of flowing water. In it the writer confines himself to obvious, well-known and universally accepted facts, and indicates how they may be utilized in order to control the silt entry into a channel.

When once a thorough grasp is attained of the simple principles enunciated in the following pages and of the various ways in which they may be applied, there need never be the slightest difficulty in excluding from any channel all silt which might deposit ; the only case in which silt cannot be excluded with the knowledge now available is where there is not enough water left over after the silt separation to carry away the silt thus excluded ; or where the surplus water has not, and cannot be, given the power to transport the surplus silt.

2. Before proceeding with the description and design of the various silt excluding devices, a few general remarks may be helpful.

By the term "Silt" as used throughout this paper is meant, sand, whose grains are visible to the naked eye, and which is capable of being deposited in the bed, say, of a channel for which Kennedy's critical velocity Ratio is 0·7 Vo ; and not the impalpable mud which can be carried in suspension even by our worst designed minors. This remark is made to forestall the comment, so often made, that some silt is a good thing.

Also the expression " Mean Velocity " means the mean of the velocities at different points of a vertical line from the bed, and not the mean sectional velocity of the channel.

Fundamental Statement.

It is known that the heavier grades of silt in a stream are carried in the lower layers of water. Every obstruction, or roughness in the bed of a channel has the effect of throwing up towards the surface a certain quantity of the water that passes over it ; any hole in the bed has the same effect. This can readily be seen by watching the surface of a stream. It will be seen that at certain points volumes of water are thrown to the surface by some obstruction or hole in the bed, giving a " boiling " effect. This can easily be verified further by releasing "whitewash" or some such colouring matter at the bed of a channel just upstream of some obstruction on the bed; or by roughening the bed at the edge of a stream where effect can be observed. Why this bottom water is thrown up is immaterial ; but it cannot be denied that it is so thrown up. Also the reason why the upthrown water draws up silt from the bed with it is unimportant for the purposes of this paper ; the fact remains that it does do so.

Dupuit says that the measure of the silt-carrying capacity of water at any point is some function of the difference in velocity of the filaments of water just above and just below that point, thereby agreeing with and confirming the above statement ; for the difference in velocity is of course caused by the roughness of the bed. Moreover the fundamental fact stated above gives a very simple explanation of some phenomena difficult to explain in any other way ; for example, cross currents, and the fact that the surface velocity of stream is usually somewhat less than the velocity a short way below the surface , further confirming the statement that water is thrown upwards by obstructions in the bed.

It would be better to state that obstructions or roughnesses cause water flowing past them to be thrown *away* from them ; for the same effect is as readily observable at the edges of a channel as at the bottom : obstructions such as grass growing on the edge can be seen to throw water away from the edge.

Thus the silt carried in the water is continually being thrown upwards and falling slowly back again till it gets another upward throw. It travels therefore with a saltatory motion, the height to which it is

thrown at each leap depending on the roughness of the bed, the velocity of the stream, and the coarseness of the silt. The reason why the coarser grades of silt do not get thrown up as high as the finer grades is that though the water containing them is thrown up, the coarse silt particles being heavier are not thrown quite so far up as the finer and lighter particles, and fall back more rapidly.

As a matter of fact, though it is true that given a fixed depth and mean velocity, a rough bed will carry more silt than a smooth (within reasonable limits, *vide* para. 5), yet a smooth bed will be able to transport a heavier *grade* of silt than a rough, though the quantity (*i.e.*, volume or weight) of the silt which it could transport would be less than in the case of a rough bed. It is not considered necessary to give the proof of this, though it is simple; as it is outside the scope of this paper, which is merely intended as a guide for the design of Silt Excluders and Silt Controllers, and not as a general treatise on the subject of the behaviour of silt. To follow up this and other similar interesting by-paths would unduly extend the paper.

The lower the layers of water, the heavier the grade of silt will be which it can transport, the heaviest moving silt merely rolling along the bed. Some writers speak of "Rolling Silt" as distinct from "Suspended Silt". It is impossible to maintain any such distinction even in a long length of the same channel ; for if the velocity or the roughness of the bed, or both, be increased, rolling silt becomes suspended silt, and a heavier grade which was previously stationary becomes rolling silt. Obviously, the smoother the bed of a stream, the lower the layer of water will be which can transport any particular grade of silt. This fact is used in devising silt excluders.

Reasons for Right Angled Offtakes Silting.

3. A fact which is familiar to practically every canal engineer is that when a channel takes off more or less at right angles from its parent channel which is carried straight on, the offtaking channel takes in a greater proportion of silt in its water than the proportion carried in the parent channel.

Though this fact is well-known, comparatively few at present know the reason for it. There are three reasons :—

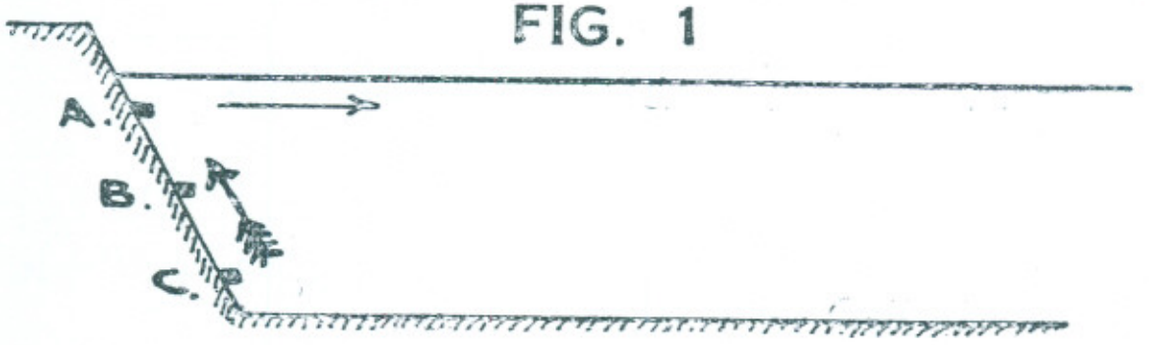
The first and by far the most potent reason is, that the upper layers of water in the parent have a considerably higher velocity than the lower layers, and have therefore a considerably greater momentum ; and consequently the lower layers, which contain the heavy silt, are deflected more easily from their course, and are drawn into the offtaking channel more readily and in greater quantity than the upper layers. This simple fact should always be borne in mind, for on it depend several interesting (and valuable) effects. Two examples of how this fact might possibly be utilized are given in paragraphs 28 and 29. The principles set forth in these two paragraphs (28 and 29) are very important and should be specially studied.

The second reason, which is probably the next in potency, is that given by Prof. J. P. Thompson in his book, *Papers on Physics and Engineering*, pages 104-05. It is very interesting and several searchers after knowledge have endeavoured to use it in the design of silt-excluding regulators. Its potency is probably a long way short of that of the difference in momentum, but it is worth while to quote the explanation from Prof. Thompson's book, and it has accordingly been given as Appendix I at the end of this paper.

When the water is deflected into an offtake it enters it in a curve, and the effect described by the Professor is therefore created.

The third reason and the one which probably has the least practical effect is the cross-currents which exist at the bottom and edges of every channel. These cross-currents are normally very gentle but their existence is an undoubted fact as any close observer may see ; and it may be worth while here to give the real reason for them, as the reason offered hitherto appears to the writer to be unconvincing. The fundamental statement made at the beginning of this paper is that every obstruction and unevenness on the bed or sides of a channel has the effect of causing the water passing over to be thrown away from it. The force with which it is thrown increases with the velocity of the water.

FIG. 1



The diagram, Fig. 1, is the cross-section of the edge of a stream.

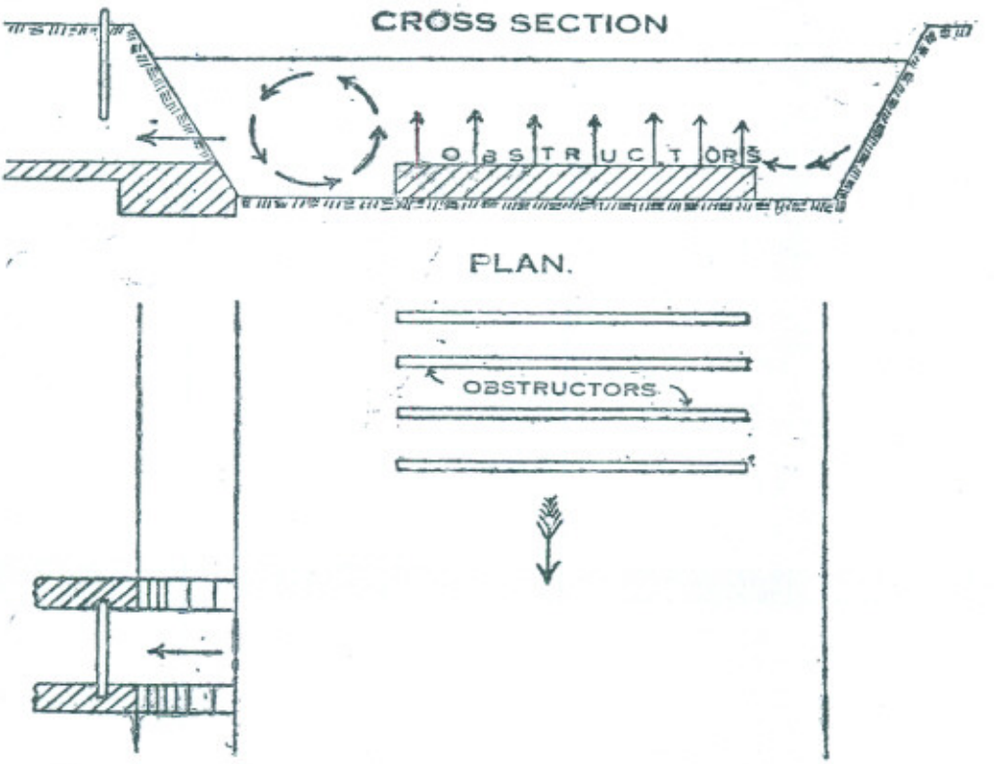
There are obstructions (roughnesses) at A, B and C. The roughness at A causes water to be thrown towards the centre of the channel in the direction of the horizontal arrow. Where does the water come from to take the place of the water so thrown outwards ? Obviously from below, where, having a less forward velocity, it is thrown away from the side with less force. Thus there is a "draw" towards the surface, from C to B and B to A as indicated by the arrow parallel to CB. Hence cross currents at the edges of a stream.

It follows further that there must be at least a tendency for another pair of cross-currents near the middle of a narrow stream, on either side of the centre where the greatest velocity is, each towards the centre. A "narrow" stream, because there would have to be a difference in mean velocity to create the centre cross-currents, and in a wide stream the difference in velocity over a considerable width is negligible.

Hence, in the case of a channel taking off at an angle with the parent which is carried straight on, if the offtaking orifice is, say, at mid-depth of the parent, it would be possible to cause it to take off a smaller proportion of silt from the parent by thoroughly roughening the bed of the parent (for its full width) say with transverse low walls on the bed just upstream of the offtake ; for that would cause heavy silt to be thrown to the surface and thus some of it which would otherwise have been sucked up from below into the offtake would be carried on down the parent channel by the surface water which has the greater momentum. The roughening would have to be in the full width, (or at least in a large width) of the parent, because otherwise the place of the heavily silt laden water thrown up would be taken by the equally heavily silt laden water adjacent to it at the bottom of the parent, since the bottom water has the least forward momentum.

There are many ways other than those described in the following pages in which the principle enunciated at the beginning of this paper could be used ; for example, it is possible by merely roughening artificially the bed of the parent channel just upstream of the offtake and a little removed from the edge, to cause a small offtaking channel to draw less silt, in virtue of the reverse-cross-currents that are created thereby. *See* Fig. 2.

FIG. 2



The obstructions (low walls built in the bed) must, of course, be so placed that the lower layers of water thrown up by them shall not have a chance of entering the offtake. This was one of the writer's

numerous early experiments, and is only of academic interest ; but it perhaps shows that practical applications of the general idea may be possible which do not " jump to the eyes ".

Common Cause of Silting.

4. There are, of course, other obvious causes for some channels drawing more than their share of silt, such as a head regulator projecting into the parent channel, stakes and bushing put into the parent channel or a ragged berm just upstream of the offtake, a cill set back behind the berm line, etc. All these set up eddies which stir up the silt and cause it to be thrown upwards and drawn into the offtake. It may be here objected that the bottom water is in any case drawn into the offtake. True, but eddies such as described, in throwing water more forcibly to the surface, increase the velocity of cross-currents at the bottom, and so draw bottom water from further away towards the edge. This is an important point and must always be borne in mind.

Often one sees a sharp bend in the offtaking channel at its head which reduces velocity and causes silt to drop.

If the offtaking channel is not a *bad* silter, the removal of these obvious defects will often cause it to cease silting. The object of this paper is however to indicate the remedy in cases where even the removal of obvious defects at the head will not cure silting, as when the gradient of the offtaking channel is too flat to enable it to carry the proportion of silt which the parent has in it, in spite of Kennedy, Lacey, etc.

If may be worth while mentioning another obvious point. Often where a channel takes off at right angles to its parent, the water in it is started on its course with a velocity practically nil. Before it can carry its share of the silt charge it must develop the necessary velocity to do so. A short reach at the head must therefore silt up till the gradient in it is sufficient to give the water the necessary impetus. Hence the silting in the head reach only. This effect can generally be got over by giving the channel a skew head, or more efficiently by the "curved wing" device described in para. 25 below.

5. It would not be out of place here to mention another fact, which though very elementary is of great importance, and is closely connected with the subject of this paper.

There is a curiously prevalent idea that by narrowing a channel by stakes and bushing without altering its gradient at all it can be forced to scour its bed, *i.e.*, to carry more silt. This idea, and persistent efforts to apply and "prove" it have cost and are costing the Government very large sums of money absolutely uselessly. It is contrary to all accepted principles, and the fact cannot be too widely advertized. It is true that in certain cases narrowing the head reach of a channel has caused silt to be scoured from the bed ; but that effect is not due to the narrowing

but to the forcing of the same supply as before (there being sufficient working head into the regulator to do so) into the channel *by increasing the surface gradient* in that reach and consequently the mean velocity. The fact that silt *has* been scoured out of the bed in these cases has confirmed the experimenter in his idea that it is the forcible narrowing that has done it.

According to Dupuit, it is the difference in velocities of contiguous laminae of water that decides the silt-carrying power of a stream. Now given a fixed mean velocity, the shallower a stream is the greater that difference of velocity must be, since at the bed it, in any case, will approximate to zero.

Therefore the shallow stream will within reasonable limits be able to carry more silt than the deep.

Kennedy's formula is $V_o = \cdot 84\ D^{\cdot 64}$. Therefore according to him also a shallow stream will carry more silt than a deep.

Now turn to Lacey's paper on " Stable Channels in Alluviums " in Vol. 229 of the Proceedings of the Institute of Civil Engineers, Session 1929-1930, Part I, page 273 (extract reproduced in Appendix II). This seems (within reasonable limits) to mean the same thing.

A glance at any one of Kennedy's diagrams will show that with a fixed slope, a fixed "N", and a fixed discharge or a fixed mean velocity the deeper a channel is, the less silt it will be able to carry ; for the Critical Velocity Ratio becomes less as the depth increases. Lacey again in his " Regime Dimension Diagrams," Plate 1A and 1B of the United Provinces Irrigation Branch Technical Paper No. 1, " Regime Diagrams for the designs of Canals and Distributaries" shows exactly the same thing, *viz.*, that given a fixed discharge, the deeper a channel is, the less silt it will be able to carry, for his value of "f" decreases as the depth increases, and "f" is the figure denoting the coarseness of the silt.

But quite apart from the authority of leaders of modern research, the greater silt-carrying power of the shallower channel is a direct consequence of the fundamental statement made in the beginning of the paper (para. 2), which statement is an irrefutable fact. For in the case of a shallow channel with fixed *mean* velocity, the velocity of the water passing close to the bed will be greater than if the channel were deep. Consequently bodies of water will be thrown up towards the surface with more force, and will therefore within reasonable limits be able to lift heavier silt from the bed than in the case of a deep channel.

It may, perhaps, be asked : What is meant by "Reasonable limits?" The reply can most simply be given by taking an example.

Consider a stream with a very rough boulder and shingle bed, of great width, and small depth, say half a foot, and a steep gradient. " Great width" is specified in order to eliminate the effect of the resis-

tance of the sides of the channel. The rugosity of the bed is so great that with so shallow a stream passing over it, the mean velocity is very considerably lessened by the rugosity of the bed. Now consider a channel of the same roughness of bed, and the same gradient, but with a depth of say 6 feet. The rugosity of the bed will now have far less effect in reducing the mean velocity, which will therefore be considerably greater. The deeper stream in this case might then be capable of moving a coarser and heavier grade of detritus than the shallower, in virtue of its greater mean velocity. (By " Mean Velocity " is meant the mean of the velocities on a vertical line from a point on the bed.)

It may now be argued that the same would apply if the depths of the two streams mentioned above were 5 feet and 6 feet, respectively. This is by no means the case : the difference in the mean velocity would have to be very considerable indeed to cause the deeper stream to move heavier detritus than the shallower one ; and seeing that the gradient remains unchanged it would require a very considerable difference in depth to change the mean velocity to the required extent.

The reason why the difference in the mean velocity would have to be very considerable in order to cause the deep stream to carry heavier detritus than the shallow is that the deeper a stream is, (with the same mean velocity), the less will be the velocity of the filament of water passing close to the bed. This fact counteracts, "within reasonable limits," the effect of the increased mean velocity resulting from a greater depth.

Good Working Head does not Reduce Silting.

6. Again it is very generally believed that distributaries silt when they have a poor working head into them : that a good working head prevents silting.

This is merely confusing cause with effect. When a distributary has a tendency to silt owing to too flat a gradient or faulty design, it will naturally start silting up its head-reach first and keep on at it till the gradient is steep enough to enable the silt to be carried further down. The result of course is that the working head available gradually becomes less and less. For the same reason it will usually be found that distributaries that silt have wider head regulators than those that do not silt for the regulators have either been widened after their initial construction in order to let more water in, or they have been made wide in the first instance owing to the poor working head available.

7. There is another point which though only indirectly connected with the subject-matter of this paper, is of considerable importance and which is perhaps not universally known, but the truth of which the writer has conclusively proved in the course of his experiments. It is that when silt is excluded from a channel a very rapid growth of berm is induced. The writer can only account for it by the drop in mean

velocity usually resulting from silt exclusion. It is generally believed that rugosity or resistance to flow along the sides of a channel will induce the formation of berms. This idea is responsible for the too universal practice of " staking and bushing " the sides of channels.

Scour in the bed of a channel occurs when the upward throw of the water due to irregularities on the bed becomes so strong that not only is all the silt which would otherwise roll along the bed thrown clear and kept clear of the bed, but the material of the bed itself is sucked up by the upward eddies. Scour ceases when the velocity of the water passing over the bed becomes too low to cause such violent upward eddies.

Now if this reason for the scouring of the bed is applicable to the sides also, as it apparently should be, it follows at once that when the mean velocity is reduced, the berm must grow more rapidly. We know that they do so. Taking this as evidence (at least) in favour of the idea that the law for the bed scouring or silting is applicable to the sides also, it follows that a rough, ragged, and ill-kept berm will tend to be eroded far more rapidly than a smooth, well-dressed one with the same velocity over it. That this is true is borne out by results observed by the writer in extended experiments on the Lower Chenab Canal, and he thinks there is sufficient evidence for the idea to be acted on at least, until it is disproved. This would mean practically a prohibition of the pernicious system of stakes and bushing which is at present so much in vogue.

In this connection it will perhaps be objected that berm growth is always more rapid near the surface of a channel, causing the berm to overhang; whereas if it were true that a lower velocity past the edge of the channel induced more rapid berm growth, the edge near the bottom should berm up far more rapidly than that near the surface. That is true, but there may be other reasons for it. Some think that the attrition of the heavier silt nearer the bottom retards berm growth, but this seems doubtful. The writer considers that this effect is due mainly to the roots of weeds and grasses at and near the surface retaining any deposit as soon as if forms, and this cannot occur deeper down where such roots do not exist. Cross-currents may help in this effect to some extent, but this is somewhat doubtful. At any rate, there seems to be no doubt that a smoothly dressed berm will grow more rapidly than a rough, irregular one.

Silt-excluding devices.

8. Reverting to the subject of silt exclusion, there are a number of methods of preventing the heavier silt in a stream entering an offtaking channel; but all of them, except " Silt Vanes," have the great disadvantages that some part of the structure is liable to arrest bits of grass, branches of trees and similar debris, which at once set up eddies causing silt to be thrown to the surface. It is for this reason that in the course of a long series of experiments extending over many years, all devices have one after another been rejected by the writer in favour of Silt Vanes, for use in distributaries where constant supervision and clearance of debris is not possible.

All the other silt-excluding devices known to the writer are described below ; but Silt Vanes, and the Silt-Vanes-*cum*-Curved-Wing arrangement are by far the most efficient of the lot in the vast majority of cases.

The only objection to Silt Vanes is that the silt exclusion from the offtaking channel is not easily controllable ; they are therefore entirely unsuitable in their simple form for use in a headwork, where the *control* of silt entry rather than the mere exclusion of depositing silt is necessary. For Headworks, however, since constant supervision is possible, even more efficient and moreover adjustable devices have been evolved, *vide* Part II of this Paper.

In cases where boulders and shingle are carried in the river at a headwork it is more than likely that guides in the nature of Silt Vanes would be extremely effective : because total exclusion of shingle and boulders from the canal would be aimed at, and there would be no question of "adjusting" the shingle entry into the canal. This as far as the writer knows, has not yet been tried. The vanes or guides in such a case would of course have to be made strong enough to resist the impact of boulders, etc. Also the curves would have to be more gentle on account of the high velocities obtaining, etc., but the system is one which certainly should be tried as the possibilities of success are very great indeed.

9. It is true that all the silt excluded from an offtaking channel has to go down the parent stream ; but it has been found by experience that this has not the marked effect in silting up the parent stream or the other distributaries taking off from it downstream of the Silt Vanes than might be expected ; and it is ordinarily quite safe to introduce Silt Vanes fairly freely for channels that silt. The extra silt thus put into the parent channel is distributed between the distributaries which had not hitherto silted and which are obviously better able to deal with the extra silt than the distributary treated ; and the additional silt which each distributary has to take is usually so small that it will not make any appreciable difference to those channels.

Cases where vanes are not suitable.

10. Silt Vanes are hardly suitable for cases in which the discharge of the offtaking channel is more than one-third of that of the parent channel ; though there have been cases of the kind where they have been used with very satisfactory results ; in such cases the Curved-Wing-*cum*-Silt-Vanes device described in para. 19 below is clearly indicated. If it is proposed to use vanes alone in such a case, care should be taken that there is enough water passing *over* the vanes to fill the offtaking channel with plenty to spare ; otherwise the velocity of water passing (more or less transversely) across the vanes to the offtaking head may become great enough to pick up heavy silt from between the vanes in passing over, and carry it into the offtaking channel.

It must also be borne in mind in such cases, that the proportion of extra silt added to the parent channel downstream of the vanes will be very considerable and could only be carried on satisfactorily if the parent

channel has, or can be given, a steeper slope downstream of the vanes, say by cutting down some fall downstream.

Careful design and construction necessary.

The correct design of Silt Vanes, though still largely a matter of common sense, nevertheless requires some knowledge and experience of their effect ; and since at present they are almost invariably incorrectly designed, it is necessary to lay down some principles and rules evolved from a careful study of the subject for the guidance of engineers desiring to use them. Even the best designed silt vanes seen by the writer hitherto have for one thing been built too far downstream, and a considerable part of their effectiveness has been lost thereby.

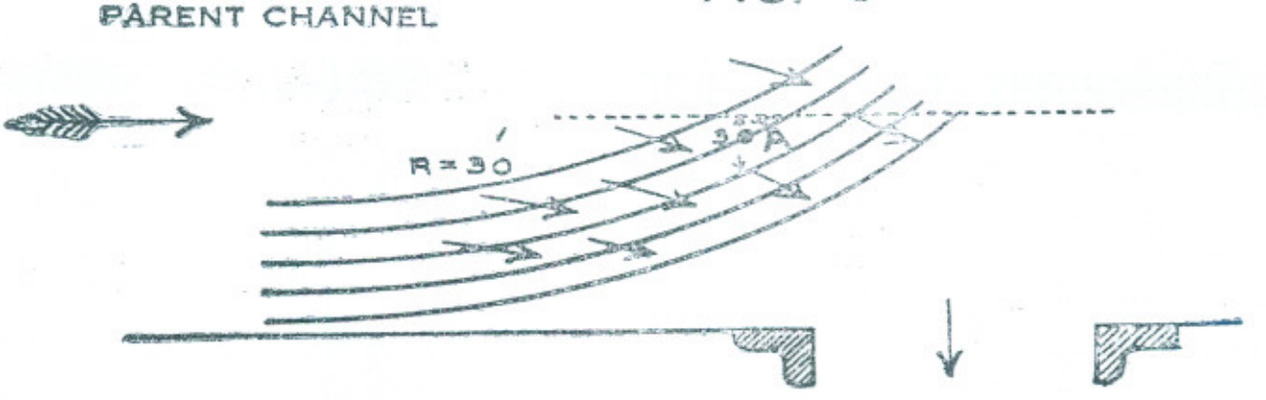
Silt Vanes if properly designed, built, and correctly positioned are surprisingly effective; they will usually cause a very heavily silting channel to scour severely ; but, on the other hand, if badly designed or built, or incorrectly positioned, their effect may be small, or in extreme cases they may actually cause *more* silting in the offtaking channel ; for example, if the upstream ends are built vertical or nearly vertical so that they arrest jungle, the effect of the vanes is completely discounted and may do more harm than good.

11. Enough knowledge has now been collected of their effects to enable definite principles to be laid down for the design of Silt Vanes and to frame the following rules.

(*a*) The minimum radius round which water (at the velocity which has usually to be dealt with) can be guided without undue afflux, may be taken to be 25 feet. If any Silt Vane has a radius of less than 25 feet, the water guided by it and the silt therein will tend to jump the vane. Obviously the minimum possible radius depends on the velocity ; therefore low vanes which only control bottom water with a low velocity may have a smaller radius than high ones. Obviously also, the greater the radius, the more efficient the vane will be. A radius of 40 feet or more should therefore usually be aimed at for the shortest vane, in small or medium sized channels.

(*b*) As the bottom water is guided round, say to the left, clearly the water just above it must veer round to the right, in the direction of the arrows, *vide* Fig. 3.

FIG. 3



This effect gets more and more marked as the water travels down the vanes, till, at some point A where the vane is at an angle of say 30° with the centre line of the channel, the water above the vane crosses the vane at an angle more like 60° than 30°. The tendency then is for eddies to be set up, sucking up the silt from between the vanes. Therefore, the downstream ends of the vanes should be tangential to lines which are at an angle with the centre line not less acute than 2 to 1 (about 27°). If this does not cause the vanes to extend far enough downstream they should be extended in straight lines at an angle of 2 to 1 with the centre line, *vide* Plate No. 1.

(*c*) If the vane nearest the offtaking channel (which will hereafter be referred to as the "Longest" vane) is situated so that some point on it passes very near the offtake, the water above the vane at that point will be travelling more or less towards the offtake and nearly at right angles to the direction of the vane at that point. The result will be severe eddies, and silt sucked out from behind the vane and drawn into the offtake. Therefore, in the longest vane, the point of it nearest to the upstream edge of the offtake should be so far removed from the offtake as not to come within the influence of too strong a "draw". This distance, shown as X in Plate No. 2, is assumed to vary from 5 feet in the case of very small offtaking channels, to 12 feet for channels of 40 or 50 feet bed width (*vide* table, Plate No. 2).

(*d*) When the silt arrives at the end of the vanes, there will be some tendency for it to be drawn again towards the mouth of the offtake. But the "draw" of the offtake will by then have lost most of its effect, and it may be assumed that the silt on leaving the vanes at their downstream end, cannot travel towards the offtake at a more obtuse angle with the centre line of the parent channel than 1 to 2. Therefore, in designing vanes a line is drawn from the downstream edge of the offtake, in the upstream direction, at an angle of 1 in 2 with the centre line of the channel, and the longest vane terminated at the point where it cuts this line, or preferably say 2 feet beyond this point as an additional precaution.

12. The above rules (*a*) to (*d*) definitely fix the longest vane. The only question remaining are: How many vanes are required? how high? and how far apart?

In order to decide on what width of the parent channel should be covered by the vaned pitching, it must be remembered that enough top water must pass over the vanes to fill the offtaking channel with plenty to spare; otherwise severe eddies will be set up and silt tend to be sucked up from between the vanes. If a definite rule had to be laid down about this, it would theoretically have to be something like this: "That width of the parent channel which carries 3 times the discharge of the offtaking channel"; but no such rule could usefully be applied in practice, because the proportion of the discharge of the parent

channel which the offtake takes off varies so greatly. For example, a single linear foot of the parent channel may carry the whole discharge of the offtake.

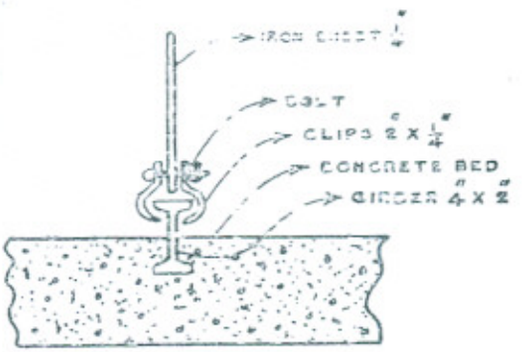
Ordinarily, if the width of parent channel covered by the upstream ends of the vanes is half the width of the offtaking channel, it will be found to be sufficient. In some cases more is advisable and in many cases less, depending on the depth of the parent channel, the height of the vanes, and whether the offtaking channel is a very bad case or not. A greater width of vaned pitching will usually be required for small offtakes, proportionately, than for large. For example, if the bed width of the offtaking channel is only 6 feet, and the parent a large channel, the width of vaned pitching may be made 5 or 6 feet if it is a bad case ; while if the offtaking channel were 30 feet wide, the pitching need probably be only 15 feet wide. A general guide will be found in Plate No. 2.

13. As to the height of the vanes, they may ordinarily be made $\frac{1}{4}$ to $\frac{1}{4}$ of the depth of the parent channel for strong effect ; but as a rule less is sufficient. More is very rarely necessary.

Vanes less than 1·2 ft. high may be made 0·4 ft. thick if built of bricks. If higher than this, a thickness of 0·8 will be necessary for stability. For efficiency, the thinner the better.

Mr. T. A. Miller-Brownlie, Agricultural Engineer, Lyallpur Agricultural College, suggests that the vanes be made of sheet iron $\frac{1}{4}$ inch thick, clipped on to an iron girder bent to the curve desired and partly embedded in concrete, *vide* Fig. 4.

FIG. 4



The clips would be made of iron strap 2″ wide and $\frac{1}{4}$″ thick and fixed at intervals of say 1 foot along the vane. The vanes would then be easily removable and it could be readily found by trial how many were required. Those not required could be used elsewhere.

This would have several obvious advantages, the chief being that there would be the minimum of obstruction in the parent channel. The writer thinks, however, that it might be difficult to make the upstream

end of the vane fit closely enough against the concrete bed to prevent bits of grass and debris being caught under the vane, which would throw up silt. Also the clips might catch debris, or cause eddies. But it is quite likely that these objections might be out-weighed by the advantages of the device and it should certainly be tried. Mr. Brownlie suggests that when the correct number of vanes is found by trial, the upstream ends, clips, etc., might be cemented over so as to remove all possibility of catching debris. This would remove all objections to the system.

The width of the channels between the vanes should ordinarily be about $1\frac{1}{2}$ times the height of the vanes.

It may be considerably more if very strong effect is not desired or in order to save expense. If it is proposed to construct only a few vanes, *i.e.*, fewer than indicated by the above rule and the type designs and table given in the plates at the end of this paper, it would be better to place them further apart, *i.e.*, to make the channels between them wider so as to cover a greater width of the parent channel, up to say half the width of the offtaking channel.

14. The bed of the parent channel covered by the vanes and for a distance of from 50 to 100 feet upstream of the vanes must be smoothly pitched, the object being to cause suspended silt to drop as low as possible in the water by the time it arrives at the vanes, so that it can be diverted by them.

The pitching and the floor on which the vanes are built should be 0·5 feet higher than the normal silted bed of the parent channel to minimize any tendency to silt being deposited on the pitched floor and so roughening it. The edge of this floor and of the floor on which the vanes are built should ordinarily be in one straight line, *vide* Plate I, and parallel to the centre line of the parent channel.

The upstream 15 feet of the pitching should be built at a slope of 1 in 10, so that the upstream edge will be sufficiently below the silted bed not to become exposed and throw up silt.

The side slope of the parent channel on the side of the offtake must be pitched for the same length upstream as that to which the bed pitching extends.

If it is found that a set of silt vanes excludes more silt than is desired from the offtaking channel, causing excessive scour, the cure is to place in the channels between two or more of the vanes nearest to the offtaking channel near the upstream ends of the vanes some obstructions, such as sacks of sand. This will throw the heavy silt upwards and it will enter the offtaking channel.

15. A not uncommon effect of Silt Vanes is to cause a heap of silt to deposit in the parent channel just downstream of their ends. This usually happens in the smaller channels where the Silt Vanes occupy most of the bed of the channel. In such cases the heavy silt is concen-

trated at the edge of the channel instead of somewhere near the middle, and as the velocity at the edge is small, it deposits there in a heap. It is therefore sometimes advisable in such cases, especially where vanes are designed for strong effect, to construct just downstream of them a set of reverse vanes. An example of these is appended as Plate No. 4. The necessity for them is not very common, and they need not be so carefully designed, as their only function is to redistribute the silt, which has been concentrated to one side of the parent channel evenly over the bed of the channel.

These reverse vanes need not be concentric. nor carefully plastered, the cut water ends should be at a slope of 1 to 3, the distance from the downstream end of the offtake to the nearest point of the reverse vane (A to B on Plate No. 4) should not be less than X as got from the table of dimensions.

Another, and more rare effect is that the clearer surface water having been diverted towards the offtake, sometimes approaches it with a considerable velocity, causing erosion of the bank, and sometimes of the bed of the parent channel just downstream of the offtake. A short length pitching will counteract this.

Important points in construction.

16. The sketches and the table of dimensions appended, plates 1 to 3, will be found to give in most cases the details required for the design ; but it is very important that in the building, the following rules be strictly adhered to :—

(*a*) The upstream ends of the vanes excepting the sloping nose must be tangential to a line parallel to the centre line of the parent channel. The sloping nose must be made straight and parallel to the centre line.

(*b*) The curves must be even and regular.

(*c*) The upstream ends of the vanes, *i.e.*, the straight part must be finished off to a slope of 1 vertical to 3 horizontal so as not to catch bits of grass and other debris. Neglect of this point would mean certain failure. The downstream ends may be built vertical.

(*d*) It is also most important that the upstream ends of the vanes must be finished to a V-shape to act as efficient cut-waters, which will not create eddies (*vide* type design Plate 1).

(*e*) The channels between the vanes, and the vanes themselves must be smoothly plastered with cement.

(*f*) Care must be taken in building the vanes that the concave faces especially are smooth and even. Roughness should be avoided, as far as possible, on the convex sides also. This will necessitate care in the selection of bricks.

Mr. T.A. Miller-Brownlie suggests that the vanes be built of precast concrete blocks, with keys cast thereon. This seems to be an excellent suggestion.

(*g*) The pitched floor upstream of the vanes must be as smooth as possible though it need not be plastered with cement.

(*h*) When the vanes are completed, special care must be taken that no obstructions are left in the bed or the sides of the parent channel for 200 or 300 feet upstream of them, such as the remains of the bund which is often built for keeping water out during the construction of the vanes ; or brickbats, etc. ; also no stakes or bushing should be left in at the side of the channel for 200 or 300 feet upstream.

17. In the appended designs if it is desired to reduce the cost, the radii of the vanes may be reduced ; or the number of vanes reduced, the vanes being spaced further apart ; but the general principles given above must be followed. A solitary curved vane properly designed and placed will often have a surprising effect in excluding silt.

If the pitching upstream of the vanes is omitted their effect will be considerably reduced. Also the omission to plaster the vanes and channels between them smoothly with cement reduces their efficiency more than one would imagine to be possible.

There is a prevalent idea that the nature of the design of the regulator of the offtaking channel will affect the design of the silt vanes. For example some engineers seem to think that a raised crest in the offtaking head will affect the height to which the vanes should be built. Such is not the case. It matters not at all what the offtaking head is like, nor even if it projects into the parent stream; or has an over-shot regulator ; and no changes whatever are usually necessary in the design of the regulator.

Cases where vanes are unsuitable.

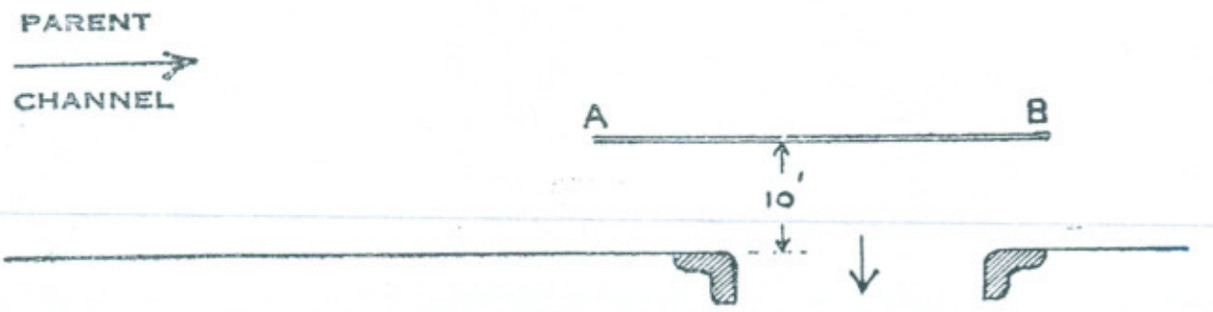
18. There are many cases, usually in small distributaries, where it will be found that there is insufficient room in the parent channel for the construction of Silt Vanes according to the design herein recommended. In such cases either this design must be modified, bearing in mind the principles on which it is based, or if, as sometimes occurs with small channels, the Silt Vanes device is entirely unsuitable, then some alternative design must be substituted.

For example, at a bifurcation between two large branches a small (usually high level) distributary is often found placed in the fork between the branches, and its situation is very likely to cause it to draw an excess of silt. In such a case clearly the "Silt Platform" (*vide* para. 24) is the most suitable device to construct. It will be found (if properly designed) to be extremely effective.

Again Silt Vanes are not very well suited to a case where a very small channel (especially if it is at a high level) takes off from a deep parent. In such a case the silt platform with curved wing would prove to be the better arrangement (*vide* para. 21).

Mr. A. Murphy, Chief Engineer, Punjab, recommends a simple straight wall, AB, built in the parent channel, parallel to the centre line of the parent and at a distance of some 10 feet from the face of the offtaking Regulator, *vide* Fig. 5.

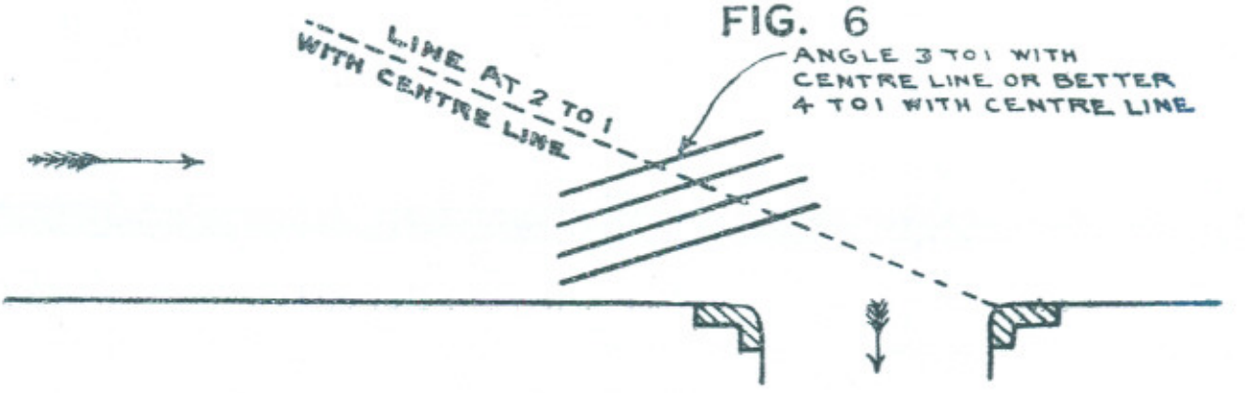
FIG. 5



He speaks very well of this arrangement; and though the writer thinks that it could only have a very limited effect, Mr. Murphy states that the effect is sufficiently powerful for most cases.

This is specially interesting in that it proves that bottom water is drawn into offtakes from a considerable distance. The writer has not tested this form; but has experimented with straight vanes built at an angle to the centre line of the parent channel, *vide* Fig. 6, and found

FIG. 6



them to be extremely effective. The curves are better; but this form may be found more convenient in certain more or less unimportant cases, such as at the narrow tail of a system, *vide* para. 27.

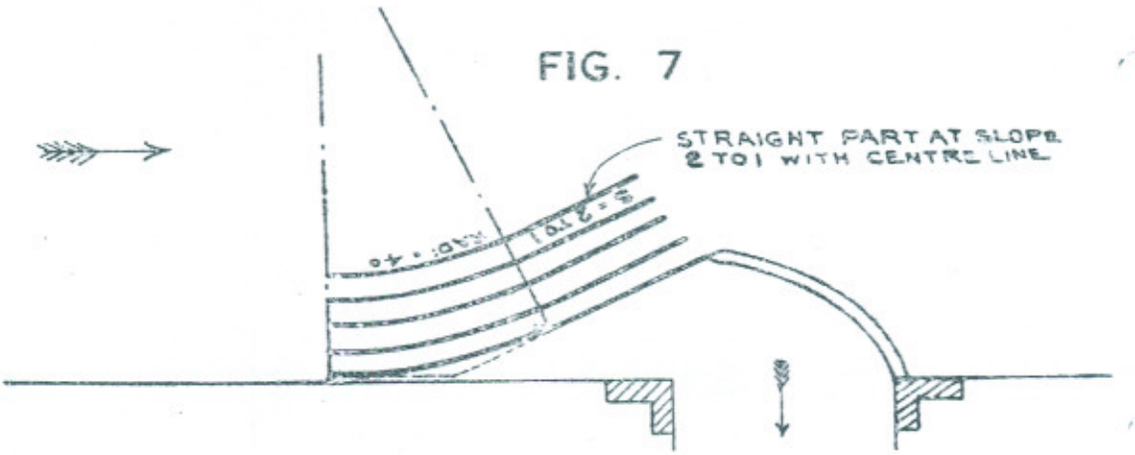
If it is proposed to put in such straight vanes, the same general principles should be borne in mind as for the ordinary curved type ; they should be built at an angle not more obtuse than 3 to 1 with the parent channel (4 to 1 is better) and must of course have the same sloping cut-water noses at their upstream ends as specified for the other kind.

It may be worth while here to mention an effect of Silt Vanes which is very frequently overlooked. In cases where they have been designed for strong effect (*i. e.*, the vanes made high) they deflect a large proportion of the water passing between them towards one side, say the left, of the parent channel. The place of the deflected water must of course be taken by a higher stratum of water, which consequently is forced to flow towards the opposite side, the right side, of the channel. The effect sometimes is to cause the whole of the water passing over the vanes to rotate like the bullet in a rifle, and the effect is clearly seen on the surface. In such cases it is easy to see at a glance whether the vanes have been constructed too far downstream, as they usually have been hitherto ; for the surface water is seen to impinge on the bank of the parent channel just *downstream* of the offtaking head, showing that the main value of the vanes has been lost. In ordinary cases, however, low vanes are amply powerful in their effect for the result desired, and, in such cases, their effect on the surface water is less readily observed.

Curved-wing-cum-silt-vanes.

19. As stated above the effect of silt vanes is extraordinarily powerful. But that effect can even further be increased by using, in conjunction with the vanes, the curved-wing device described in para. 25 below, thus :— (Fig. 7.)

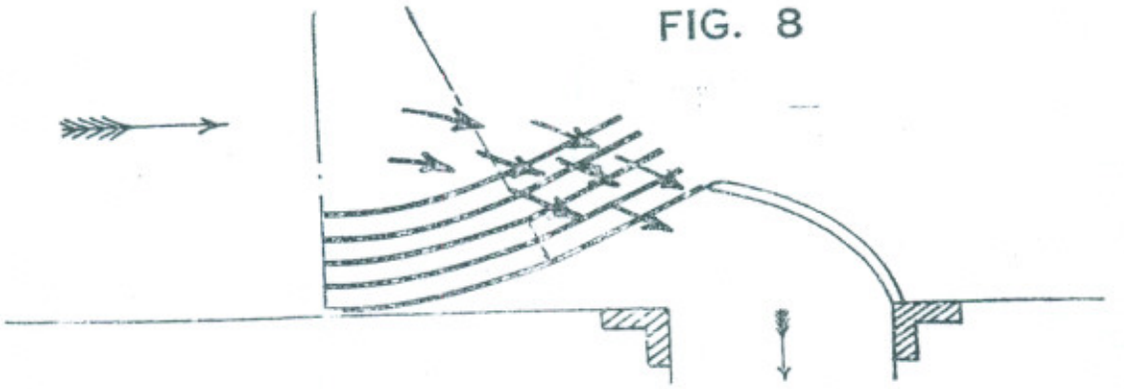
FIG. 7



An example is shown on Plate VIII of how the vanes should be designed in such cases. The effect of this design is that not only is all the surface water enclosed by the curved-wing forced into the offtake, but a considerable portion of the upper layers of water (not necessarily quite at the surface) outside the curved-wing is also deflected and forced in. The sketch below, Fig. 8, gives a rough idea of the effect. The

arrows indicate the direction to which the upper layers of water, (*i.e.*,

FIG. 8



the layers just above the vanes) are deflected by the vanes ; the reason, of course being that the place of the bottom water which is forcibly deflected by the vanes must be taken by the upper water, giving the rotary effect described in the last paragraph. This effect could be further accentuated by constructing the curved-wing so as to enclose a greater portion of the discharge of the parent channel than is required to fill the offtake, *vide* para. 29.

Such drastic action as this Curved-Wing-*cum*-Silt-Vanes arrangement will very rarely be necessary ; ordinarily only in cases where the offtaking channel takes off a large proportion, say $\frac{1}{3}$ or $\frac{1}{4}$, of the discharge in the parent ; or where the parent is too narrow for the ordinary design ; and when it *has* to be resorted to, it must be remembered that the proportion of silt passing down the parent will be very much increased and steps will probably be necessary to enable the parent to carry it on.

Before passing on to the next device it may be useful to give a few examples of special or exceptional cases. Where a large branch takes off from a canal and silts, the most satisfactory arrangement to resort to is the Curved-Wing-*cum*-Silt-Vanes. An example of this is shown in Plate No. 5.

In such a case the silt vanes must be put in with great caution, for fear of the parent channel being overwhelmed with silt. The best plan (if closures of the canal are not difficult to arrange for) is first to try the effect of the curved-wing alone. If the effect is found not to be strong enough, *low* silt vanes may be constructed, the height of which can be increased later if still more silt is to be excluded.

Probably the most awkward case is where a large channel breaks up into several branches or distributaries at one site, and it is desired to exclude silt from one of the branches, without putting all the silt thus excluded entirely into any one of the other branches.

The Silt Vanes must be designed in such cases with great caution as their effect is far more powerful than the beginner in their use will realize. Low Vanes should be constructed at first, perhaps 0·4 or 0·8 ft. high ; which can easily be raised later if desired.

On Plate 6 three examples are given of vanes to distribute silt in different ways. Three large channels P, Q, and S, with discharges of 200, 400, and 300 cusecs respectively take off the main channel whose total discharge is about 900 cusecs. If we wish to exclude from Q as in case 1, the dimensions X and Y should bear the same ratio to the bed width, as their discharges bear to the total discharge *i.e.*, $X=\frac{2}{9}$ B, $Y=\frac{3}{9}$ B. Curved-wings are shown but Silt Vanes alone would go a long way to producing the desired result.

In case 2, to exclude silt from Q and divide it equally between P and S the channel P must take $\frac{2}{5}$ of the silt and X is made $\frac{2}{5}$ B. In case 3 to exclude all silt from P and distribute it equally between Q and S, S must take $\frac{3}{7}$ of the total silt and X is made $\frac{3}{7}$ B.

Silt tunnels.

20. The next best arrangement for excluding silt is the silt platform, or what is more commonly called silt tunnels. This device consists of a slab usually of reinforced concrete placed horizontally in the parent channel opposite the offtaking head, supported on piers or walls, at such a level as to prevent the heavily silt-laden water entering the offtake. It is most simply explained by the diagram, Plate 6. In the design of this form of silt excluder there are several somewhat difficult points to be decided.

There are in the first place two variations of this device, *viz.* :—

(*a*) a platform with a curved extension of the downstream wing-wall of the offtaking channel built on top of it so as to guide all the clear surface water flowing above the platform into the offtake, and

(*b*) a simple platform with no guide-wing built on it.

The main points in the design, the level of the platform, its width, length, shape, etc., will be entirely different in each case.

Generally speaking this form of silt excluder is only suitable for use in deep channels, as will appear from the considerations necessary in the design, and for comparatively small offtakes. The form with the guide-wing will be the best in ordinary cases and the form without the guide-wing only in special cases where the construction of a wing may be impossible or unsuitable ; as for instance in the case of a small high level channel taking off between two branches; or where the offtaking channel is required only to be fed in the *kharif* season ; in this latter case the guide-wing would form an undesirable obstruction with no object during *rabi* season ; *see* Plates 7 and 8.

Design with guide-wing.

21. The simpler case, that with the curved guide-wing, will first be discussed.

The principle to bear in mind is of course the same as for most of the other silt-excluding devices. First the heavy silt suspended in the water is made to drop into the lower layers of water, by constructing a short reach of smooth pitching in the parent channel just upstream of the offtake, and pitching the side slope of the parent channel in this length. At the downstream end of this bed pitching the horizontal slab is constructed, so that it shall divide the water, the heavily silt-laden part passing under the slab and the silt-free water over it.

In order to prevent any of the silt-free water from passing past the offtake, down the parent channel, a curved guide-wing is built on top of the slab, as an extension of the downstream wing wall of the offtaking head.

Then the questions arise: At what level shall the platform be built? What shall the transverse width of its upstream end be? and how far upstream shall it extend?

22. As to the level at which the platform should be, the two deciding factors are the height necessary for the "tunnels" or space under the platform through which the silt-laden water must pass, not only in order to exclude enough silt, but to minimize the chance of the tunnels becoming blocked with debris; and the discharge required to fill the offtaking channel.

It is obvious that the higher the tunnels are made, the more silt will be excluded from the offtake; but this is not the most important consideration. We must see that there is no chance of the tunnels becoming blocked by jungle and debris. It would ordinarily be unwise to make them less than 2 ft. high, and even that is taking risks; because if it were less, a submerged branch rolling along the bed would be very liable to get caught at the mouth at the tunnel and stick there. The result would be that it would throw all the heavy silt up to the surface and it (the silt) would be taken into the offtaking channel; so that the offtaking channel might be caused to silt more heavily than if the platform had not been built at all, owing to the exaggerated cross-currents which would be created in the bed of the parent channel.

Next, the platform must be constructed so that during the minimum supply in the parent channel at which the offtaking channel is required to run, there shall be enough water passing over the platform to fill the offtake, with some to spare, for reasons given below.

There is a point of considerable importance which should be mentioned here.

If the curved-wing is designed so as to enclose more water over the platform than is required to fill the offtaking channel, most of the excess water will be forced under the platform. The result will be a considerable increase in the velocity under the platform which will tend to keep the heavy silt passing through the tunnels from depositing either in the tunnels or just downstream of them. Also, since some of the silt-free upper water enclosed by the curved wing will be forced under the platform, the proportion of heavy silt in the water passing through the tunnels will be reduced. Both these effects will be valuable. Therefore the more water cut off or enclosed by the curved-wing the better for the design. But practical considerations and the avoidance of excessive obstruction in the parent channel will of course limit the extent to which these advantages can be pushed.

These considerations will fix the height at which the platform may be placed, and its width at its upstream end. Ordinarily, the writer considers that there should be enough water passing over the platform, at the lowest supply in the parent at which the offtake is required to run, to fill the offtake, with 10 % to spare.

To recapitulate : in making this design the first point to be decided on is, what should be the lowest level of the supply in the parent at which the offtake is required to run. The next thing to decide is the level at which the platform should be built.

Then the width of platform necessary to take the required discharge over it can be calculated.

23. Now as to the detail of design, *see* Plate No. 6. Clearly the most important consideration of all is the elimination of the risk as far as possible of catching jungle and debris. To achieve this, it is necessary to end the walls, or piers, supporting the slab, at a slope of 1 vertical to 3 horizontal upstream, and to make their upstream ends of cut-water shape. Also the sloping part should begin 1 foot away from the edge of the platform. Then if a branch, or bit of rubbish strikes the nose of a pier, it will slide up the pier and not stick when it arrives at the junction of the pier with the platform. Similarly the upstream end of the curved guide-wing, built on the platform should have its upstream end built at a slope of 1 to 1.

The upstream edge of the platform might still catch jungle, but that cannot be helped : it is a defect inherent in the design.

The platform may in this design be ended at the upstream edge of the offtake, since there is enough surface water to fill the offtake, and therefore no chance of the lower water being drawn up.

Advantage of curved-wing type.

One advantage which this design has over the simple platform without a guide-wing is that water enters the offtake with a considerable velocity which may be equivalent to a couple of inches of extra working

head. This is a great help in preventing the tendency for silt to deposit in the head reach of the offtaking channel. Another advantage is that the platform may be made smaller if there is a guide-wing.

One great disadvantage of the silt tunnel design which Silt Vanes do not share is that it results in an excessive charge of silt being passed *at the edge* of the parent channel just below the offtaking head instead of somewhere near the middle of the channel as in the case of the Silt Vanes. This may deposit and form a heap which may, in some cases, by blocking the outfall to the tunnels, render the excluder inoperative. This is one of the reasons why this device is only suitable for comparatively large and deep parent channels, and comparatively small offtakes. In such cases the danger of the silt heap forming can be minimized as explained above.

A few Silt Vanes constructed just at the exit of the tunnels to lead the silt into the centre of the channel would probably improve this design.

Silt accumulated just downstream of the tunnels might be washed out, to some extent at least, by closing the offtaking channel. The result would be that the water enclosed by the guide-wing would be to a large extent forced through the tunnels ; the lower layer of water just upstream of the tunnels (having less velocity and momentum than the upper layers) being deflected towards the centre of the parent and so not passing through the tunnels.

In the case of a very small minor, say of 5 or 6 cusecs taking off from a channel, say 8 ft. deep the writer considers that this form is even better than Silt Vanes.

Design without guide-wing.

24. The case of the simple platform without the curved guide-wing will now be considered. This form should only be built where, for some reason, the guide-wing is objectionable or impossible.

In this case the design is more difficult. It is not known how much of the silt-free water over the platform will pass on down the parent channel and not enter the offtake at all, so it is difficult to say how wide the platform should be. The writer considers that ordinarily the platform should be wide enough to take enough water over it to fill the offtake with 25 °/₀ to spare. This, with the considerations mentioned in para. 19 fixes the width of the platform.

The downstream edge of the platform might be made at an angle of 60° to the centre line of the parent channel. The upstream edge should also theoretically be at an angle, (of perhaps 60°) to the parent channel ; because the direction of water flowing towards the offtake just upstream of it would be more transverse to the direction of the supporting walls at a point further removed from the edge of the parent stream than at a

point near its edge. Therefore the platform should theoretically be carried further upstream as it gets further removed from the edge. But, it is doubtful, whether this is really necessary.

The upstream edge of the platform at the edge of the parent channel may be from 5 to 10 feet upstream of the upstream edge of the offtake. Usually 5 feet will be enough.

On Plates 7 and 8 will be found examples of cases where the simple platform without any guide-wing is necessary, with general details as to its design.

In these designs the width of the platform may largely depend on the position of the piers of some adjacent regulator as the dwarf walls on which the platform rests may have to be in extension of those piers. This will have to be decided on by the designer according to the conditions in each case. A width equal to the depth of the parent channel would probably be sufficient, if a greater width is inconvenient to arrange for.

There are situations where it is not possible to build a dwarf wall to support the platform, as, for example, when the dwarf wall would obstruct necessary flow in some direction. Pillars to support the platform would in such a case be possible, but have the great objection that they would catch branches and debris and so set up eddies. In such cases it may be necessary to have the platform, or part of it, unsupported at its outside edge, *i.e.*, cantilevered.

Such a case exists in the Manchar Kharif Distributary on the Lower Chenab Canal Main Line Upper. The difficulty in such cases can usually be got over by a little ingenuity on the part of the designer.

Curved Wing Silt Excluder.

25. Probably the third best form of Silt Excluder is the "Curved Wing." This device is fairly well-known, but neither its effect, nor the reason for that effect is usually fully understood. It consists of an extension of the downstream wing wall of the offtaking channel into the parent channel in an upstream curve, thus : (Fig. 9.)

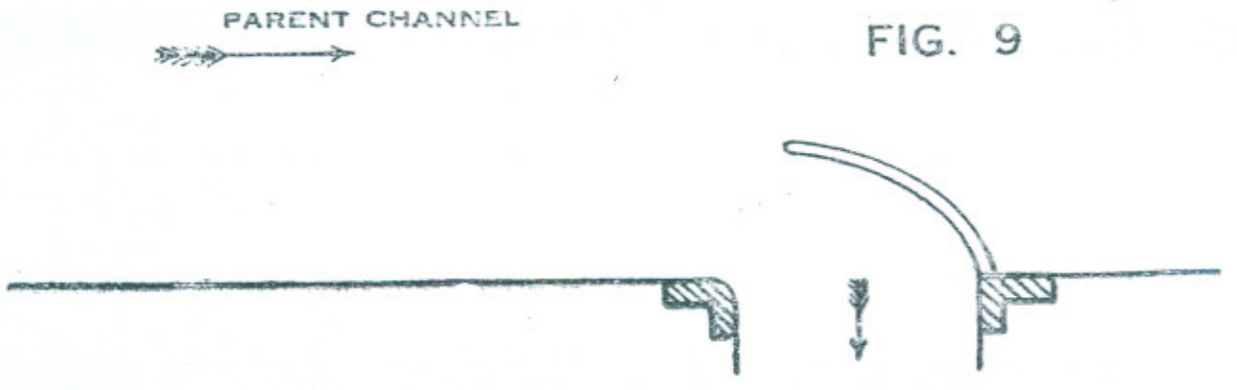


FIG. 9

Mr. W. P. Thompson in a paper for the Punjab Engineering Congress in 1920, discussed this form ; but Mr. A. S. Gibbs had used it many years before. It is very effective in preventing the deposit of silt at the head of a channel ; but it is not generally realized that it actually excludes silt.

As explained in para. 3, a channel which takes off at an angle from a parent which goes straight on draws into itself a greater proportion of silt in its water than the proportion which the parent carries. After the curved wing has been constructed it forces *all* the surface water as well as the bottom water into the offtake, which consequently then takes off exactly the same proportion of silt in its water as the parent channel carries, so that the effect of the curved wing is actually to *reduce* silt entry.

But in addition to this, the curved wing causes the water to be introduced into the offtake with a considerable velocity so that the normal tendency to drop silt in the head reach is obviated.

The pitching of the bed and sides is not necessary in this form.

As to the extent to which the wing shall project into the parent channel, ordinarily it would project far enough to enclose enough of the discharge of the parent to fill the offtaking channel when the parent is running the lowest supply at which it is desired to run the offtaking channel full ; but this need by no means necessarily fix the amount of its projection in every case. In this connection the principle discussed in para. 28 should be carefully studied.

As to how far upstream the curve is to be taken, it need not necessarily extend to opposite the upstream abutment of the offtake ; but should extend a good way up, say upto 3/4 of the width of the offtake. To take it the whole way up to opposite the upstream abutment would be better, but may in some cases not be convenient.

Nor need the upstream end of the curved wing necessarily be exactly tangential to a line parallel to the centre line of the parent, nor the downstream end tangential to the centre line of the offtaking channel. These last two considerations will be decided by the radius of the curves it is desired to give the wing.

There is no doubt about the effectiveness of the device ; it has been tested and proved, but its effect is obviously limited. It might be used in cases where the offtaking channel has, in virtue of its gradient, etc., the *same* silt-carrying power as the parent. If the offtaking channel has less silt-carrying power, Silt Vanes are indicated, or silt tunnels.

A variation of the device is to leave openings at the foot of the curved wing, so that the bottom water can escape and flow off downstream into the parent channel. This is probably an improvement, but would clearly necessitate the cutting off more water by the curved wing, *i.e.*,

making the wing extend further into the parent channel. In deciding how much water should in this case be shut in by the curved wing the point mentioned in paras. 22 and 23 concerning silt depositing in the parent channel must be carefully considered.

Raised cill.

26. A device which many have pinned their faith on, but which is, in fact, very inefficient, is the " Raised Cill." It is certainly better than nothing, but that is about all that can be said for it. It consists of a simple raised cill, or wall, across the mouth of the offtaking channel, at such a height as to allow only as much water to pass over it is as will fill the offtaking channel. The mouth of the offtaking channel is usually bell-mouthed so as to enable a long cill to be made, so that it can be built at a higher level. The idea of course is the vain hope that only surface water will go over the cill. It was probably the first attempt at excluding silt. Messrs. Gordon & Scratchley in 1908 introduced the system, together with a skew head, and curved upstream wing, into the Punjab for distributaries, where it was certainly an improvement on the old simple right-angled offtake with no effort at excluding silt. But it was used many years before that, *e.g.*, at our headworks.

Later Mr. F. W. Woods in 1916 elaborated it in his " Rising Cill" device, which is described at the end of his paper in the Punjab Engineering Congress for 1916.

It consisted of a raised masonry cill across the offtaking regulator, with the regulating gate housed behind the cill when the offtaking channel was fully open ; which gate was raised as required when the supply had to be reduced, so as to form an "over-shot" regulator.

In order to make it more effective, the regulator was made very wide, so that the raised masonry cill could be built at a higher level.

It was exceedingly expensive, involving an enormously wide regulator, and also exceedingly inefficient, as was fully proved in the case of the Nasrana Distributary of the Jhang Branch of the Lower Chenab Canal in the Punjab, and in other cases. As stated above, it has *some* effect but not enough. A raised cill with the object of excluding silt exists at present in most of our Canal Headworks.

The chief reason why it cannot have much effect is just that the bottom water having less forward momentum is more easily deflected into the offtake even over the high cill than the more swiftly moving surface water.

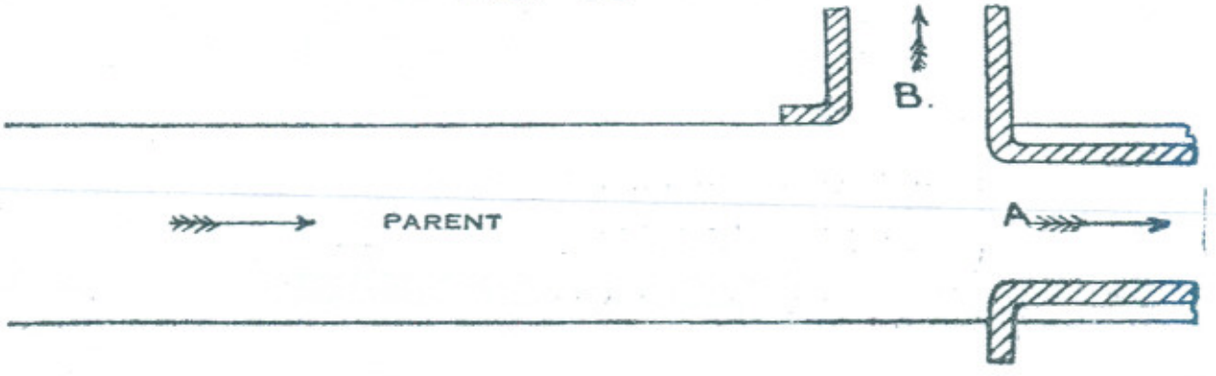
It used to be thought that the reason, bottom water was taken in over the cill was that the cill itself created eddies which stirred up the silt ; and efforts were consequently made at one of our headworks, to minimize this effect by rounding off the top of the cill ; but of course it had no effect. As a matter of fact, the tendency would be in such a case rather to assist the bottom water to get in !

This device is so inefficient and unscientific that it is not thought necessary to give a design of it.

Cases where standard designs not suitable.

27. There are a number of situations in which the common standard devices are not suitable. In such cases, complete success may usually be achieved by applying intelligently the principles underlying the more ordinary silt excluders. For example, it is of very common occurrence that a distributary system ends in two small minors, one of which silts heavily (probably on account of flat gradient) while the other does not silt at all. The distributary just above the bifurcation is too narrow for the satisfactory introduction of the ordinary form of Silt Vanes and too shallow for the ordinary form of silt tunnels. How is such a case to be dealt with ?

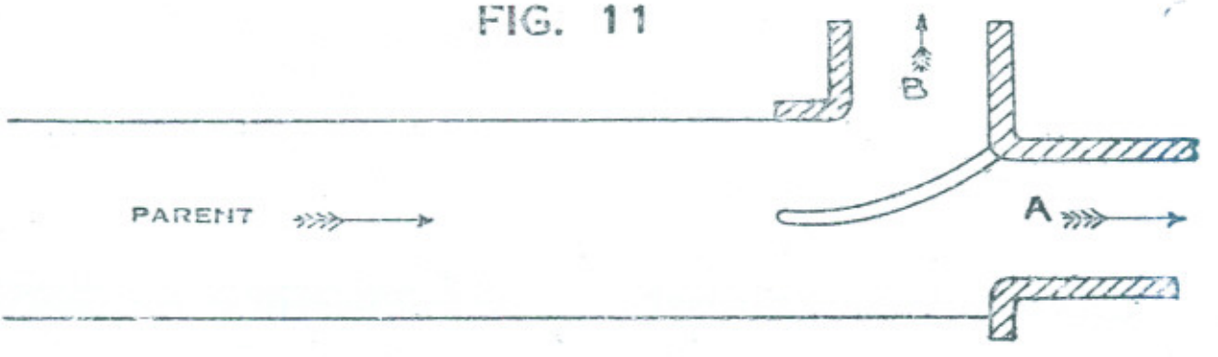
FIG. 10



Suppose, in the diagram. Fig. 10, minor A silts, and minor B scours

The idea that is likely to occur to one who has not given very much consideration to this subject will almost invariably be to build a wall thus (Fig. 11).

FIG. 11



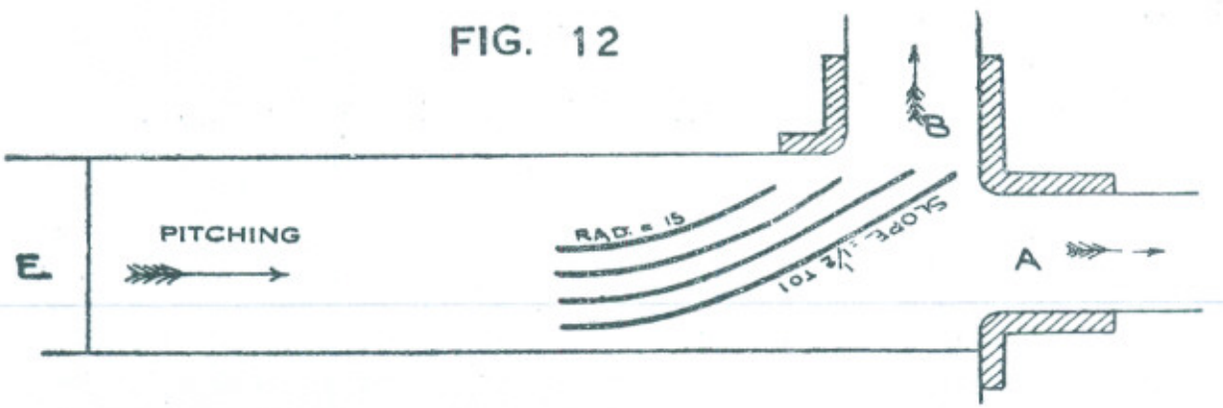
up to the level of the maximum supply in the parent channel. This by itself will prove (has, in fact, repeatedly proved) to be absolutely ineffective.

When it fails, he would, in all probability extend the wall upstream, dividing the parent channel in the proportion of the discharges of the

minors, forgetting that it is not possible to *force* a channel with a flat gradient and low velocity to carry the same proportion of silt in its water as one with a steeper gradient. The correct method of dealing with such a case is to put into minor B a greater *proportion* of silt than into minor A. This is a simple matter.

Put in a short length, say 25 feet, of pitching AE in the bed of the parent channel; and construct a few Silt Vanes (say three or four) to guide the silt into minor B, thus :— (Fig. 12.)

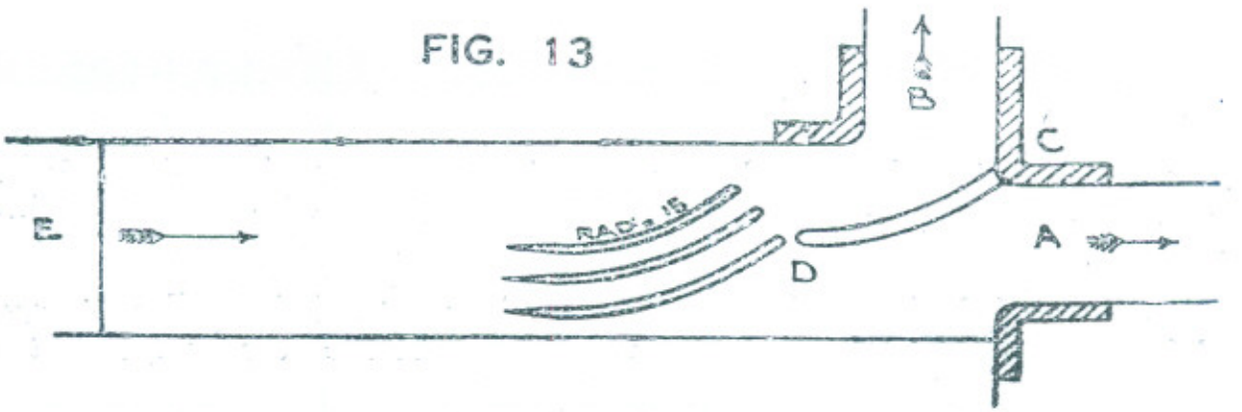
FIG. 12



The height of the vanes to be $\frac{1}{4}$ of the depth of the channel. The radius of curvature of the vanes in such a case where the velocity is comparatively low may be less than in ordinary cases : 15 feet would suffice. Also the straight part downstream of the curve may be made $1\frac{1}{2}$ to 1 with the centre line of the parent channel instead of 2 to 1. Such details may be varied according to the conditions at the site, the designer applying the general principles to suit the particular conditions of the site in question.

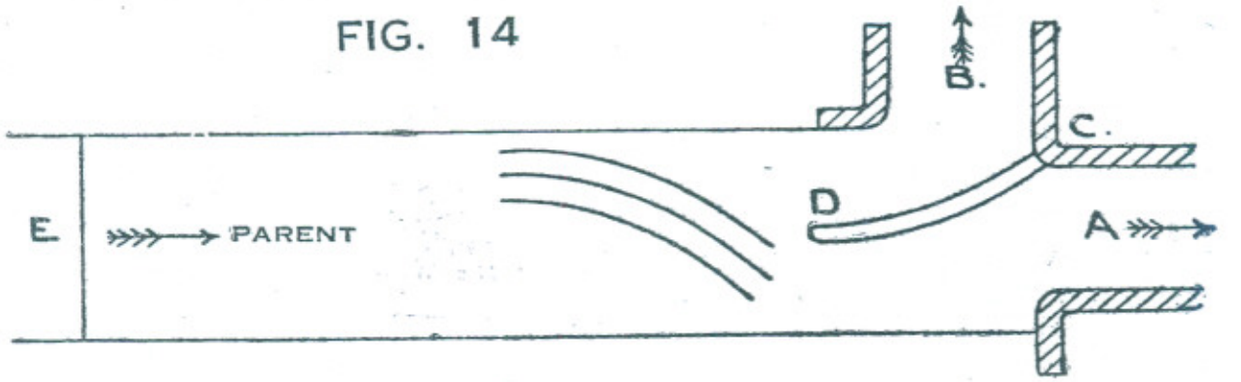
Or, better still, build a wall CD up to full supply level in the parent and then put in Silt Vanes upstream of this wall thus :—(Fig. 13.)

FIG. 13



If it was minor B which silted and minor A which scoured, the proper solution would be to build the wall CD as before and put in the vanes the other way round, thus :—(Fig. 14.)

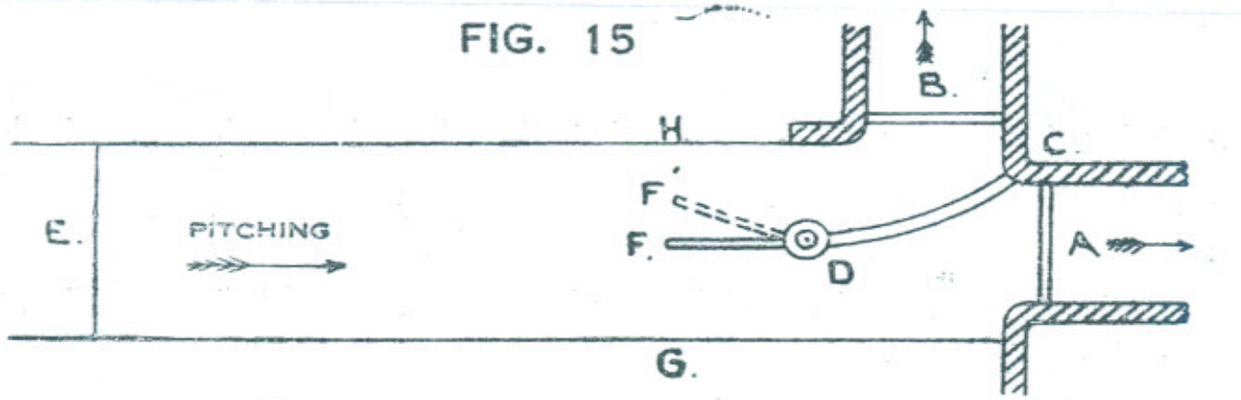
FIG. 14



28. While on the subject of the bifurcation of a small channel it may be worth while mentioning a possible utilization of the effect of momentum touched on in para. 3.

Take the case under consideration in the last para. *See* Fig. 15.

FIG. 15



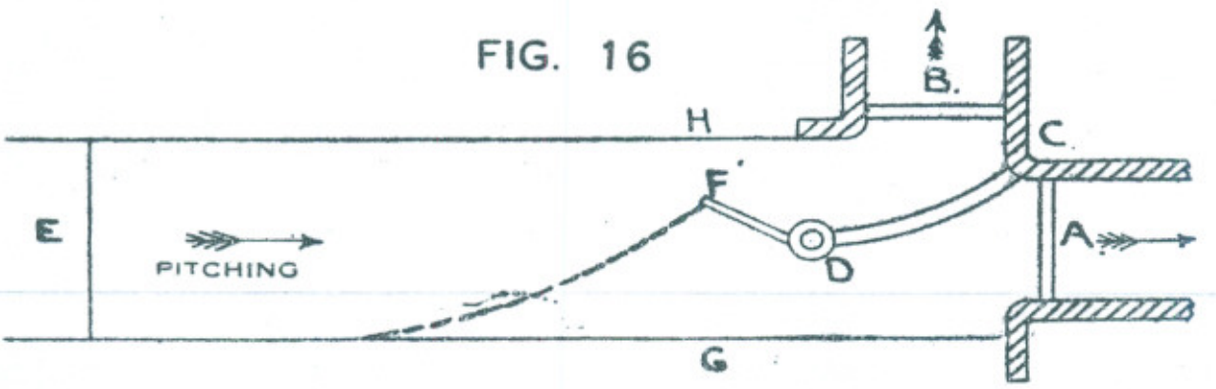
Build a wall CD up to full supply level dividing the parent in the proportions of the supplies of the minors. The bed of the parent is pitched A to E. Assume that there are adjustable regulators at the heads of the minors, or even modular flumed heads. At the upstream end D of the wall CD attach a gate or divider DF hinged at D and of the full depth of the water. Now if the divider DF is swung into the position DF′, the mouth GF′ made will enclose a greater discharge than the minor A can take. What will happen?

Since there are regulators at the minor heads, the discharge which would ordinarily have occupied the width HF of the parent, will be forced through the narrow opening H F′. That is, part of the discharge which would ordinarily have occupied the width GF′ will be forcibly deflected into the opening HF′. Which part of the water? The lower layers obviously, since they have a less forward momentum and are more easily deflected. The result then will clearly be that into minor A will pass *all* the surface water between G and F′ and part of the lower layers of water between G and F′ will be forced into minor B.

Thus by adjusting the hinged gate DF we could adjust the silt entry into the two minors.

A critic has said that while admitting that the position DF′ would exclude silt from minor A and cause minor B to take more silt, he considered that the reason was not as given by the writer above, but was that the high velocity through HF′ would carry more silt and the low velocity through GF′ less. How ? He could not explain, and nor can the writer. It is true that in the position DF′ the approach to minor A would silt up, forming a shelf of silt as shown by the dotted line thus :— (Fig. 16.)

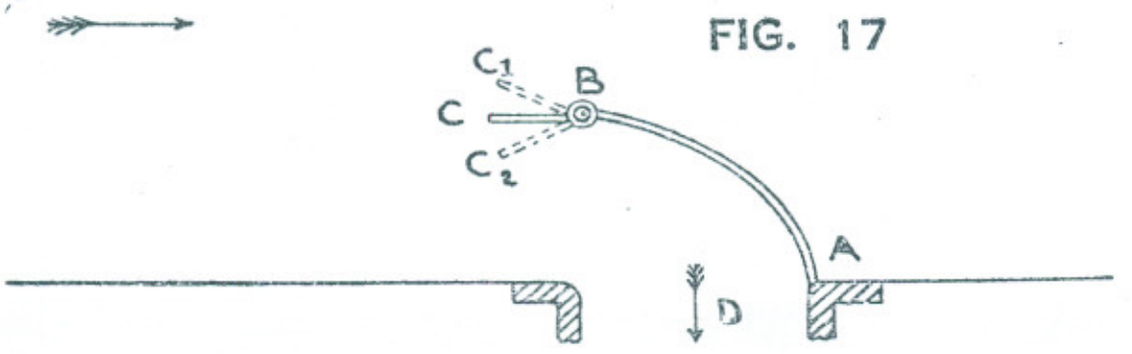
FIG. 16



and that that shelf would form a kind of advanced cill or guide vane which would guide silt into minor B ; but that, the writer holds, would not be the *main* reason for silt being excluded from A. The main reason would be the difference in momentum.

29. The same idea could easily be applied to the "Curved Wing" device :—(Fig. 17.)

FIG. 17



AB is the curved wing, a wall built up to full supply level of the parent channel. BC is a vertical gate or divider, hinged at B.

When divider BC was swung into the position BC_1 more of the surface water, having the highest momentum, would be enclosed or cut off by the gate, and since the regulator of the offtaking channel D will be adjusted to pass only the supply required by it, a larger proportion

of the surface water will pass into D than when the divider BC_1 was in its original position BC. Similarly, with the divider in the position BC_2 the offtaking channel would take a larger proportion of bottom water and silt. The writer has not tested this device, but it would appear to be worth trying. In any case in which trial of it were proposed the first thing to consider would have to be the working head available into the offtake.

When the divider BC was in the position BC_2 if the water cut off between C_2 and the edge of the parent were not enough to fill the offtake, a certain amount of working head would be necessary in order to cause sufficient supply to be drawn into the offtake to fill it. Now a silting channel cannot have any working head to spare ; therefore, in constructing the device the wing AB would have to be so designed that when the divider BC was in the maximum inward position BC_2 there would be enough water between C_2 and the edge of the parent channel to fill the offtake without inducing any of the water outside C_2 to be drawn in ; in other words the normal discharge in the parent between C_2 and the edge must be just enough to fill the offtake, so that no working head would be necessary to fill the offtake. Then, as BC was gradually swung back from BC_2 towards BC_1 the offtake would take less and less silt.

Syphon Regulator.

30. The next device which must be mentioned is Ashford's Syphon Regulator.

This was an ingenious device for syphoning the water from the parent into the offtake ; the idea being that since the entrance mouth of the syphon only dips into the surface layer of the parent, bottom water would not be drawn in. The writer has not tested this form ; it was designed and constructed by Mr. John Ashford, late Superintendent of the Central Canal Workshops at Amritsar for the Madhopur Headworks of the Upper Bari Doab Canal and installed there in 1910, and a diagram of it is given on the next page (Fig. 18).

The object was to put a stop to shingle being swept into the canal by sucking into the canal only surface water. Mr. Ashford informed the writer that the idea was dropped because the device sucked in shingle freely. The reason for this, in the writer's opinion, undoubtedly was that although the surface water passing immediately under the bell-mouth (entrance) of the syphon would be sucked into the canal, the balance of the supply required to fill the canal would be sucked from those layers of water which had the least forward momentum ; and that consequently silt and shingle would be sucked in in almost as great quantities as with an ordinary raised cill.

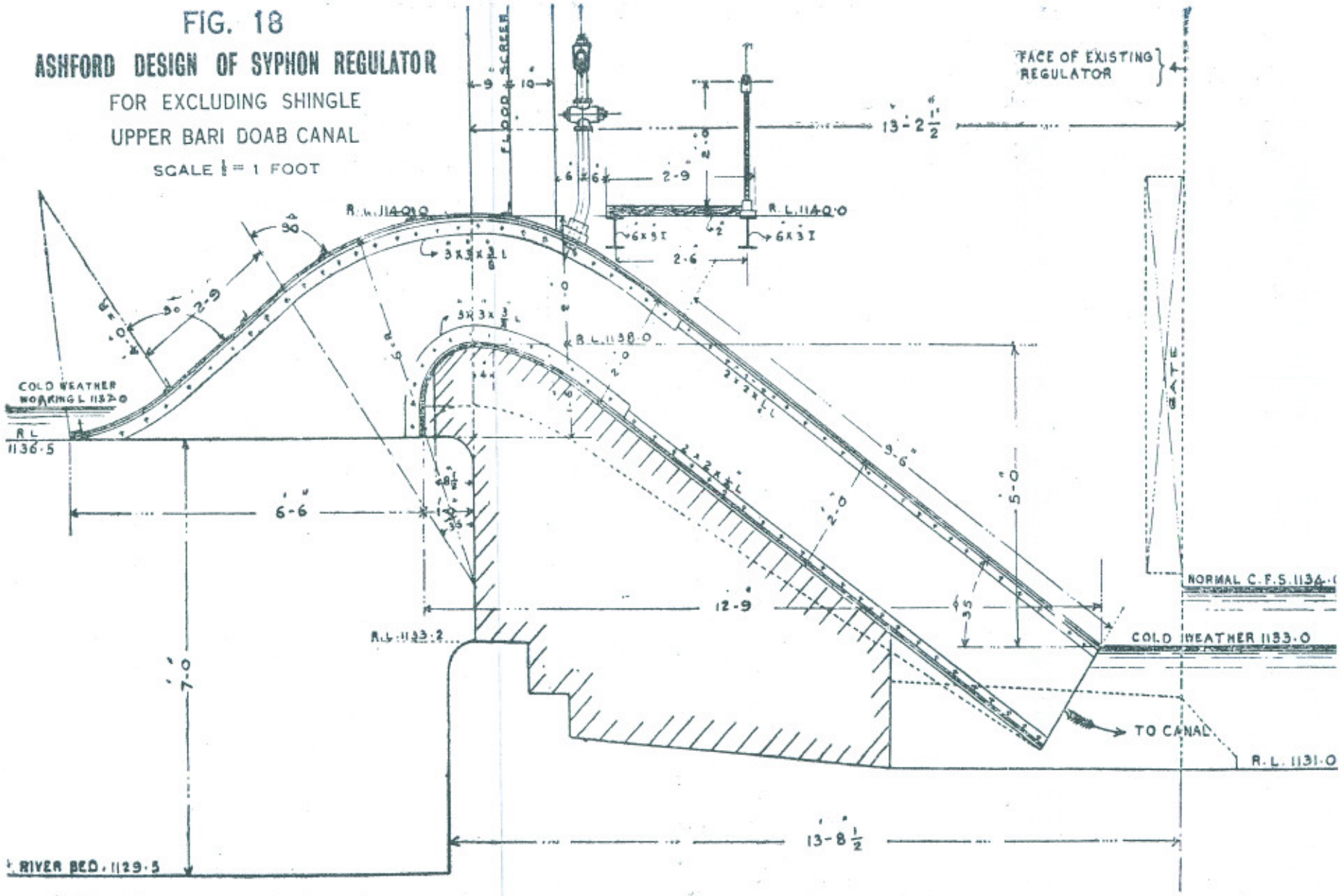
FIG. 18

ASHFORD DESIGN OF SYPHON REGULATOR

FOR EXCLUDING SHINGLE

UPPER BARI DOAB CANAL

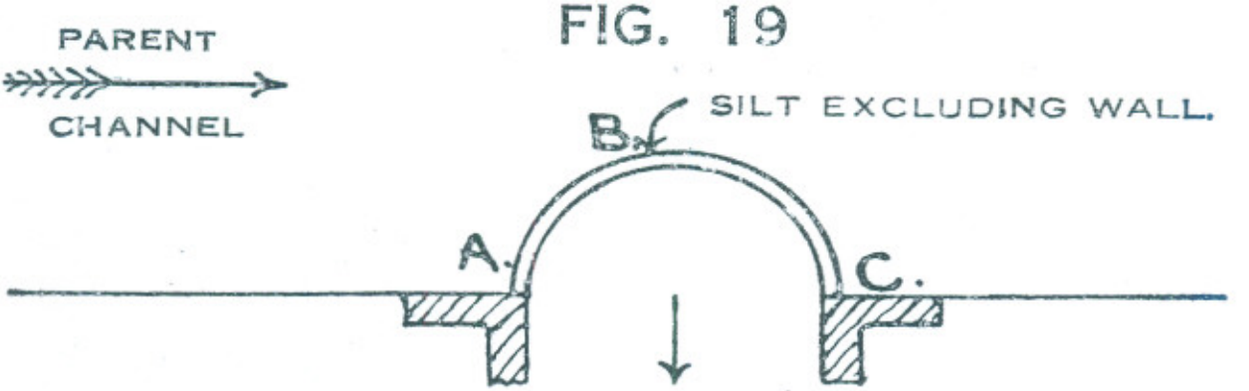
SCALE $\frac{1}{8}$ = 1 FOOT



Gibbs' Semi-circular Wall.

31. Mr. A. S. Gibbs, many years ago, constructed the arrangement shown in the following diagram (Fig. 19).

FIG. 19



Opposite the offtake, and completely enclosing it, he built a semi-circular wall ABC of such height, that at the lowest supply in the parent at which it was desired to fill the offtake, enough water would spill over the wall into the offtake to fill it. This is merely a variation of the raised cill idea and has the additional defects that the base of the upstream portion AB of the wall would certainly throw bottom water to the surface ; and it therefore need not be further commented upon.

Other devices.

In order to complete this note of the various silt excluding devices hitherto put forward, mention must be made of the designs described by Messrs. A. S. Gibbs and F. V. Elsden in their papers for the Punjab Engineering Congress of 1916. Both of these designs are virtually variations of the "Curved-wing" described in para. 25 above ; and would probably succeed in the same degree and for the same reasons as the curved-wing. The writer has not actually tested either. They need not be described here as the reference to their design given above will suffice.

APPENDIX I.

Extract from a paper by Professor James Thompson, F. R. S., read at the proceedings of the Institute of Mechanical Engineers at Glasgow. 6th August 1879, and reprinted at pages 103-105 in the book *Papers in Physics and Engineering*, by Professor James Thompson.

It was very much in the same way, and for like reasons, that the water in a river bed flowed more quickly along courses adjacent to the inner bank of a river bend than along courses adjacent to the outer. Hence the question had occurred to him :—

Why then did not the inner bank wear away more? As a matter of fact, we know that it did not ; but why was this so, if the water scoured more quickly along the inner bank than along the outer? For a long time he could not explain this ; but afterwards he had found the true explanation. The water of a river, in flowing round a bend, pressed outwards in virtue of centrifugal force, and so there was a transverse slope of the water surface rising from the inner bank towards the outer, as shown in the cross-section, Fig. 2. Thus at any one level in the stream there was for this reason a greater pressure near the outer bank than near the inner. The case might be better stated thus. The free level for any particle of the water near the outer bank was higher than the free level for any particle near the inner bank at the same level and in the same cross-section ; and the water tended to flow from the place of higher free-level to the place of lower free-level ; but the centrifugal action kept the water outwards against that inward tendency.

Further, the most special point of the explanation was the following. At the resisting bottom there was a thin lamina of water at all times prevented by fluid friction, or viscosity, from having so high a velocity as the general average velocity of the body of the stream above it ; and consequently it had not enough centrifugal force to keep it out against the inward tendency given by the higher free-level at the outside than at the inside. Thus the water at the bottom must have a prevailing tendency from the outer bank towards the inner, and must tend to carry inwards with it gravel, sand, mud, and other detritus, and leave them deposited at the inner bank.

Conjointly with this inward flow at the bottom, there must be in the middle and upper body of the stream a prevailing flow towards the outer bank; but the outward flow would be more gentle than the inward, being participated in by a much larger body of water.

FIG. 1

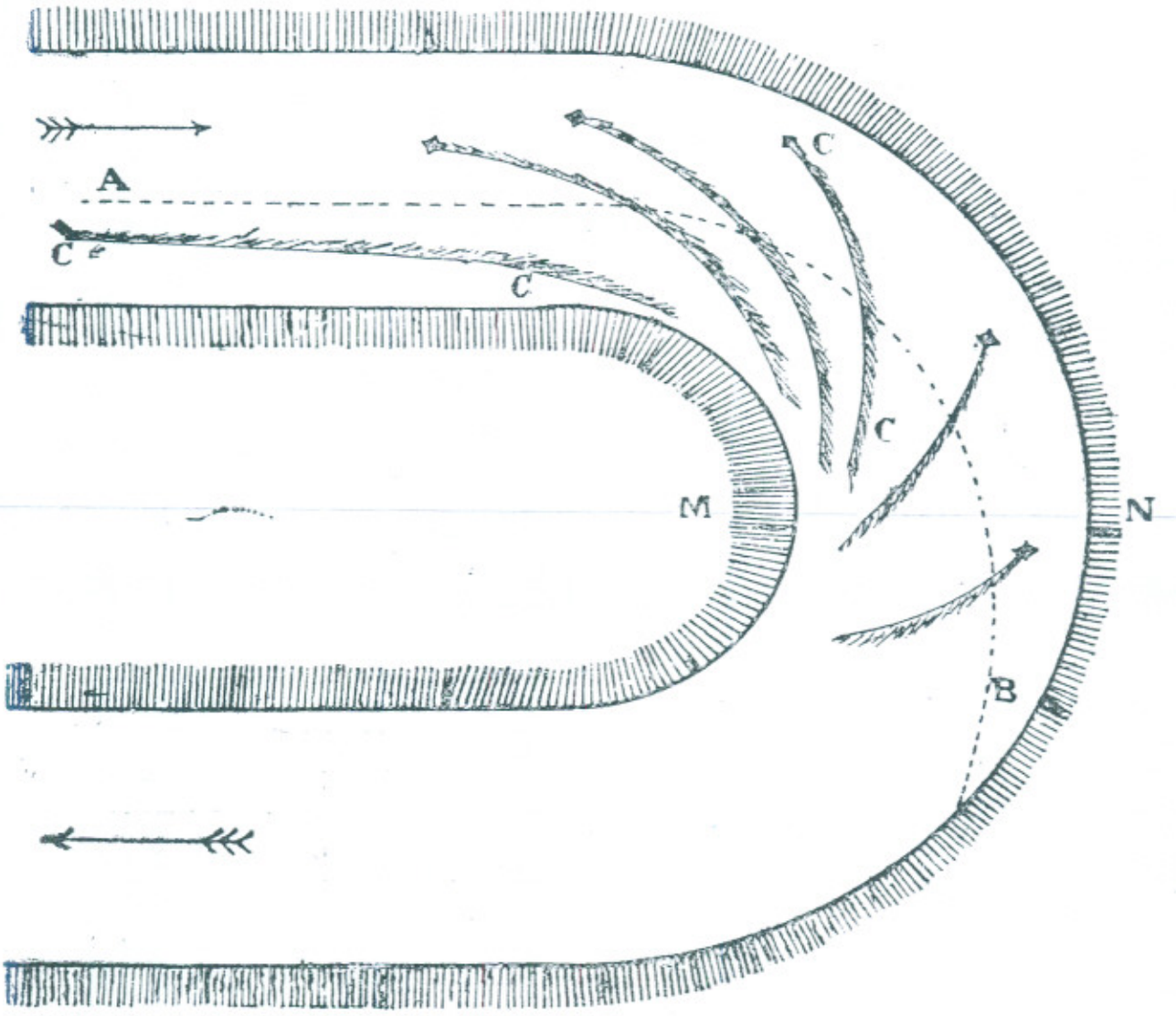
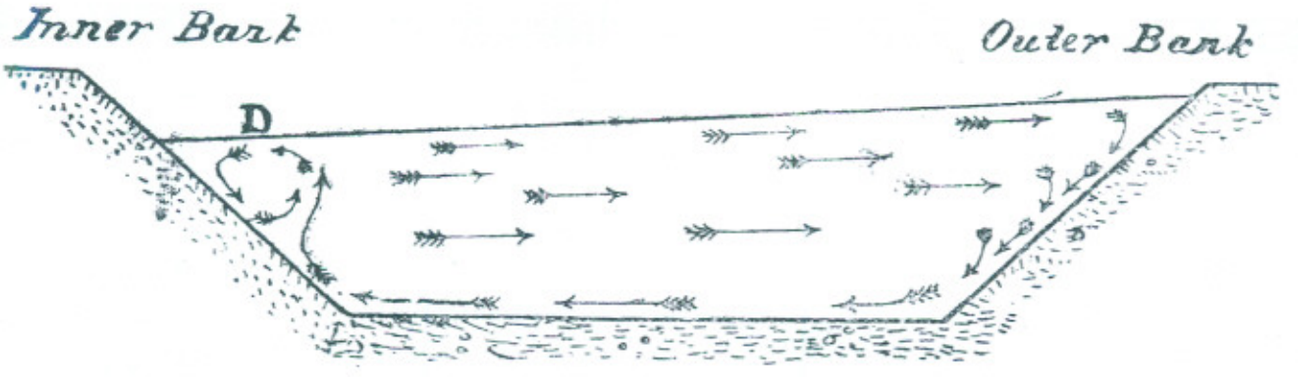


FIG. 2



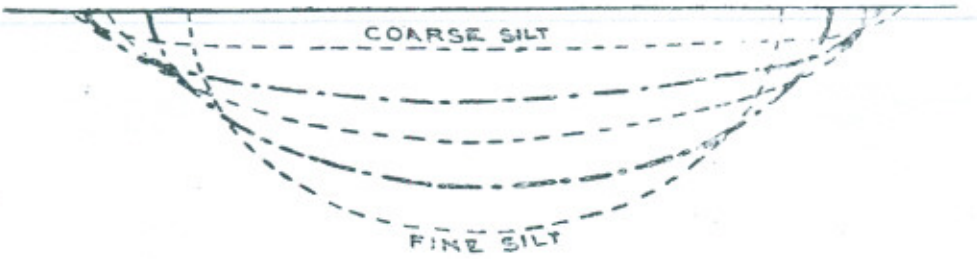
Section at M N

APPENDIX II.

Extract from Lacey's Paper on " Stable Channels in Alluvium" in Vol. 229 of the proceedings of the Institute of Civil Engineers, Session, 1929-30, *Part* 1, *page* 273.

This somewhat remarkable formula—shows that for a given discharge the wetted perimeter of a stable channel is constant and independent of the fineness of the silt transported, the silt merely controlling the "shape." If channels with horizontal beds are considered, then by "shape" is understood the ratio of bed-width to depth ; if channels are visualized as having semi-elliptical cross-section, then by shape is understood the ratio of the major axis to the semi-minor axis. Thus in Fig. II,

FIG. II



the wetted perimeter is a constant for any given discharge, but the shape of the cross-section depends on the silt. The coarser the silt, the flatter the semi-ellipse and the greater the width of water surface, the finer the silt, the more nearly does the section approximate to a semi-circle. The figure illustrates by means of a simple mathematical relationship what is a matter of common observation to those who have made a study of stable river cross-sections in different types of silt. Thus two elementary principles govern the dimensions of stable channels in alluvium : all stable silt-transporting channels flowing with the same mean velocity tend to assume the same "shape"; and all stable silt-transporting channels of the same discharge have the same length of wetted perimeter irrespective of the particular grade of silt carried.

DISCUSSION.

The Author in introducing his paper on Silt Exclusion from Distributaries remarked that the only thing he had to say was, that when he wrote the paper, he had no intention of submitting it to the Congress. In the paper he had purposely confined himself to well-known facts, avoiding any mention of any but those which were necessary to explain the reasons for the rules laid down in the paper, so that there should be no hesitation by engineers in accepting and acting on those rules.

He apologised in placing before the members so very elementary an array of facts ; his explanation was that the paper was mainly intended to be a set of type designs and not a treatise on the subject of silt control in general.

Mr. Kanwar Sain said that the policy so far generally adopted was that a silt-excluder, may it be vanes or platform or any other type, was put up at the regulator of a distributary which showed signs of silting. The trouble was shifted from one distributary to the other. The remodelling officer was proud of his achievements and proceeded on long leave. His successor came and in the absence of any record of the past behaviour of the either channel, changed the order of things. The trouble might all be shifted to the tail channels of a tail-sub-division on the canal. In that way the game went on. Frequent transfers help in preventing the situation from becoming awkward.

It appeared to him that a methodical way—it had some practical difficulties which could be overcome—of handling the problem of silt would be : first to know how much total silt was entering the head of the canal and then to distribute that silt content according to what any channel on the way could properly manage. A channel with a good command could dispose off its silt charge easily ; while poor command might show signs of indigestion even with a lesser silt charge.

The problem of silt could perhaps be solved if the following three things were known, (*a*), how much silt had to be disposed of from the head to the tail of a canal ; (*b*), what quantity of silt each offtake could take and (*c*), the means of designing the head regulator of any channel in such a way that it would draw more or less the share of silt assigned to it. It would thus be necessary to know the silt withdrawal capacity of any design or device adopted. What was required at heads of distributaries was not exclusion, but adjustment of silt.

Silt exclusion of course was essential at the head regulator of a canal and the action of the silt ejector recently built by Mr. Nicholson at Khanki would be watched with keen interest by the profession.

Mr. B. L. Uppal while discussing Mr. King's paper, said that the paper was very interesting indeed, and it was evident that the writer had devoted considerable time in studying the subject. The trouble of silt deposit in some of the distributaries or minors was experienced by generally all the canal engineers. In one of the papers last year,

Mr. Sharma gave a history of the attempts made to remodel the head regulator of Mithalak Distributary on the Lower Jhelum Canal because the channel was silting badly. The problem led Mr. Woods to bring in his theory of silt indices and in pursuance of that theory, some of the regulators were altered from 'undershot' to 'overshot' arrangement of regulation, but the remedy was not quite satisfactory.

The author had struck a right conclusion that the trouble was due to the offtaking channel being at right angles to the parent channel, because the offtaking channel did not get any help from the velocity of approach in the parent channel. It could be avoided if the offtakes were placed at an obtuse angle instead of the right angle. Mr. Uppal said that Engineers were so far accustomed to see offtakes generally placed at right angles to the parent channel, even if the offtake was to be a ditch channel going along, and parallel to, the parent channel. It was probably due to the fact that an Engineer as a Draftsman finds it easier to draw out plan of a square head than that of an oblique head. Wherever possible, it would be more desirable to have offtakes at an angle varying from 120° to 150° to the centre line. Such oblique offtakes were proposed by him for ditch distributaries of Gugera Branch of the Lower Bari Doab Canal. They had the following advantages :—

(*a*) Entry from the parent to the offtake was smooth and there was some velocity of approach into the offtake.

(*b*) The curve in the head reach of the ditch channel was gentle.

(*c*) Less land was required under the offtaking channel in the head reach till it met the parent channel, where it was located within the existing land width of the parent channel.

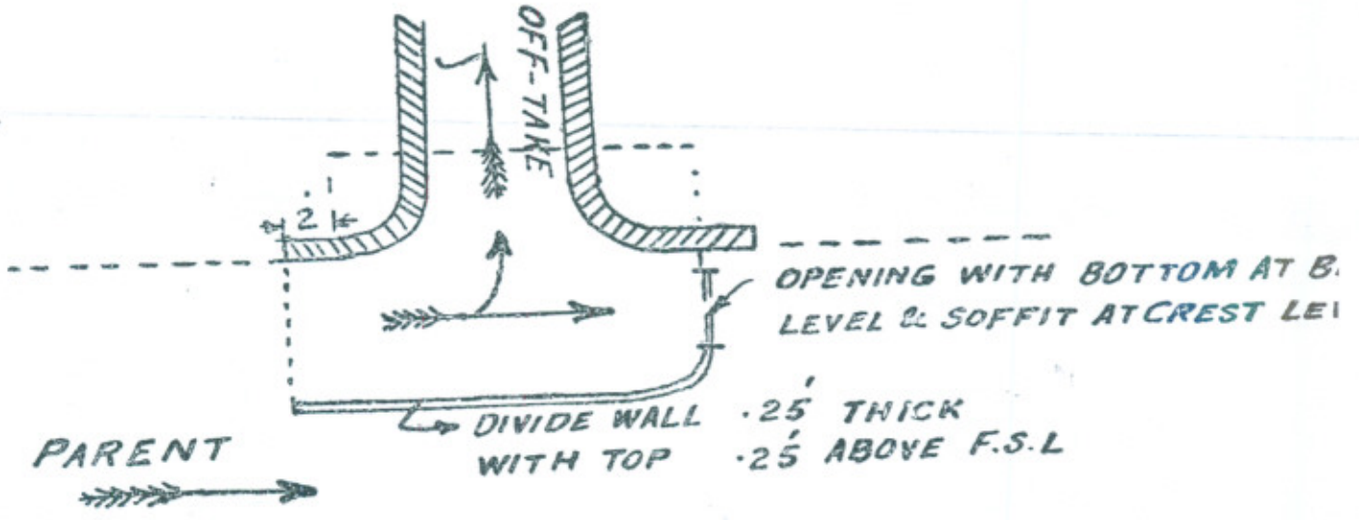
Thus, wherever alignment of the offtake channel permits, Engineers should prefer the oblique head to the square head. But in cases where the general alignment was more or less at right angles to the parent, and Engineers could not avoid having a square head, he did not think that they should be afraid of that. It was desirable that in such cases they should have smooth entry at the head, so that the offtake did not get extra charge of silt.

In most cases of channels silting in the head reach, it was noticed that the trouble was due to defective entry at head. In some cases a raised crest with vertical upstream side was provided in front of a head with the idea that only surface water might be drawn into the offtake but the object was not fulfilled, as the vertical wall having been probably placed in the wrong position, helped in raising the water from the bottom to the surface, and the channel silted as badly as before. In some cases, the sloping upstream wing wall of the head disturbed water in the parent channel before its entry into the offtake. The same trouble was noticed when a head was set back behind the average berm line of the parent channel. One such case had been successfully cured recently by giving suitable approach wings to ensure smooth entry into the offtake. On

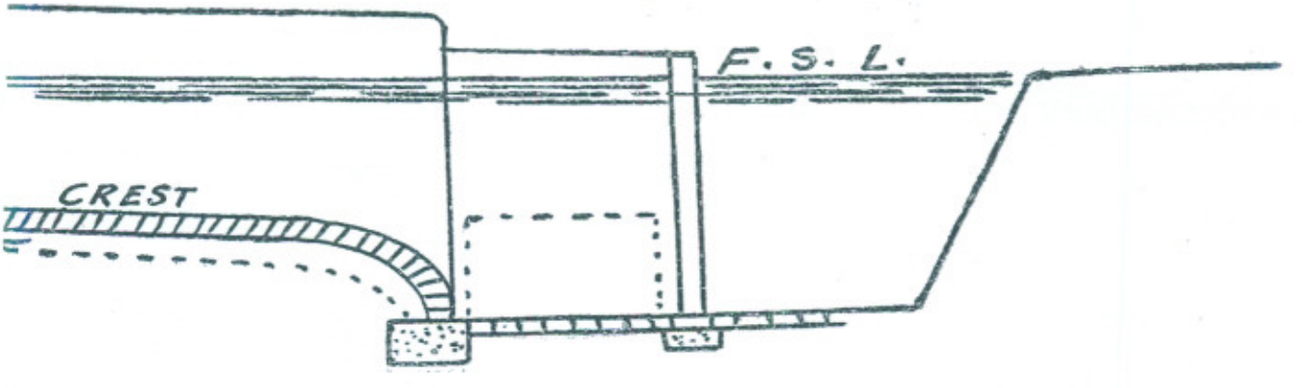
the Lower Bari Doab Canal, remodelling of channels was being done on certain lines laid down by Mr. R.A. Routh, Superintending Engineer. To describe those lines in detail would require a lengthy note, but he might add that generally the remodelled channel was considerably improved and permissible supply at the tail was always insured but it was noticed that some of the offtaking channels did not stick to the designed section and slope, because in some cases, the entry into the offtake was not smooth. In such cases, Mr. Routh had recently provided silt vanes on more or less the lines given by the author and it was hoped that they would be successful. Mr. Uppal added that he had successfully made masonry wall .25′ thick up to a height of $2\frac{1}{2}$ ft. in cement mortar of strength 1 : 3.

In case of a small minor, a thin divide wall had been provided on a pitched bed, as shown in the sketch below.

PLAN



SECTION



The distance of the divide wall from the upstream face of the approach wing of the minor head was kept so as to intercept $1\frac{1}{2}$ times the discharge of the minor. The divide wall started from about 2 feet upstream of the point from which curve of the wing wall starts and ended at the point where curve of the downstream wing ends. The minor head had a raised crest and in the end portion of the divide wall, where it met the downstream wing wall, an opening was left with its bottom at the bed level of the parent channel and soffit at crest level of the flume. The idea was to secure smooth entry into the head of the minor and to pass the 50% extra discharge which was trapped by the divide wall, comprising mostly the bottom water, into the parent channel through that opening.

The silt vanes suggested by the author will certainly mitigate the silting trouble but, as mentioned by himself, the extra silt saved from the offtake will go to the parent channel and prove a nuisance lower down, where it might be found that there was not enough water to deal with the silt charge.

Thus obviously the aim should be to distribute the silt equitably. That can be done in the following ways :—

1. Wherever possible, the offtaking channel should be given oblique head so as to have its proper share of silt from the parent channel.

2. As far as possible, the outlets should be at the bed level of the channel so that they may draw their full share of the silt charge.

3. In the case of square offtakes, the head should be placed so that the approach wings are in line with the berm line of the channel, thereby ensuring smooth entry into the offtake.

4. The head of the offtake should not be placed too close to the fall in the parent channel. The idea of having a common wall at a bifurcator and thus saving a little money has proved to be fallacious.

5. At every offtake, the section of the parent channel generally alters both for bed width and depth. The head of the offtake should be designed so that the upstream wing wall was placed in line with the upstream berm line, while the downstream wing wall should be placed out so as to be in line with the berm line required below the offtake. The sections required above and below the offtake should be given and controlled by pacca profiles. This was not being done at present on some canals though in the opinion of the speaker it was most essential for securing smooth entry into the offtake.

6. Normal width should be maintained everywhere on a channel. So far they had been basing their design of sections for a channel on Kennedy's or Garrett's diagrams which though accurate, are not definite, but thanks to the investigations made by Mr. Lacey they can now fix bed widths, depths and slope of a channel to suit the desired value of C.V. Ratio on which depends the silt conducting capacity of a channel. The speaker had verified that for channels in good regime, the relation :

$$P=2\tfrac{2}{3}\sqrt{Q}$$ was very true.

This formula helped the Engineers in selecting the proper bed width and depth and proper slope to give the desired C.V. Ratio. Having designed a channel with proper sections they must see *that those sections were maintained.* The speaker laid great stress on the point, as it was admitted, that no Sub-Divisional Officer or Subordinate was worrying himself over it and on every channel they found abnormal widths due to some causes or other. With a channel kept in correct designed section, the silt distribution would be quite equitable and he did not consider that the engineers would actually need the silt vanes except in the case of an exceptionally bad offtake.

Mr. Mithal explained that two months ago he constructed two silt vanes at the head of Joshi distributary which after running 20 days showed a reduction of 3 *hissas* of silt. Similarly Habri distributary on the Western Jumna Canal, as a result of fitting silt vanes, now takes a greater discharge. He further described his experience in Raya Division in 1930 and suggested that where silt vanes are constructed they may be removed one by one as conditions improve until a divide wall is left in the end.

Mr. Colyer referred to pages 269 &271 of Mr. King's paper and said that if the author alluded to the tightening of a channel by floating-spurs or stakes-and-bushing in order to induce it to rescour its bed, he saw no harm in this, provided the head was available. He knew from experience in several cases that contracting the width of a channel did result in clearing some silt from the bed and obtaining a much better channel.

Referring to Mr. King's remark that a shallow stream would carry more silt than a deep one,within reasonable limits, the speaker said that the important point was to find out what those limits were. This was one of the most pressing problems in the Punjab. He thought Mr. Lacey's diagrams would probably give satisfactory results, but that the problem of fixing the limit, up to which a shallow stream would carry more silt than a deeper one, needed further investigation. Probably Mr. Lacey's system would overcome this difficulty but he did not know for certain whether it would. With regard to Mr. King's statement on page 270, paragraph 6, that a good working head did not reduce the risk of silting, the speaker's own experience was that a good working head *did* reduce the risk of silting by insuring a good initial velocity and thus preventing initial deposit. What one had to remember about silting in the head reach was, that, with a channel near the critical velocity point, loss of energy would cause silt-deposit and this silt would never be picked up again, because there was no residual energy in the channel for that purpose. Mr. King himself had said on pages 284-285, that extra working head was a great help in preventing silt-deposit in the head-reach. Mr. Colyer further considered that the stream-lining of heads in both the horizontal and vertical planes, was of great importance. Referring to page 271 of the paper, he found that Mr. King was opposed to any system of fluming by what he had called "unnatural means" *i.e.*, of hanging-spurs or fixed-spurs. The speaker, on the contrary, found that flumes which

did very useful work could be formed by the introduction of spurs to cause silt-deposit behind them. He did not quite agree that the deposit of fine silt was due to its being retained by weeds and reeds, but thought that it was due to the more clinging nature of the suspended-silt as compared with the bed-silt. The speaker after examining a very fresh silt-deposit had found that the reeds and weeds grew afterwards and were not themselves the initial cause of the deposit. Referring to page 272 para. 9 he said that it raised the question of excluding silt from a distributary and letting it go down the parent channel hoping that it would find a channel which was more ready to carry it than the one from which it was excluded. This was, he considered, correct only in some special cases, but, as everybody recognised, silt-exclusion could not go indefinitely from distributary to distributary and the exclusion must eventually be done at the head of the canal. To his mind the ideal to be aimed at in silt-control was proportional distribution, *i.e.* excluding the harmful silt, at the head of the canal, and then effecting the proportional distribution between the distributaries, of what was left. For this distribution axial offtake was of great importance.

In the case of curved wing or divide-walls, the speaker did not think it sufficient to mask only a portion of the offtaking regulator, but considered it essential that the divide-wall should be sufficiently far upstream as to ensure division of the supply and the silt while the flow was still axial. He made it a practice to design the width of the offtaking flume such as to give a velocity of about 10 per cent less than that of the adjacent filaments of the parent channel, so as to avoid any 'draw' towards the distributary.

Mr. Gerald Lacey remarked that the author deserved the thanks of canal engineers for a valuable contribution to the solution of a problem that urgently demanded a solution. He agreed with the majority of the author's conclusions but did not always quite follow the arguments by which he supported them. The author had kindly referred to his paper, " Stable Channels in Alluvium." In that paper it was assumed that regime channels swept forward a constant regime silt charge. His paper therefore was not intended to show " what the design of a channel should be to enable it to carry a given silt charge," but was intended to demonstrate what the design of a channel carrying its regime silt charge should be for any given *grade* of silt. His paper dealt with constant silt charge and varying grades of silt, whereas the author's dealt with constant silt grade and a varying *charge*. Both problems required solution. The author had quoted his paper as proof that a shallow stream can carry *more* silt than a deep one ; the paper however was designed to show that shallow streams carried a coarser silt grade, and showed further that for a given discharge there was a fixed section which gave best results, and that mere increase in width without limit was as detrimental as undue contraction. These remarks did not mean that the author was incorrect in stating that shallow channels within limits could better carry a heavy charge of silt than deep ones.

The best authority was possibly Karl Grove Gilbert. In his work *Transportation of Debris by Running Water*, Gilbert states that "for any combination of slope, discharge, and fineness it is possible to reduce capacity (the maximum load of debris which a given stream can transport) to zero by making the stream very wide and shallow, or very narrow and deep." He however goes on to state that "width is a factor ; a broad channel carries more (debris) than a narrow one." The author therefore was quite correct in stating that within reasonable limits a shallow stream carries more silt than a deep one, and in condemning bushing and staking as a means of silt transport.

If a channel was asked to carry more silt than the available slope could support, it was correct to state that a good working head was no cure. A good working head however did at least permit of the channel by forcing down supplies, running at its designed discharge until clearances could be effected. If the working head was poor, the channel was hopelessly handicapped.

Mr. Inglis stated that the subject of silt exclusion from offtakes had been investigated in great detail in the Bombay Presidency and he explained the design that was finally adopted for the Barrage Canals which was very simple and satisfactory. It consisted of fluming the parent channel and fixing the heads of the offtaking channels so as to take off from the upstream, converging walls of the flume. In the converging portion of a flume the high velocity top-water tends to flow straight on into the offtakes; or, where there is no offtake, dives down at the sides ; while the bed water, carrying the heavy silt, concentrates in mid-stream, due to acceleration of the bed velocity. Unless, therefore, the offtaking channel is very large—so that the side draw caused reverse curvature of flow, thus neutralising the flume effect—the offtaking channel draws considerably less than its share of bed silt. This question has been dealt with in Bombay P. W. D. Technical Paper No. 26 "Report on tests made on a model of a group of regulators at Oderolal."

With small offtakes, by which is meant offtakes drawing a small proportion of supply, it is not difficult to exclude bed silt ; but much remains to be done before we can distribute the silt between parent and offtake as we desire. This question is under investigation at the Khadakvasla Hydrodynamic Research Station, near Poona.

Mr. Inglis considered that under no circumstances would a tunnel be necessary or desirable for excluding silt from an offtake from a canal. Other methods would be much cheaper, and much better. The author had stated: "It is not generally realised that curved wing silt excluder actually excludes silt.... There is no doubt about the effectiveness of the device ; it has been tested and proved, but its effect is obviously limited. It might be used in cases where the offtaking channel

has, in virtue of its gradient, etc., the same silt-carrying power as the parent. If the offtaking channel has less silt-carrying power, silt vanes are indicated or silt tunnels."

From this it appears that the author does not himself realise that the amount of silt drawn can be regulated within wide limits by the design of the curved wall ; and the fact that he has stated that " a variation of the device is to leave openings at the foot of the curved wing so that the bottom water can escape and flow off downstream into the parent channel. This is probably an improvement...." shows that he has not grasped the fundamentals of " silt pond " and " open flow."

The author has made no mention of the silt excluder used in the United Provinces, which works on exactly the same principle as the Sind Flume design and is cheap and adequately effective except where the offtake is large. In this design the side slope is warped to vertical at the offtake, which is over a raised cill, and is then warped back to the normal side slope downstream.

That Mr. King's vanes are highly suitable in the case of small channels and to remedy excessive silt draw even in large canals is undoubted and he deserves great credit for introducing them.

Mr. Nicholson referred to the great work Mr. King had done towards the solution of the Punjab silt problem and acknowledged that his imagination had been stimulated in many ways when he was posted at Rupar under him. He agreed with what had been said that silt exclusion other than at the head regulator of a canal was very like clearing up your own garden and throwing the rubbish into that of the next door neighbour. The conditions as regards silting on the Lower Chenab Canal had become extremely critical. The subsidiary regulator would never have been built had it been realised that it was only carrying out the methods which had been successfully adopted at Rupar as described in the Irrigation Branch Paper No. 9, in plan and not in section, where there was only 1′ head available. The channels on the Lower Chenab Canal in some cases were now silted to 6″ over the top of the old K. G. outlets. The silt excluder which was being constructed at Khanki was evolved from the ideas of Messrs. Gibb and King. The idea described by Mr. Inglis had been adopted independently by him at a three notched fall where the head of a minor had been fixed in the converging wing wall upstream and a roof slab had been constructed in front of the regulator orifice with a side wall which enabled the bottom water to be drawn under the slab into the first notch of the fall. The speaker described the silt excluder under construction at Khanki across the first 6 bays of the main regulator which consisted of 3 tunnels 7′ × 10′ in section parallel to the face of the regulator upstream and discharging into the first bay of the undersluices into which they extended up to within a few feet of the gates. The result of its working during hot weather will be

watched with a view to its further extension across the other bays of the regulator.

Mr. King in concluding the discussion on his paper said that he did not agree with Mr. Colyer and other speakers concerning proportional distribution of silt. It was obviously unsuitable to give every distributary the same proportion of silt in its water because the critical velocity ratios of distributaries varied greatly.

Referring to Mr. Colyer's remarks about a good working head reducing silting, Mr. King said that he had probably expressed his meaning badly in the paper. He admitted that the greater the velocity of entry into the offtake the less would be the tendency to silt depositing, provided that the energy of that velocity (or part of it) were conserved for the head reach of the offtaking channel, and not dissipated immediately after passing the orifice.

Referring to Mr. Lacey's remarks, Mr. King said that if a stream A were capable of carrying a coarser grade of silt than another stream B, the stream A would also ordinarily be capable of carrying a greater quantity of some fixed grade of silt than B ; and that therefore his quotation of Mr. Lacey's paper in support of his contention was justified. He (Mr. King) was aware that under certain conditions stream A might not be capable of carrying a greater quantity of silt of a fixed grade than B; but those conditions never occurred in the cases for which the paper was written, *i.e.*, in streams with natural beds.

Regarding Mr Inglis' remarks Mr. King agreed with Mr. Inglis that the tunnel arrangement would at any rate be rarely preferable to other means of excluding silt from a channel taking off from a canal. There are, however, a few cases in which the tunnel device might be the best. For example, in the case of a very small and very high level minor, of say 4 cusecs, with a flat gradient, taking off from a heavily silt-charged parent of great depth, say 8 feet. Such a case is the Koru Minor of the Lower Gugera Branch of the Lower Chenab Canal.

As to Mr. Inglis' statement that the author was apparently not aware that the silt drawn by the curved wing device can be regulated by the design of the curved wing, Mr. King said that it appeared to be fairly obvious from the description of the device and its effects that the silt entry can be so regulated; but it would equally obviously be impossible to frame definite rules as to its design which would be applicable to every parent channel regardless of the proportion of silt which it carried.

Mr. King thought that Mr. Inglis' reference to the difference between " still pond " and " open flow " conditions showed that he (Mr. Inglis) has misunderstood the design under discussion, (the curved wing device). If properly designed, there would be no question of " still pond " conditions.

The author regretted that the United Provinces device was omitted from his paper.

In conclusion, Mr. King wished to thank those who made appreciative remarks on his paper.

The President thanked Mr. King for giving this paper to the Department before leaving. This was the labour of his life time.

DIRECTION FOR LAYING OUT SILT VANES.

From the upstream edge A of the off-taking head draw a line A. B., at right angle to the centre line of parent channel, of the length specified as X in the table of dimensions.
Through the point B draw a line C. B. D. at an angle of 2 to 1 with the centre line of the parent channel, cutting the edge of the parent channel, at C, upstream of the off-taking head.
Draw another line E. F. parallel to the centre line of the parent channel and one foot away from the toe of the side pitching,
Or where it should be, cutting the line C. B. D. at G.
Now find a centre H such that an arc of radius R. (of length specified in the table of dimensions). will touch both the lines C. B. D. and E. F. this will best be done by bisecting the angle D. G. E., from H. draw H. K. at right angles to the centre line of the parent channel.
With centre H. and radius H. K. draw an arc of a circle K. L., of such length that the inclination of H. L. to H. K. is 2 to 1.
The curves must all end at the lines H. K. and H. L.
Now from the downstream edge of the off-taking head draw a line M. N. in a direction upstream from M. and at an angle of 2 to 1 with centre line of the parent channel.
From L lay off a distance L. P. along the line C. B. D. such as to project 5 feet (or less, as may be desired) beyond the line M. N. ; then K. L. P. is the position of the longest vane.

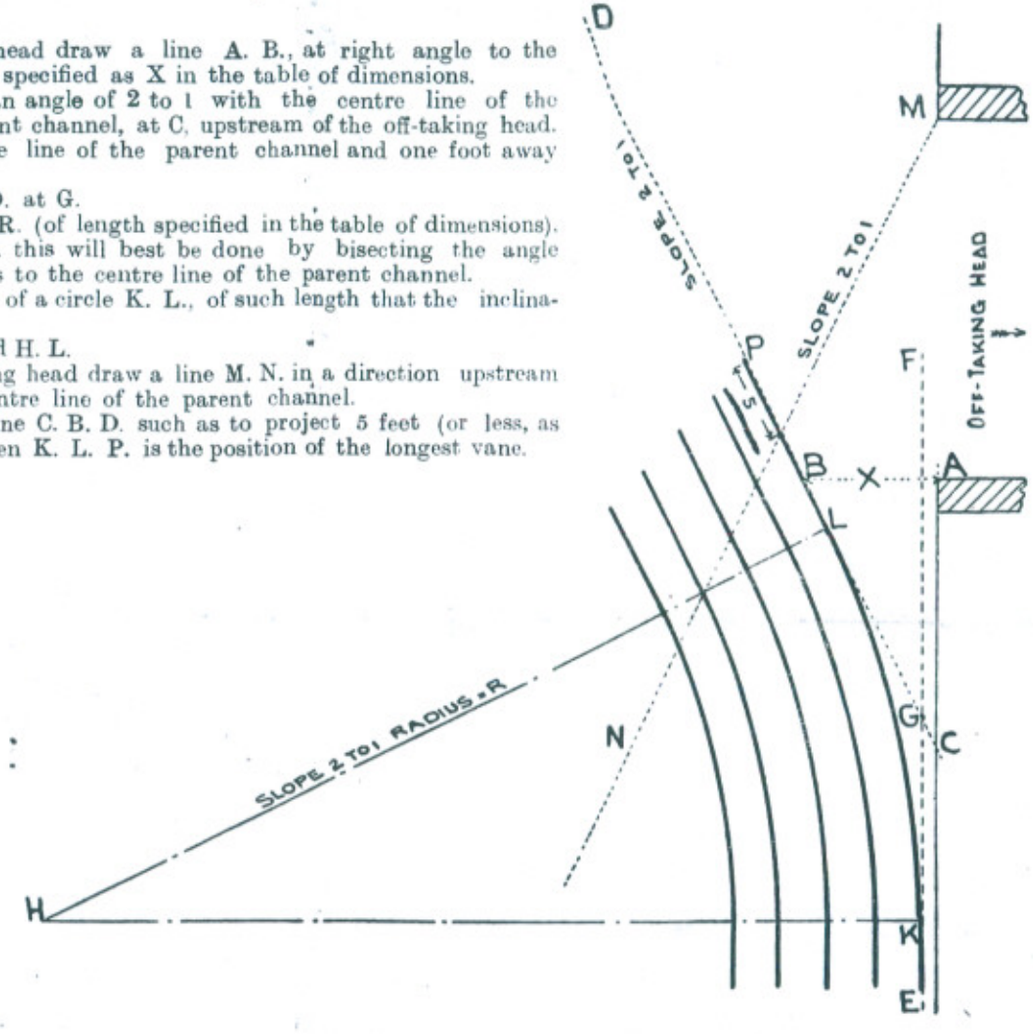
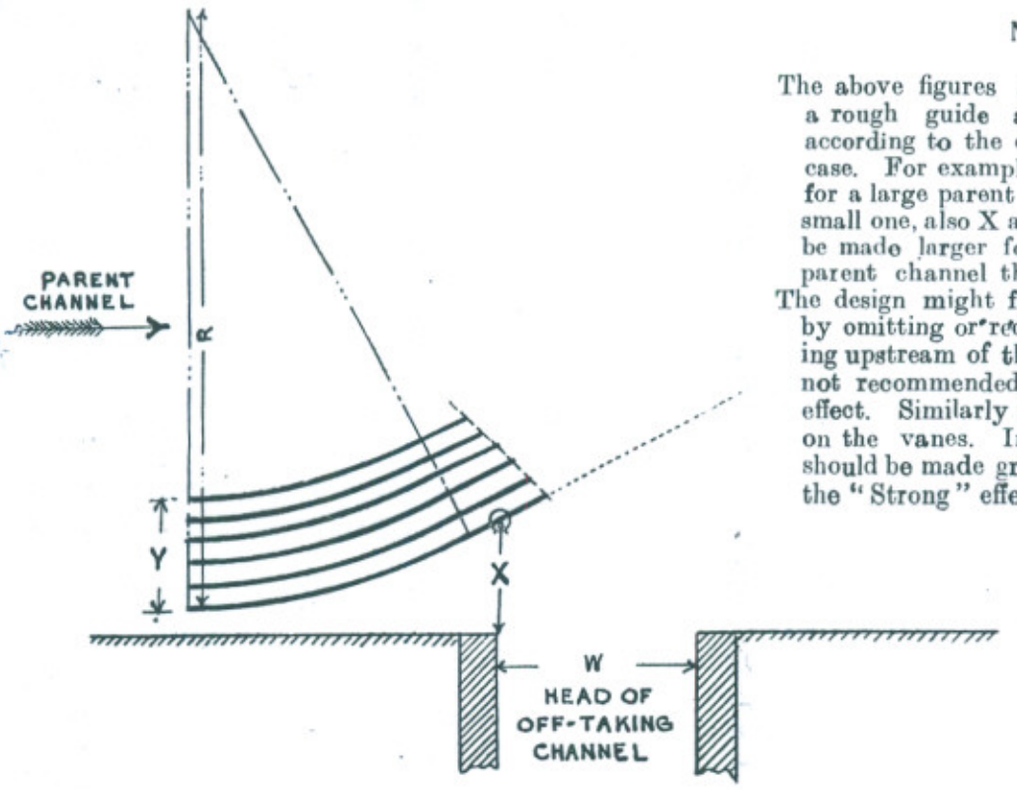


TABLE OF DIMENSIONS FOR SILT VANES

WIDTH OF CHANNEL=W.		2	4	6	8	10	12	16	20	25	30	40	50	100
For strong effect.	Value of X	4	5	6	6	7	8	8	9	10	10	12	12	
	Value of Y	2	3	4	5	6	8	9	11	13	15	20	25	
	Value of R	30	35	40	40	45	45	50	50	50	55	65	100	
Cheaper design (less effect).	Value of X	3	4	4	5	5	6	6	6	6	6	9	9	
	Value of Y	2	2	4	4	5	5	6	7	9	12	15	18	
	Value of R	25	30	30	30	30	30	35	35	35	40	50	75	
Minimum dimensions recommended.	Value of X	3	3	4	4	5	5	6	6	6	6	6	6	
	Value of Y	2	2	3	4	5	5	6	7	8	10	10	12	
	Value of R	25	25	30	30	30	30	35	35	35	40	40	50	

INDEX SKETCH PLAN OF SILT VANES

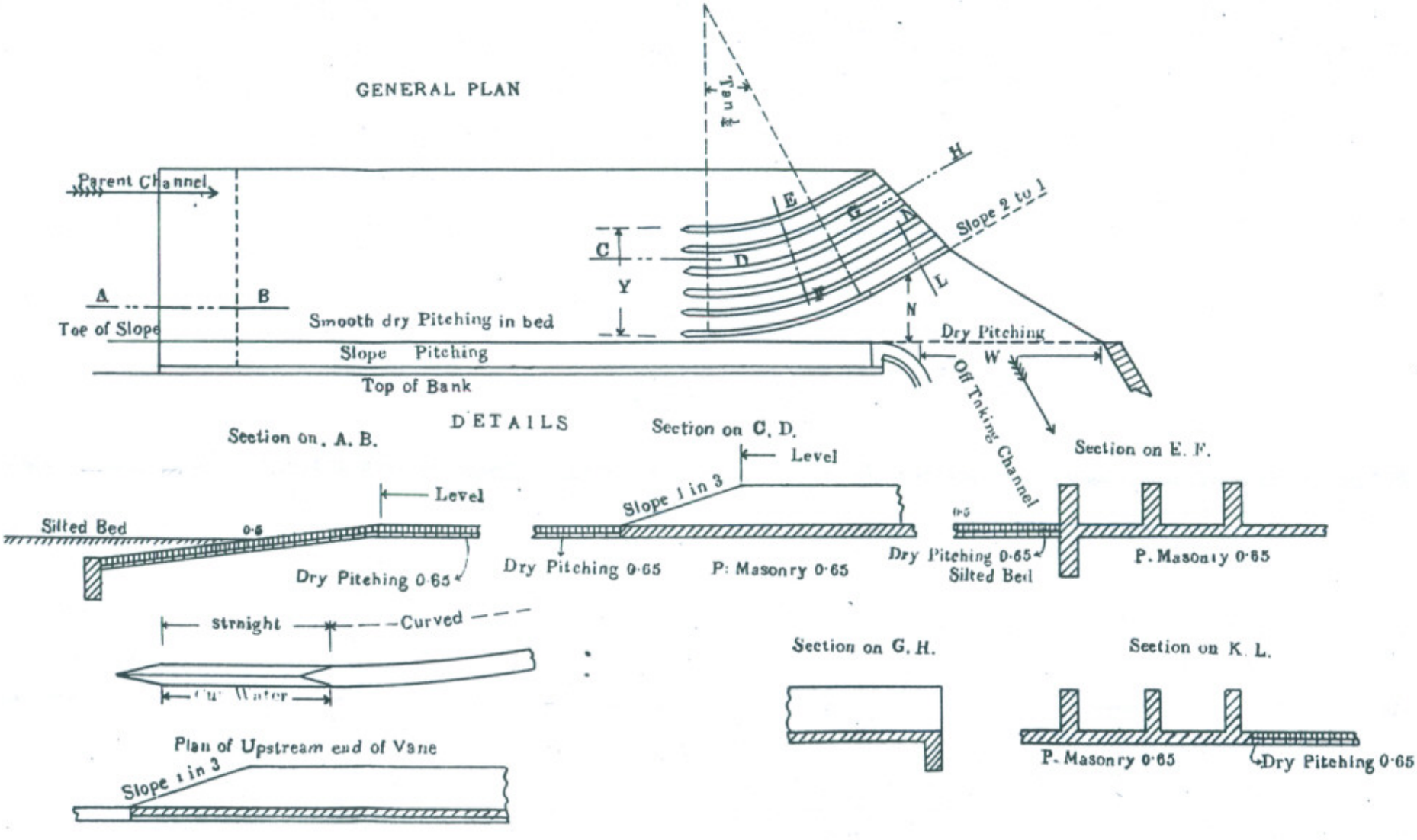


NOTE.

The above figures are only intended as a rough guide and must be varied according to the circumstances of each case. For example R should be greater for a large parent channel than for a small one, also X and Y would ordinarily be made larger for a large and deep parent channel than for a small one.

The design might further be cheapened by omitting or reducing the bed pitching upstream of the vanes, but this is not recommended as it vitiates their effect. Similarly for the cement plaster on the vanes. In very bad cases Y should be made greater than is shown in the "Strong" effect columns above.

DESIGN FOR SILT VANES.



DESIGN OF REVERSE VANES

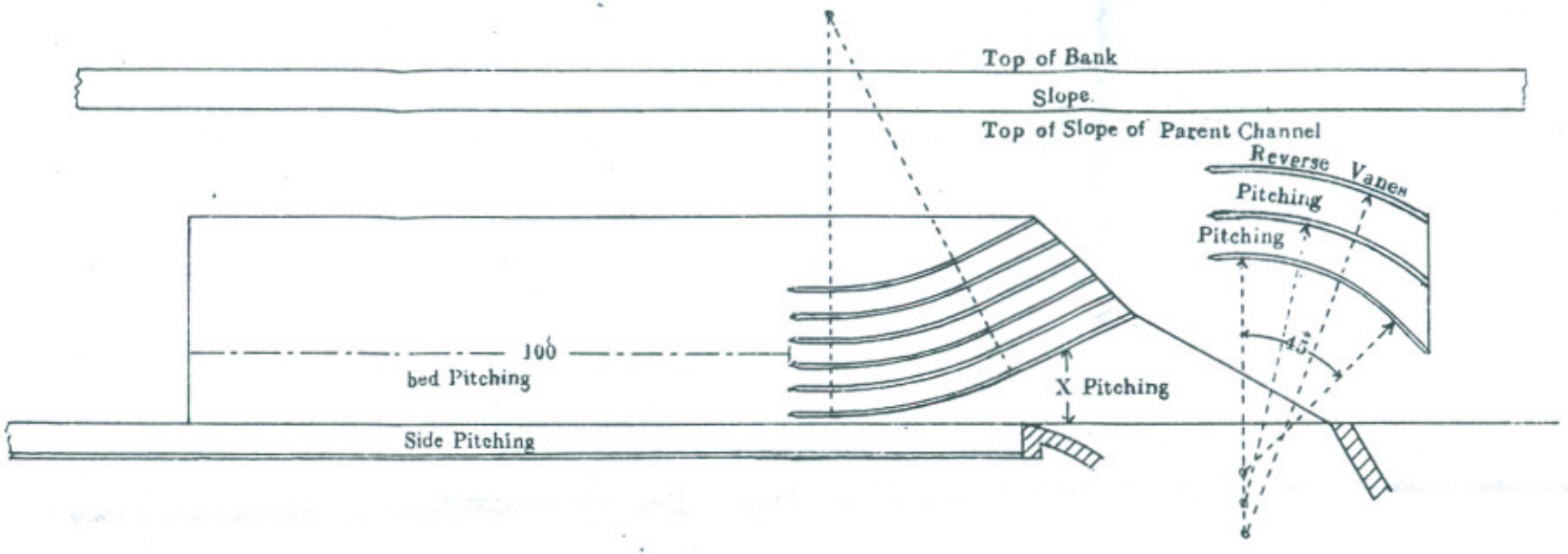
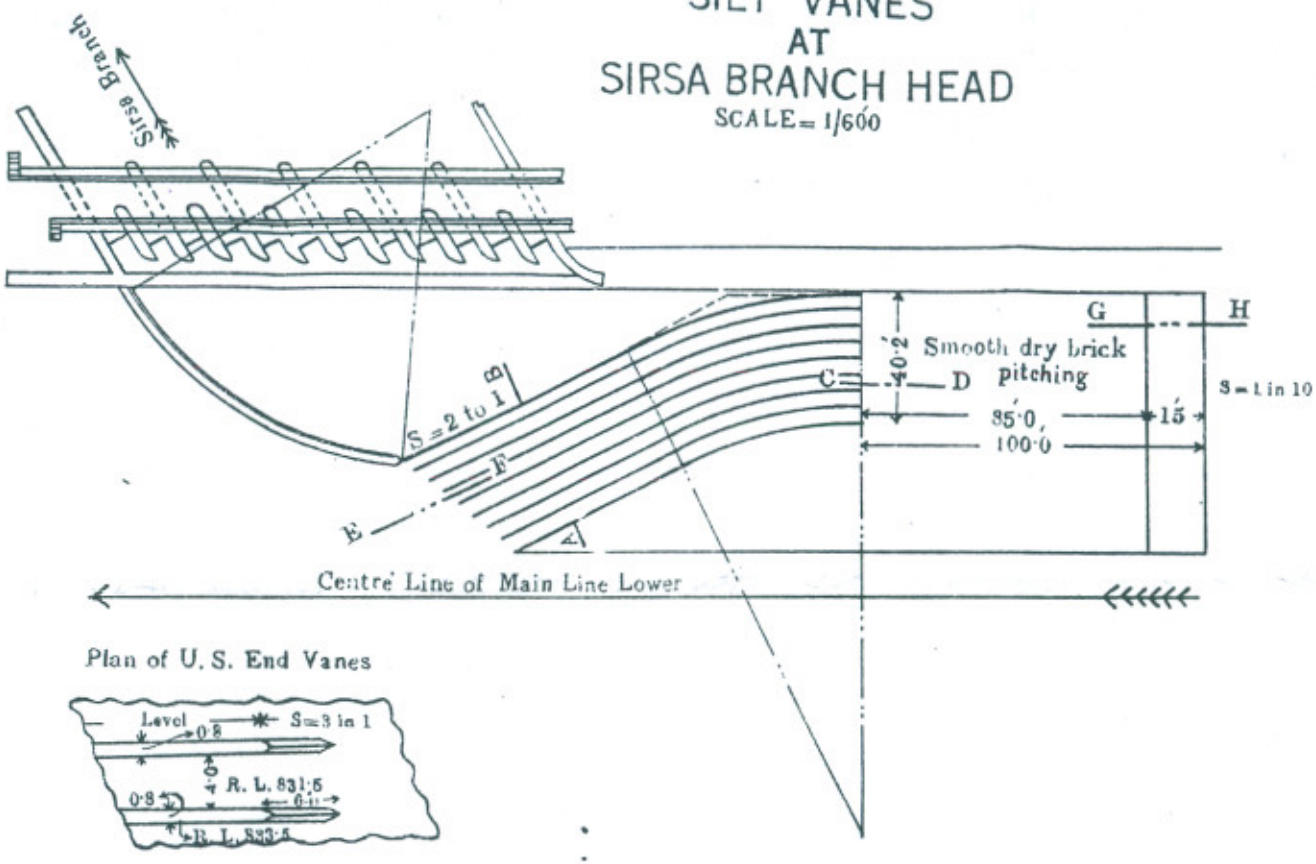


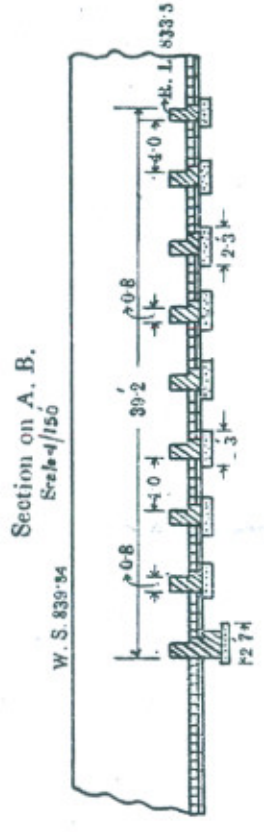
PLATE V.

SILT VANES AT SIRSA BRANCH HEAD

SCALE = 1/600

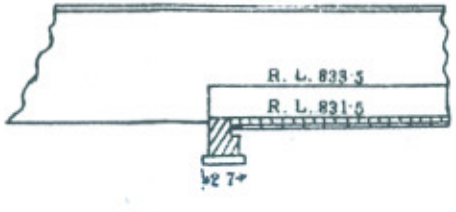


Plan of U. S. End Vanes

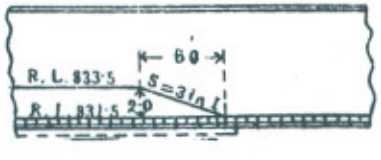


Section on A. B.
Scale-1/150

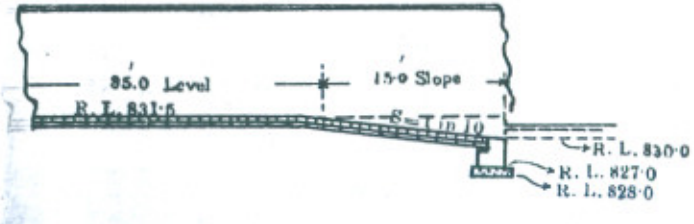
Section on E. F.



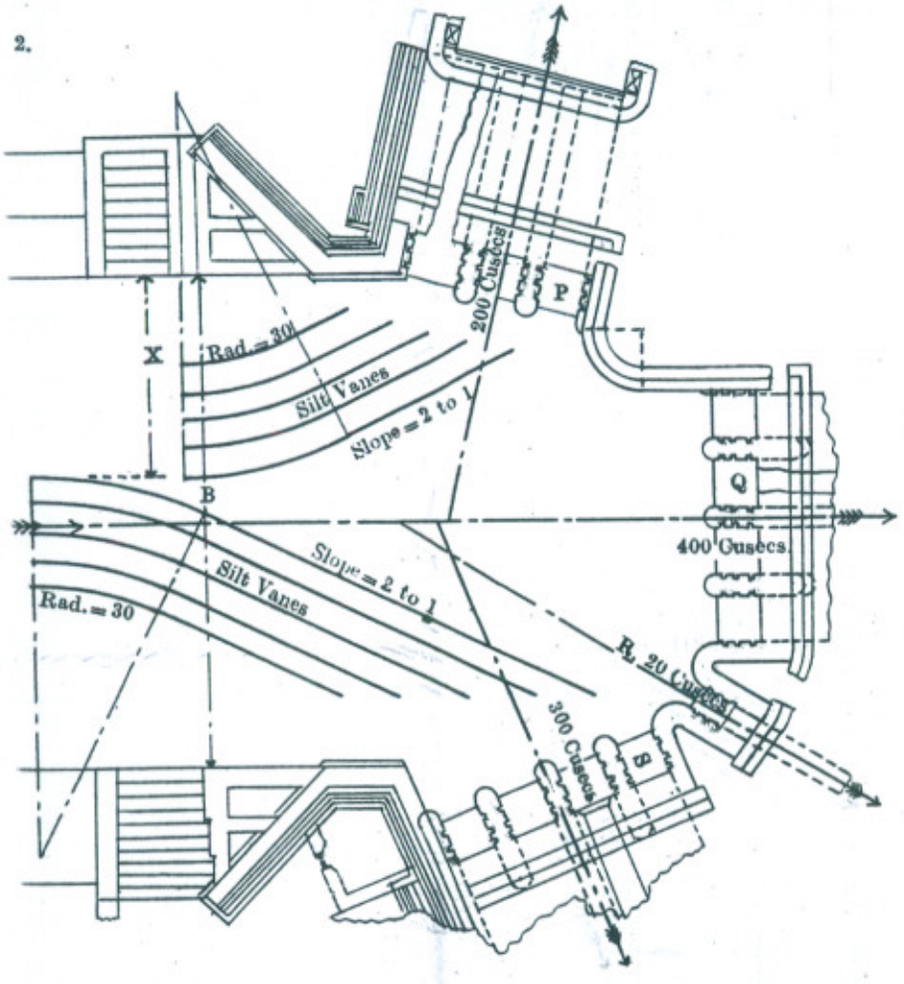
Section on C. D.



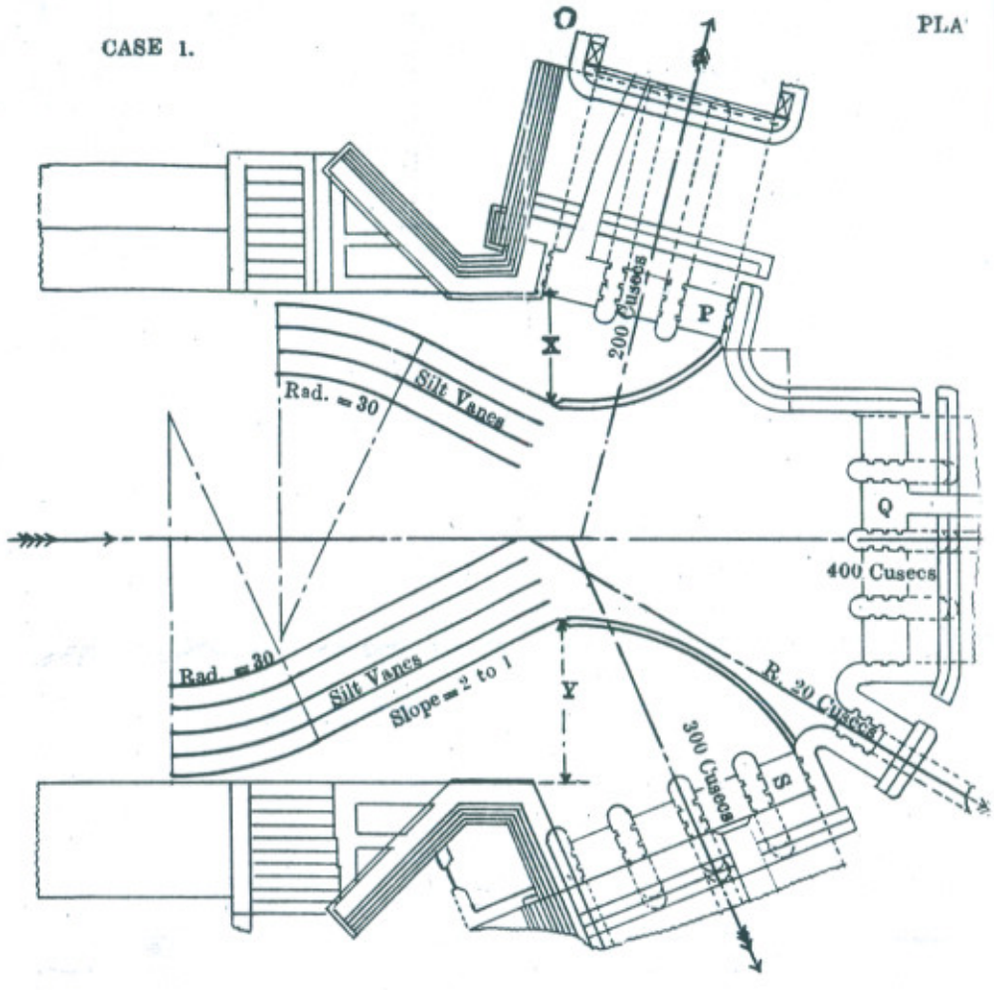
Section on C. H.



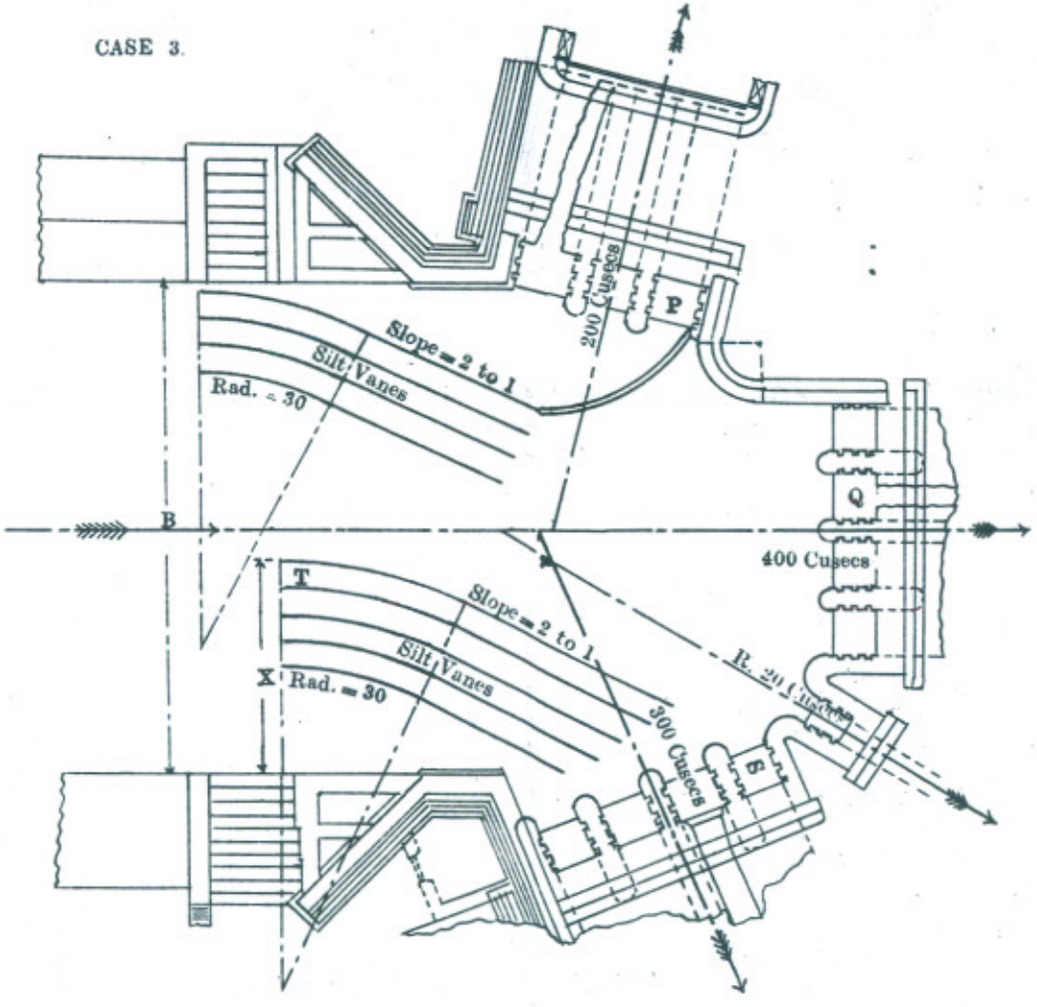
2.


X
Rad. = 30
Silt Vanes
Slope = 2 to 1
200 Cusecs
P
Q
400 Cusecs
B
Rad. = 30
Silt Vanes
Slope = 2 to 1
R, 20 Cusecs
300 Cusecs
S

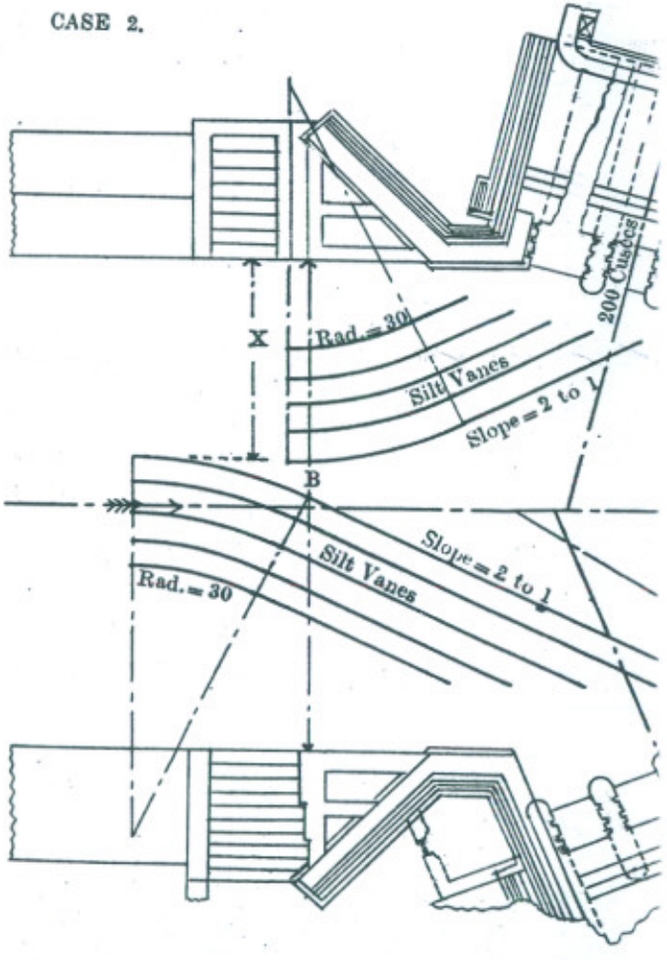
CASE 1.


O
X
200 Cusecs
P
Rad. = 30
Silt Vanes
Q
400 Cusecs
Rad. = 30
Silt Vanes
Slope = 2 to 1
Y
R, 20 Cusecs
300 Cusecs
S

CASE 3.

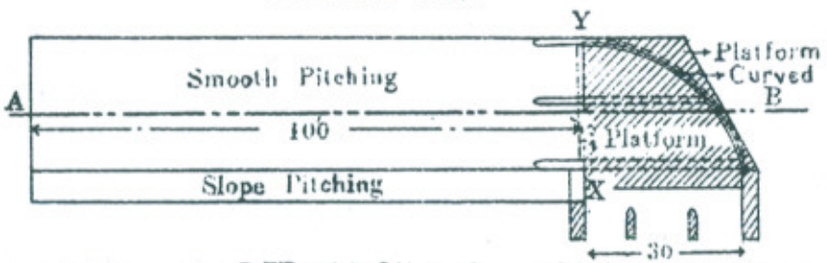

200 Cusecs
P
Slope = 2 to 1
Silt Vanes
Rad. = 30
B
Q
400 Cusecs
T
Slope = 2 to 1
Silt Vanes
X
Rad. = 30
300 Cusecs
S

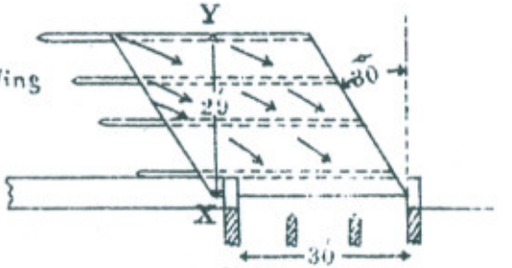
CASE 2.


200 Cusecs
X
Rad. = 30
Silt Vanes
Slope = 2 to 1
B
Slope = 2 to 1
Silt Vanes
Rad. = 30

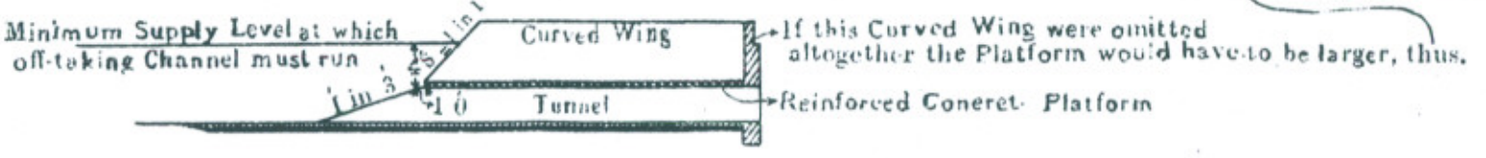
DESIGN OF SILT PLATFORM

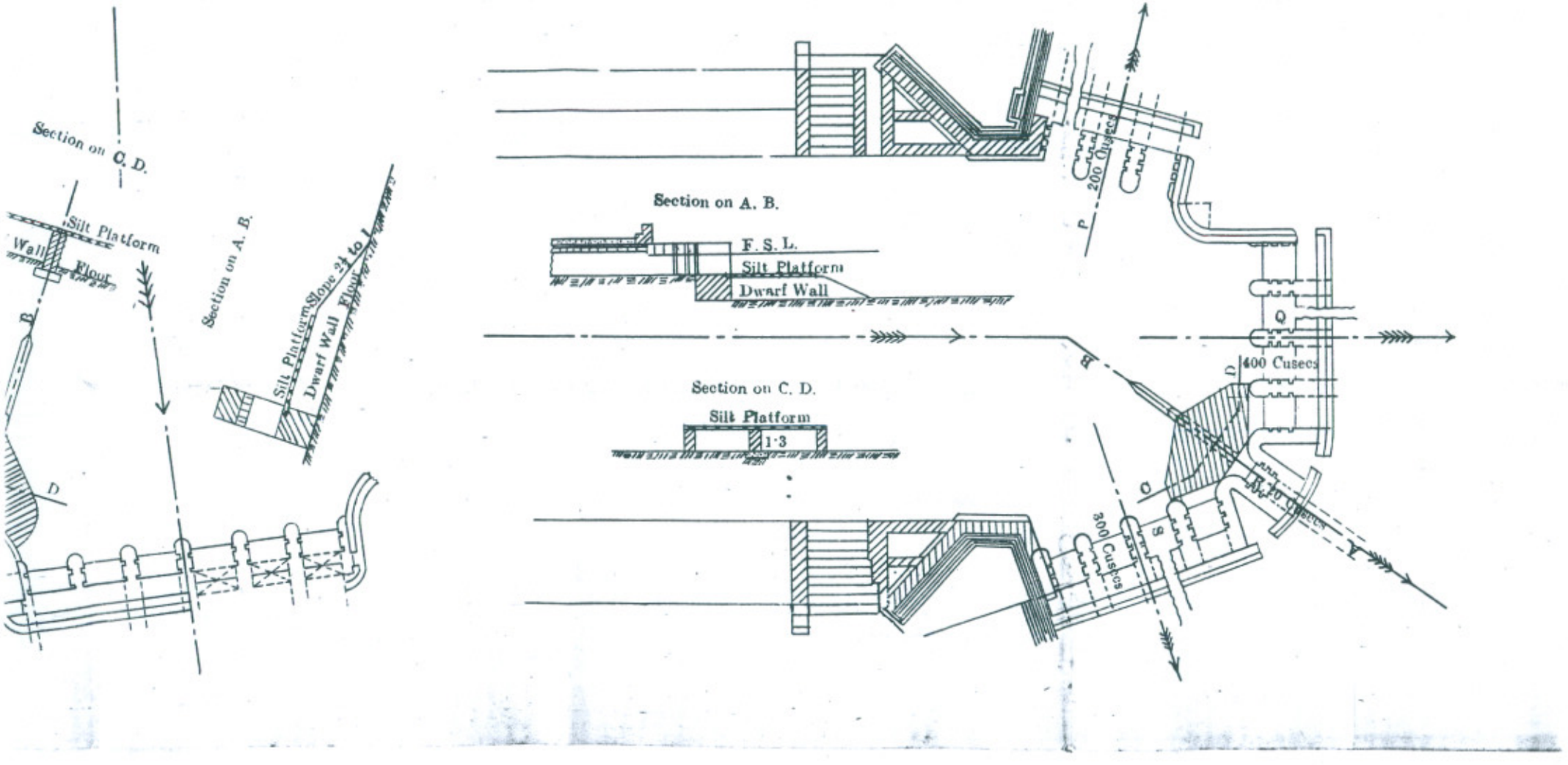
GENERAL PLAN

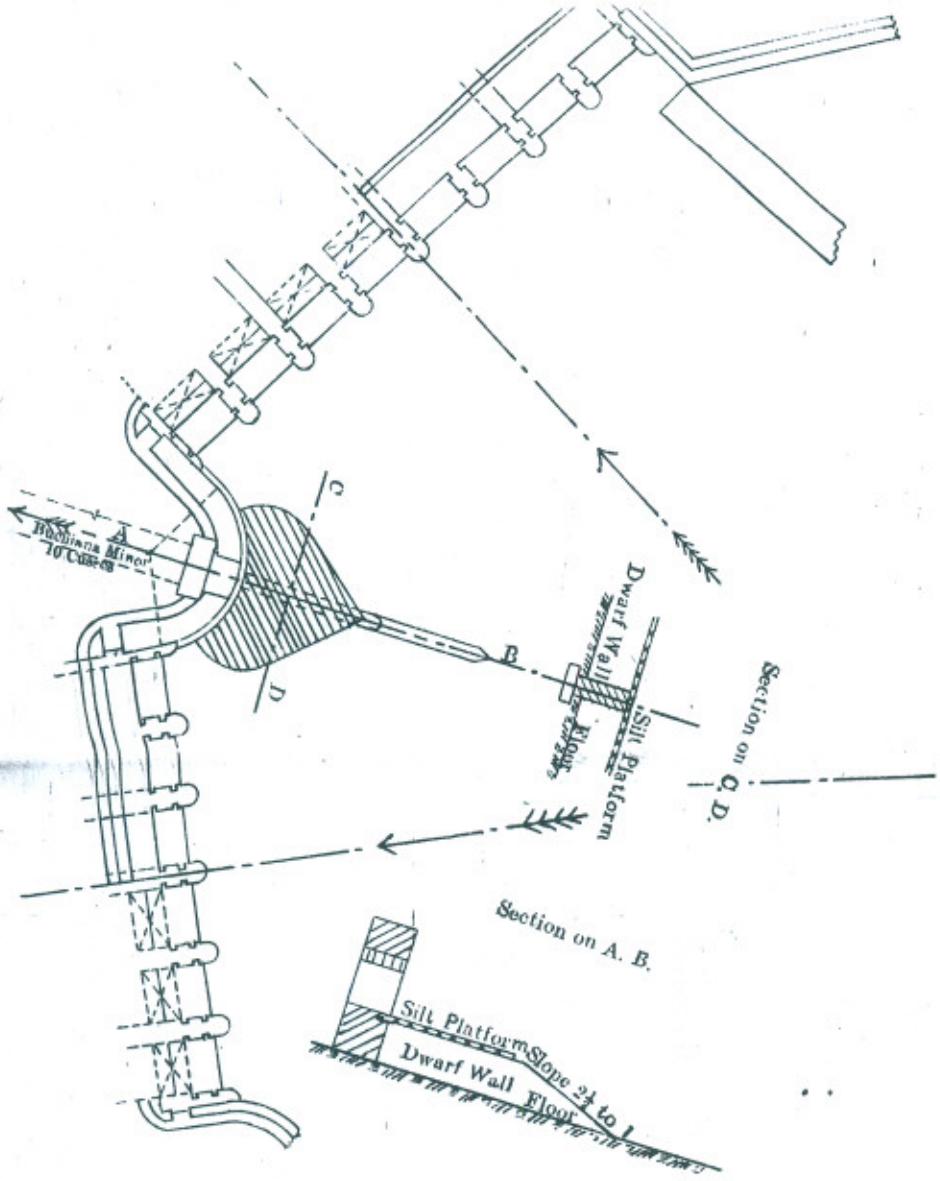


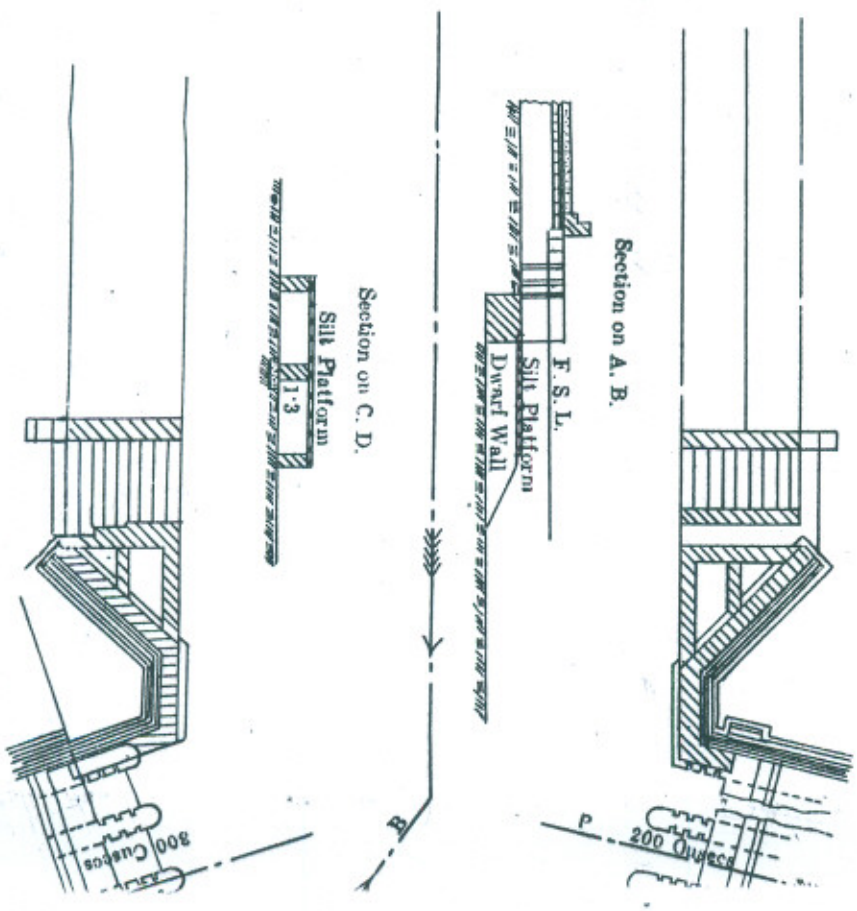


DETAILS ON A. B




Section on C. D.
Silt Platform
Wall
Flour
B
D
Section on A. B.
Silt Platform Slope 3½ to 1
Dwarf Wall
Flour
Section on A. B.
F. S. L.
Silt Platform
Dwarf Wall
Section on C. D.
Silt Platform
1·3
P
200 Cusecs
Q
400 Cusecs
R
D
S
300 Cusecs
100 Cusecs


C
D
B
Section on C. D.
Dwarf Wall Floor
Silt Platform
Section on A. B.
Silt Platform Slope 2½ to 1
Dwarf Wall Floor


Section on C. D.
Silt Platform
1:3
B
Section on A. B.
F. S. L.
Silt Platform
Dwarf Wall
P

CANTILEVERED SILT PLATFORM FOR MANCHAR DISTY. R. D. 40

SCALE = 1/200

SECTION ON C. D

