DISTRIBUTARY OFFTAKES IN RELATION TO SILT CONDITIONS.

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Introduction.

The design of distributary head regulators in relation to the silt conditions of the distributary and canal system in general is a subject which does not appear to have received very much attention up to date. The practice has been to design such head regulators solely with a view to passing the required supply through them at a velocity which did not cause heavy disturbance below the head; the silt conditions of the canal system being ignored. Reference books on irrigation channels dismiss the subject of distributary heads with a few words concerning the gate and gearing, and the only departmental investigation of the subject which appears to have been made is a note written by Mr. Gibb, Executive Engineer, when in charge of the Upper Gugera Division of the Lower Chenab Canal.

There has been no lack of examples of distributaries giving trouble by silting, but this appears generally to have been attributed to incorrect grading of the distributary; and attempts to remedy it have taken the form of regrading—the importance of the correct design of the head regulator having been overlooked, except for occasional exclusion of heavy silt by the provision of a raised cill.

In the Upper Gugera Division, owing to the command generally being poor, regrading would appear to have presented great difficulties, and Mr. Gibb therefore sought to overcome the silt difficulty by careful and scientific design of the head regulators. In his note on the subject some important principles of distributary head design are clearly brought out, and his designs based on the theories he has advanced appear to have met with some measure of success, but in the writer's opinion his reforms do not go far enough, and still further improvement in design is possible and desirable.

Functions of a Distributary Head.

The function of a distributary head regulator is primarily to admit a certain fixed supply of water from the parent channel to the distributary under varied conditions of supply in the former. Where clear water has to be dealt with nothing further is required, but where silt is present, it is also necessary that the water admitted to the distributary should carry with it the same proportion of silt of all grades as is present in the water of the parent channel. Complete exclusion of silt or even exclusion of the heavier grades of silt is not only unnecessary, but is actually detrimental; for though exclusion of heavy silt from a particular distributary may, and probably will, completely cure silting in that one channel, it must be remembered that the silt so excluded must be deposited somewhere, and must therefore make its presence felt sooner or later by causing trouble in some other distributary or in the main canal or branch concerned. In the case of a relatively small distributary, this would not probably be serious, but with a distributary of some size, silting in the parent channel seems a probable result, and might occur as follows. Assuming the silt carrying capacity of the parent channel to be uniform throughout its length, it follows that if a volume of water is abstracted from it without taking with it a proper proportion of silt, the water of the parent channel downstream of the head of the distributary will contain a greater proportion of silt than it is able to carry, and consequently silt must be deposited in the bed. This silt deposit will in turn flatten the gradient of the water surface in the whole reach upstream of the head, whereby its silt carrying capacity will be reduced, and silting will occur until such time as the normal gradient is restored. This action can continue indefinitely, and will result in a gradual but steady rise of bed level in the reach, which, if allowed to continue long enough, would adversely affect the conditions of supply at the head of the reach. Such silting in the parent channel, though slow, cannot be regarded as desirable and should not be permitted to continue. The parent channel would not, however, be affected in this way were it to be so graded that its silt capacity increases below each distributary head in a proportion sufficient to enable it to carry the higher proportion of silt resulting from an insufficient quantity having been drawn off by the distributary, but in this case the silt proportion would constantly increase towards the tail end of the branch, and the lower distributaries would therefore be more and more liable to serious silt trouble, due, not to any defect in their grading or in design of their own heads, but to incorrect designs of the head regulators of the distributaries in the upper reaches of the parent channel.

It may, of course, be a long time, even many years, before any such detrimental effect on the parent channel or the downstream distributaries becomes apparent, but there can be no doubt that unless each distributary is made to carry its own share of silt of all grades, some such effect is ultimately certain to appear, and the great importance of designing distributary heads to satisfy this condition is therefore apparent. It may be laid down, then, that a distributary head regulator to give really satisfactory results must, besides taking the proper volume of water, draw off with that water its full share of silt, and the distributary channel must be so graded that it can carry that silt, and pass it off through the outlets to be distributed over the fields. The fact that complete exclusion of heavy silt has occasionally been aimed at in distributary head design may be attributed to a false analogy having been made between a distributary head in a main canal and a canal head in a river. The two cases are not in any way comparable, since a river can and does dispose of its silt by passing it down ultimately to the sea, whereas a canal can only dispose of it by passing it into the distributary channels.

Distribution of silt in a main canal.

In order to arrive at some method of ensuring that a proper proportion of silt is drawn off into each distributary, it is first necessary to consider how the silt is distributed throughout the section of flow in the canal, and this unfortunately is a subject on which there is little reliable information. It is known that there is a gradation from fine to heavy silt downwards from the surface of a stream, but it is not known what variations, if any, exist in the quality and quantity of silt in a transverse plane. It has been stated, on the authority of Stearns, that there exist in a canal transverse currents from the sides to the centre along the surface of the channel, and by inference from the centre to the sides along the bottom, and Mr. Gibb in his note, already referred to, draws the inference that the heavier grades of silt are drawn towards the banks, and the finer towards the centre, a principle on which he bases his designs. This however does not appear to be necessarily a correct inference, even admitting the presence of the cross currents. If any such transference of heavy silt to the sides takes place, it must inevitably result that the water near the banks becomes overcharged with heavy silt, and growth of berms and local bed silting near the banks is certain to ensue, but many main and branch canals show no very definite signs of such local silting. It would follow therefore either that no such transference takes place, and hence there are no such cross currents, or else, if the cross currents exist, the heavy silt after being carried to the banks by the bottom current is returned towards the centre by the top current. This latter action would however result in a fairly uniform distribution of all grades of silt throughout the depth of the channel, and is therefore at variance with the ascertained fact that the silt is of a coarser grade towards the bed. It therefore seems not unreasonable to suppose that no such cross currents exist, and it becomes a fair assumption that the distribution of silt transversely is nearly uniform. This may be expressed in other words to the effect that in a transverse section of the stream every vertical strip of water carries approximately the same proportion of silt of all grades as is carried by the stream as a whole. This is a highly important conclusion, and must form the basis of correct design of distributary head regulators.

Form of opening required.

The correct form of opening for a distributary head should be such that the water admitted carries with it a proportion of silt identical with that in the parent canal, and since the silt content of the water varies in a vertical direction, but is very nearly constant in a transverse direction, it follows that the opening should extend through the whole depth of the parent channel, should be constant in size in a vertical direction, and variable in a horizontal direction for adjustment of supply.

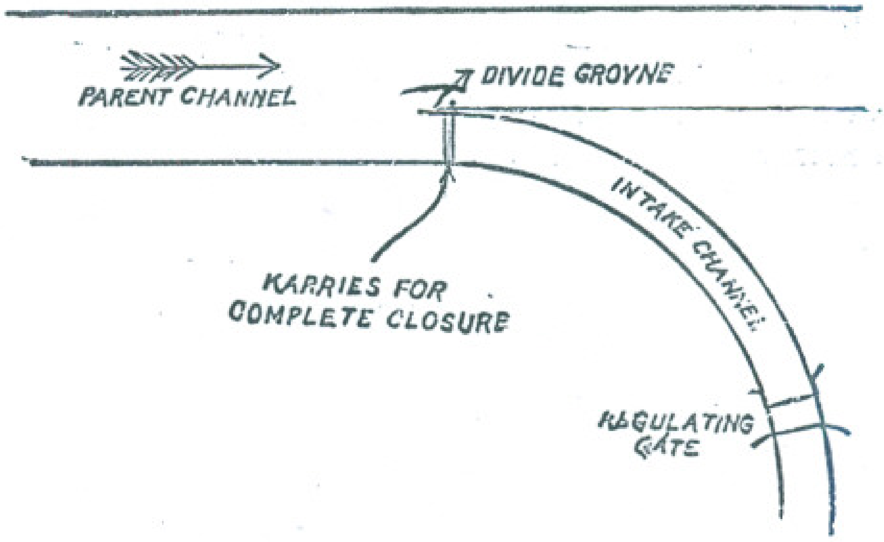
The same principles are arrived at from a different point of view based on Kennedy's silt theory. Kennedy has shown that the silt carrying power of a channel varies with two quantities only, the depth and velocity. It therefore follows that to preserve uniform silt carrying power both these quantities must remain unchanged. Distributary heads as now constructed are absolutely opposed to these principles. They have frequently a raised cill which excludes the bottom water of the parent channel, while their horizontal dimensions are fixed and their vertical dimensions variable. This is very convenient to simplify gate construction, but pays no regard whatever to silt regulation. The most common type of gate, a dropping gate, beneath which the supply is admitted, draws in the lower layers of water and takes in with it an excessive amount of heavy silt. If a high cill is provided, or a rising cill gate employed, the less heavily silt charged upper layers of water alone are admitted, and an excess of heavy silt is owing to variation of velocity over the cross section of the parent channel and change in the wetted perimeter at the bifurcation point ; and probably the best that can be done is to proportion the width of the opening so as to give the same mean velocity as that prevailing in the parent channel, in which case, under normal conditions of flow, the deviation from a condition of steady flow at the bifurcation would be small, and probably not sufficient to affect seriously the silt conditions.

There remain however some more serious difficulties to be overcome. Firstly, distributaries are not always in flow, and an offtake constructed on the principles here evolved would very soon give serious trouble were it to be closed while the parent channel remained in flow, owing to the silting which would occur in the dead water standing in the upper part of the intake channel above the regulator. This could be partly remedied by the provision of some means of closing the channel, at the bifurcation point, but even so, slack water would exist in the angle just above this subsidiary head, and a bank of silt would be liable to form there. It is not easy to see how this can be got over except at prohibitive cost, but fortunately such conditions are little likely to occur during kharif flow, and during rabi flow the water carries very little silt. It seems possible, therefore, that this difficulty could be sufficiently overcome by the provision of a light subsidiary regulatorj at the bifurcation point which could be closed by flash boards. This would be used only for complete closure and not for regulation of supply.

There arises another difficulty when it is required to run a full supply in the distributary with a low supply in the parent channel. Under these circumstances the area of flow at the bifurcation point would not be sufficient to carry the discharge of the distributary at the normal velocity of the parent channel, and there must unavoidably be acceleration upstream of the bifurcation point. This, while not desirable, seems unavoidable, and under the circumstances reliance must be placed on the infrequency of this condition during kharif flow for avoidance of ill effects, while owing to there being no change in direction of flow upstream of the bifurcation, the occasional occurrence of acceleration is not likely to be of serious consequence.

Summary of conclusions.

The form of distributary offtake which appears correct in view of the consideration so far advanced is as sketched below.



It will be seen that the parent channel requires special treatment, in that the reduction of bed width below the distributary offtake should be on one side only, instead of being symmetrical about the centre line.

The distributary offtake consists of four parts :—

(1) The divide groyne or cut water.

(2) Karrie grooves at the bifurcation point for use when the distributary is completely closed.

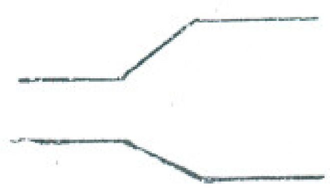
(3) The intake channel.

(4) The regulator.

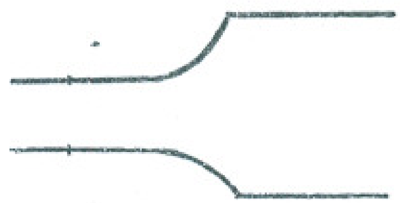
Of these No. 1 should be as sharp as possible, which points to the use of reinforced concrete for the thinner portion. No. 2 may consist merely of side walls and a pacca floor with karrie grooves to permit of complete closure of the opening. No. 4 may be a regulator of any type designed to pass the full discharge required throughout the probable range of supply level in the inlet channel. No. 3 will be an open channel to carry water from the bifurcation point to the head regulator.

The design of this channel requires some further consideration on account of the very varied conditions which may prevail in it in different cases. At the bifurcation point it is required to have the same depth and mean velocity as the parent channel, and its bed width will be approximately the same fraction of the bed width of the parent channel as its discharge is of the discharge of the parent channel. These dimensions will probably not be suitable for adoption throughout its whole length, and may be modified below the bifurcation to any more suitable section of equal silt carrying capacity.

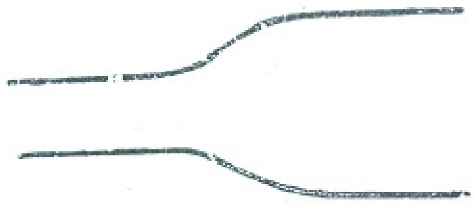
The change of section should however be made very gradual, a term which is deserving of further explanation. Changes of section are at present made almost invariably in the form of a uniform slope from dimension to dimension thus—



Occasionally some further refinement is attempted by putting in a curve thus—



Neither of these, however, constitutes a really gradual change. In the first example there is a sudden change of direction at each end of the tapered portion, and in the second, while the narrow section is left on a gentle curve, no attempt is made to ensure easy entry to the wider section. A change of section to be truly gradual should be made thus—



If in conjunction with an increase of bed width, a decrease of depth is required the bed must be raised, and this also should be done by a reverse curve and not by a straight slope, *i.e.* as shown by the firm line below and not as shown in a broken line.

This subject might be enlarged on at considerable length, but enough has been said to show what is intended by the term "gradual."

The intake channel will be designed for normal conditions, *i. e.* a full supply in both the parent channel and the distributary, but it may also be required, occasionally, to take a full supply for the distributary when a reduced supply is running in the parent channel. In this event the area of flow will be reduced, and the velocity and hence the surface slope must be correspondingly increased. The resulting supply level at the regulator must be carefully calculated for the worst case, so that the regulator may be designed to work with a full distributary supply at all stages between this and the normal condition.

In extreme cases the velocity required to pass a full distributary supply, when a low supply is running in the parent channel, may be greater than the soil can stand, and in such cases it will be necessary to pitch the intake channel throughout. As an example of the application of this method of design the more important details of an actual offtake have been worked out in the appendix and illustrated in the plan attached.

Extent of application of the main principle involved.

The main argument on which the foregoing notes are based is that silt should be equally distributed throughout a canal system, every distributary taking its full share. An obvious criticism of this argument is that all distributaries have not the same capacity for disposing of silt. Where command is good, a distributary can perhaps dispose of far more than its proper share of silt, and where command is poor it may be unable to dispose of as much as the normal quantity. From this point of view, it might seem desirable to design the offtakes of channels having good command to take an overload of silt, thus relieving those having poor command. Where it is in any way possible to design an offtake to carry off a known excess or defect of silt, this might be the most satisfactory procedure, although it penalizes the zemindars of well commanded districts by overloading their land with silt, but in the present state of knowledge of silt distribution it is quite impossible to design offtakes in this way, and attempts to do so are not likely to result in any improvement on the present conditions, which necessitate constant readjustment of both head regulators and grading; there being no certain knowledge as to which is really in fault. It would, therefore, appear that it is better to design offtakes to take their exact share of silt, since it will then be certain that silting in the distributary is due to incorrect grading. Where command is good, regrading such channels will present no difficulties, and although in other cases it may not be easy, it is likely to prove ultimately the most efficient and satisfactory method of treatment, even if more costly, since it should result in the establishment of a nearly permanent regime.

In some cases such regrading will no doubt necessitate an increase of full supply level in the parent channel, and this will certainly be costly, but the money will generally be well spent if the distributary is thereby converted from a bad to a good one; three great advantages accruing, in that the cultivators will be more contented, remission of water rate will be less frequent, and the labour and cost of repeated remodelling saved.

Not the least advantage of this method of treatment, *i.e.*, designing all distributaries to take their full share of silt, is that, having so designed the head regulators, there is certainty that measures taken to cure silting in one distributary will not in any way upset the regime of the parent channel or of other distributaries—a condition which cannot possibly be obtained if any attempt is made to balance excess of silt in one channel against a defect of silt in another.

Conclusion.

The methods here proposed for design of offtakes of distributaries are somewhat revolutionary in character, and even though they may be accepted as in the main correct would require to be tested before adoption on any considerable scale, and it is suggested therefore that a single small branch canal should be selected somewhere for experiment on the lines indicated.

Obviously it is useless to experiment with single distributaries or with anything less than an entire branch, and it is equally apparent that the principles advocated cannot be full tested in a short time. On the other hand, after remodelling on the lines proposed, the branch dealt with must be carefully watched for several years before it can be definitely pronounced to be a success or failure, and during the course of that period it will probably be necessary to regrade some of the distributaries. Incompleteness of knowledge of the transverse distribution of silt in an open channel is a weak point of the data worked from, and though it has been shown that a nearly uniform transverse distribution is possible, it is more probable that the central portion of the stream will carry rather more silt than the side portions. This would to some extent vitiate the proposals made, but the difference in silt content is probably not enough seriously to affect them. It is doubtful whether it would be possible to make any useful experimental investigation of the distribution of silt in a transverse plane, as any apparatus used to obtain samples would cause local disturbance of the silt conditions, which, in the case of the heavier grades of silt near the bed, might completely falsify the result; but, in any case, there would be little advantage from a more accurate knowledge of the subject, since the practical difficulties in the way of any selection of the part of the cross section, from which the supply should be drawn, are so immense, that it is compulsory to take the supply from one side of the parent channel, although the silt content of the water near the sides may not be the same as that at the centre.

The author had hoped to be able to carry out some experiments with regard to the existence of transverse currents in a canal, but circumstances have made it quite impossible to find time for this, and this paper remains both in this and other respects somewhat incomplete. It may however serve to stimulate discussion and indicate a direction in which experiment and trial seems desirable.

APPENDIX.

Details of a design of a distributary offtake.

DATA OF MAIN CANAL.

	Above offtake.	Below offtake.
Bed level	.. 731·59	
Bed slope	... 1 in 5,000	... 1 in 5,000
Bed width	... 80 feet	... 68 feet.
F. S. depth	... 5·7 feet	... 5·55 feet.
F. S. discharge	... 1,331 cusecs	.. 1,124 cusecs.
Rabi depth	... 5·05 feet	... 5·05 feet.
Rabi discharge	... 1,081 cusecs	... 910 cusecs.

DATA OF DISTRIBUTARY.

Bed level	... 730·00	...
Bed slope	... 1 in 4,000	...
Bed width	... 18 feet	...
F. S. depth	.. 4·55 feet	...
F. S. discharge	... 207 cusecs	...
Rabi depth	... 4·05 feet	...
Rabi discharge	... 170·5 cusecs	..

The offtake must have the same depth as the parent channel *i.e.*, 5·7 feet, and the same mean velocity 2·92 feet per second. The sides being vertical this will require a width of $\frac{207}{2\cdot92 \times 5\cdot7} = 12\cdot5$ feet nearly.

Grading at 1 in 5,000, with a depth of 5·7 feet, the intake channel would require a bed width of 13·5 feet when it becomes an ordinary earth channel with 1 to 1 side slopes. The velocity would then be reduced to 1·9 feet per second. This section however is not suitable as having a critical velocity ratio of only 0·85 V_o and would be liable to silt. The bed slope must be increased to 1 in 4,444, when the section will become, 18·5 feet bed width, with 4·5 feet depth and the critical velocity ratio V_o.

At the offtake point the channel has vertical sides, and a width of 12·5 and depth of 5·7 feet. This has to be converted to a channel with 1 to 1 side slopes, 18·5 feet bed and 4·5 feet depth.

At the same time the centre line must diverge from the parent channel on a reasonable curve, continuing on this curve until it joins the alignment of the distributary.

The intake channel must remain vertical sided, until a sufficient width, say four feet, is obtained between the side of the parent channel and of its distributary, beyond which point the top width of the divide groyne may remain constant, and the side slope of each channel may be increased until it is 1 to 1. The channel walls will be of brickwork until the side slope is flat enough for dry pitching, which will be continued up to the point at which the side slopes become 1 to 1.

Throughout this length the bed width will be 12·5 feet, but, as soon as the side slope becomes 1 to 1, the bed width will be gradually increased, and the bed level raised until the final section of 18·5 feet bed width and 4·5 feet depth is attained. The point at which this takes place is the nearest point to the bifurcation at which the regulating gate should be placed.

In order to obtain actual dimensions it is necessary to fix the radius of the curve on which the distributary should leave the parent channel. No rational formula exists on which to base this dimension, and intelligent guess work must be resorted to. The limit of curvature of a canal is sometimes taken as a proportion of the bed width, but there does not appear to be any scientific ground to support such a rule, and it seems, on the other hand, that the radius should more properly be a function of the velocity head. A reasonable value appears to be—

$$R = 50\ V^2$$

where R = radius of curve
V = mean velocity

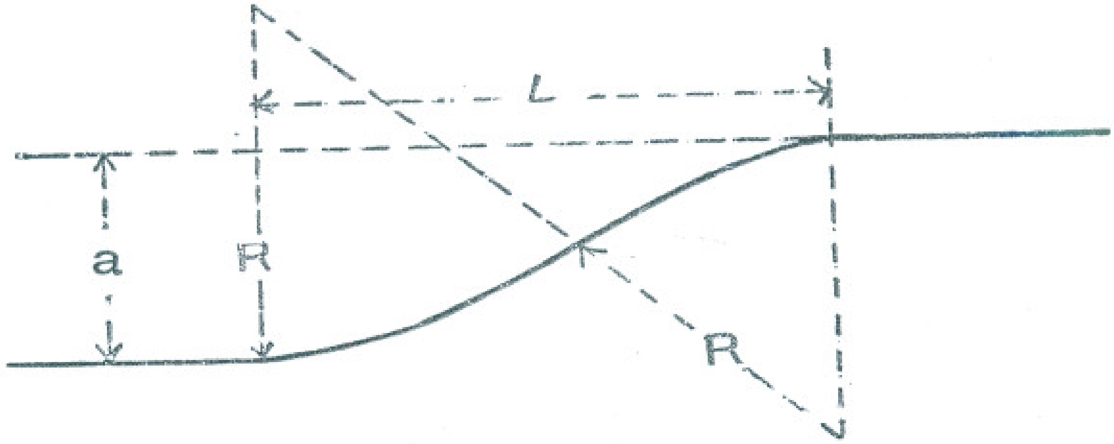
This is purely empirical, but seems at least to be logical.

For the channel in question the mean velocity being 2·92 fs. the minimum radius will be—

$$50 \times 2{\cdot}92 \times 2{\cdot}92 = 375 \text{ feet.}$$

This radius will determine the point up to which the sides will be vertical, and also the point at which they become 1 to 1. The first will be where the divergence of the two channels is four feet, and the second where it is 4 plus $2 \times 8{\cdot}7 = 21{\cdot}4$ feet which work out respectively to 54·6 feet and 128 feet, so that the channel will be vertical sided for 54·6 feet and will obtain 1 to 1 side slopes 128 feet below the nose of the divide groyne

From this last point the cross section will commence to change, and the change can be in the form of a simple reverse curve of large radius. In this case the change of bed width being 18·5--12·5 = 6 feet the displacement of one side will be 3 feet.



Taking the radius four hundred feet we get

$$L = 2\sqrt{a\ R + \left(\frac{a}{2}\right)^2}$$

2

$$= 2\sqrt{3 \times 400 + \left(\frac{3}{2}\right)^2}$$

= 70 feet nearly

which is the length required for changing the cross section.

The total distance from the bifurcation point to the point at which the final cross section is attained is, then, 128 + 70 = 198 feet, and the regulating gate must be not less than this distance from the bifurcation point.

It is almost impossible to calculate with any accuracy what will be the surface slope in this length. There is a decrease of mean velocity from 2·92 feet per sec. to 2·00 feet per sec. which will theoretically give a reduction of velocity head of $\frac{2{\cdot}92^2 - 2^2}{2g} = 0{\cdot}07$ feet In a gradually changing channel such as this, it may probably be assumed that not less than 0·05 feet of this will be converted to a rise of level, waste in eddies being inappreciable. On the other hand, a gradient of not less than 1 in 5,000 will be needed to overcome frictional resistances, which in 198 feet will amount nearly to 0·05 feet. We may assume therefore that there will be no surface fall in this length; the energy required to overcome friction being supplied by the decrease of velocity.

The regulating gate may be located at this point 198 feet from the bifurcation, and it is quite immaterial what form the gate takes, provided that it is capable of passing a full supply into the distributary with the lowest level of supply in the parent channel at which a full supply is ever likely to be required.

In the case under consideration, with full supply in both channels the fall through the regulator will be 2·74 feet, and in rabi working, the head available from the parent channel at the bifurcation point to the distributary below the regulator is 2·59 feet, but assume that provision must be made to pass the rabi supply with a depth of only four feet in the parent channel. The available head will then only be 1·54 feet, from which must be deducted the head needed to carry the supply through the intake channel. This again is not susceptible of accurate calculation, but may be assumed to be $1{\cdot}25\,\frac{V^2}{2g}$, where V is the velocity now needed at the bifurcation point namely 3·7 feet per sec. The loss of head will then be $\frac{1{\cdot}25 \times 3{\cdot}7 \times 3{\cdot}7}{64}$ $= 0{\cdot}25$ feet nearly, so that the head finally available at the regulating gate will be $1{\cdot}54 - 0{\cdot}25 = 1{\cdot}29$ feet, and the regulator must be able to pass 170 cusecs with this head.

The detailed design of the regulator presents no special features and need not be considered here.

Discussion on Distributary Regulators.

(Messrs. Gibb's, Schönemann's and Elsden's Papers.)

Mr. Gibb, in introducing his paper, said that the general subject of silt was legitimately divisible into two parts, first the problem of how and to what extent water became charged with silt, and secondly how the charge behaved with regard to distribution and direction of travel after it was there. The attempt made in his paper to begin at the second part of the problem, and to neglect the first, was not altogether satisfactory, but to have included the whole subject of silt in channels would have taken the Congress too far away from the immediate subject of distributary heads, and would have enlarged the field of discussion so much as to make it unlikely that they would have arrived at useful conclusions. However, the matter had been settled by Mr. Schönemann, whose paper ostensibly took up the problem at the very beginning, and dealt with the whole subject of silt. The basis of discussion had been widened accordingly.

He was in substantial agreement with Mr. Schönemann where he described the conditions of flow that make for lifting silt from the bed and sides of a channel. Apart from the travel of sand particles by being pushed up on to each other's backs, as described by several writers, the simplest way in which a charge of silt could be got, would seem to be provided by the unequal pressures to which the boundary planes were subjected, owing to the presence of eddies or other cyclic flow structures in the stream. The bounding surface, in advance of and behind the axis of rotation of such a cyclic flow structure, would be subjected to higher pressure than that part of the boundary which was immediately opposite and therefore nearer to the axis. The higher pressure on either side would be communicated through the porous soil or sand, with the result that opposite the axis of rotation the particles would have a greater pressure from the water in the soil around and behind them than they would have from the water in front, and would therefore be pushed into the stream. Any cyclic flow structure would produce this result, whether the streams were closed cycles or continuous, and the fact mentioned in Appendix B that eddies of true free vortex type would exist with horizontal axes did not matter.

He also agreed with Mr. Schönemann that, other things being equal, the intensity of cyclic flow and, therefore, of silt getting ability, depended on the rate of change of velocity along lines at right angles to the boundary, but the power of a cyclic flow structure to get silt would depend on whether such structure was pressing itself against the boundary or not.

In Appendix B he had suggested that the couples applied to the axes of rotation, by the uniform distribution of forward velocity, resulted in residual moments of momentum, which caused or tended to cause precession about a third axis, that is the axis parallel to the direction of flow. Taking for instance cyclic flow about horizontal axes across the canal; the end of an axis that was being pushed forward would tend to precess downwards into the bed, while the precession of the other end which was being held back by slow forward flow, would tend to lift the cyclic structure away from the bed. Thus, though the ability to generate cyclic flow might be more or less uniform, yet inequalities of the distribution of forward velocity as a whole made one part of the stream much more effective in getting silt than another.

Apart from this disturbing influence, however, the method of expressing the silt getting ability of the stream in the form of the numerical silt index used by Mr. Schönemann was not quite a happy one. Two channels might have the same silt index, calculated by this method, and yet have such a difference in the form of their velocity curves as to show conclusively that one would get much more silt than the other. The attempt to express silt getting power numerically was quite unnecessary, unless the figure had some known or surmised relation to a definite quantity of material per cubic foot of water, which Mr. Schönemann's index had not. Velocity diagrams were simple, could be easily compared, and told a much more complete and truer story than a numerical index did, or could.

He still more objected to Mr. Schönemann's use of his silt index. This by itself could not make silt, nor could it cause silt to vanish once it was there. It could only indicate what was likely to happen in the presence of an available supply of silt; but Mr. Schönemann's treatment of distributary heads indicated that if water carrying a small silt charge entered a pipe with a low silt index, and, owing to a change in the pipe section, issued from it at the other end with a high silt index, then the charge of silt at the exit would be correspondingly higher than that at the entrance. The silt index had increased, therefore the silt charge must have increased, but where had the extra charge come from? It must have been created in the pipe. The silt index under a distributary head gate or over a sill was obviously of little or no importance, because there was no silt there to lift no matter how able and willing the water might be.

Probably Mr. Schönemann meant that the approaching water was gradually working up to a maximum silt lifting ability, though it did not reach that maximum where available silt was still exposed to it. Still, the approaching stream was bound to have a silt getting power greater than the normal and increasing as it neared the gate. In this case the silt index at the last point, where the water was in contact with available material, was the important one, and not the figure for the opening under or over the gate.

So far he had criticised Mr. Schönemann's paper as a means of explaining his own views on the first part of the silt problem, namely how the water got its charge, which had not been dealt with in his own paper. Before going on to the second part of the problem, he had to refer to that part of his own paper in which he dealt with the relative merits of what Mr. Schönemann called overshot and undershot regulators. In his paper he had taken up a position, which on further consideration he had found to be untenable, and from which he wished to retreat before the attack on it developed. His difficulty was that he could not see how the relatively small difference in the level of the orifices could affect the approaching stream without postulating something in the nature of a reversed jet, which was only possible if the liquid could sustain tension; but since liquids could not sustain tension a reversed jet was impossible. The postulate was wrong—a reversed jet was not necessary. The same condition of flow would arise if the water was imagined to be annihilated at the orifice. In fact it did not matter where the water went after it reached the orifice so long as it got out of the way. His own diagrams (Figs. 13 and 14),* if completed, supplied the solution. As they stood these diagrams were, he admitted, dishonestly drawn. The stream lines stopped just where they were becoming important. If all the stream lines were filled in and produced, it would be found that a great many of them terminated on the boundary. The stream between two such lines was evidently closed. It received no supply and, therefore, contained only dead water. Taking, for instance, the case of Fig. 13, which represented flow to an orifice at bed level, and imagining the diagram continued on to the right for a long distance, then nearly all the stream lines shown would eventually reach the surface and terminate there

* Page 80.

It was evident that a cover could be put on the channel, fitting close down, and following the curve of the last stream line that reached the surface, and thus shut off contact with all the water above that stream line. Such an imaginary frictionless cover would not in any way interfere with the full discharge reaching the orifice. In fact if the liquid were non-viscous, and if direct stream line motion obtained, the whole of the liquid above the stream line, which terminated on the surface at the head of any reach, would be stationary, and flow would only occur in the streams below that line. In water, however, they were fortunate in having a viscous liquid, and in canals a very turbulent flow and circulating currents, with the result that those closed upper streams were continually being fed from below, but even so their discharge was not likely ever to become so much as it would have otherwise been. Similarly in the case of an orifice at surface level (Fig. 14), all streams terminating on the bed were closed, and would contain only dead water, except in so far as the turbulence and circulating currents of the stream gave them a supply to carry. There would still remain the difference in the total kinetic energy involved in the two cases, which was pointed out in his paper; and this meant that, in the case of a drowned orifice, the sink that was acting was stronger than that which acted in the case of open flow over a crest, and the adjustment of the amount of this kinetic energy would have an important influence on the silt getting power in the channel upstream, because it was the strength of the sink that determined the form of the stream line curves. Accordingly he was now prepared to agree to the importance attaching to the level at which water passed through a regulator across a canal which dealt with the whole supply, but care should be taken in applying this to the case of a distributary head.

Where the influence of an orifice level was exerted only by a tenth or hundredth of a canal's supply, its effect on the silt charge in the canal as a whole, upstream of the distributary head, would not be very appreciable. The influence must very rapidly dissipate itself throughout the whole supply in the canal, because the marginal strip of water, destined for the distributary in which the effect would be generated, had one entire vertical face wholly open to the canal, and any inequality of flow at different levels in this strip would be rapidly neutralised through the direct lateral communication which existed between the marginal stream and the normal stream system of the on-flowing supply. He was now by no means prepared to say, as he did in his paper, that the effect of the orifice level at a distributary head was negligible, but he thought that it might safely be said that its influence was not nearly so important in the case of a distributary head as it was at a regulator across a canal. This brought them back again face to face with the principle of the conservation of matter. That principle forced them to admit that a stream, as it passed a point, could not go on continually augmenting its silt charge at that point without continually excavating a hole, which must go on perpetually deepening, unless some change in the conditions took place. In practice the conditions did change almost immediately. Scour increased the water way and the exposed boundary was thereby removed farther from the stream filaments of high velocity, consequently the velocity gradient became less steep, and the silt getting ability became less and less, till a condition of equilibrium was reached when the water passed away from the point with just the same silt charge as it approached it.

A locality of high silt getting ability in a channel could not possibly be a continual source of augmentation of the silt charge unless there was a continually increasing cavity from which the material was being taken. The converse was also true. When such a continually increasing cavity did not exist, the high silt charge taken into a distributary could not be accounted for by a locality of high silt getting ability just upstream of its head.

There was only one possible way of accounting for the known phenomena, and that was based on the second part of the silt problem, namely the behaviour of silt in the channel after it had been picked up. Mr. Schönemann did not deal with this part of the subject at all, while Mr. Elsden simply denied the existence of cross-circulating currents in a canal. It did not occur to him, when writing his paper, that anyone would deny the existence of cross-circulating currents, any more than it occurred to him to question the validity of the principle of the conversation of matter as Mr. Schönemann had done. He thought that these currents had been a common place of the existence of every canal man. They were so extremely evident. One could see surface floating matter being carried from the side out into the stream, and one could watch the densely silt charged water boiling up along the sides of any canal.

Mr. Bellasis mentioned the currents for a straight channel on pages 163 and 267 of his Hydraulics, treating their existence as an accepted fact, and quoting an investigation of them by

Stearn, published in volume xii of the American Society of Civil Engineers.

The trouble about these currents did not arise from any justifiable doubt as to their existence, but rather from the difficulty of accounting for them. In Appendix B he had put his suggestion regarding their origin very shortly and crudely, but a study of the theory of the gyroscope would convince anyone that if there were any cyclic motion at all about axes at right angles to the direction of flow, then the couples imposed on the axes, by ununiform forward velocity, must cause the precession of the whole cyclic fluid structure in the manner described. It was noteworthy that the couple need not be such as actually to turn the axes: the application of the forces constituting the couple was all that was needed to cause precession, and no work need be done by the couple on the axes. Experiments with a toy gyroscope would show this clearly, while a very simple experiment in a peg tumbler would demonstrate how the principle of the gyroscope worked in a liquid. Having started a vortex in a tumbler of soda-water, tilt it towards you and the tail of the vortex, indicated by the gas bubbles, would fly over to one side while the head of the vortex pressed up against the other side of the glass. Stir the soda again and tilt the glass away from you and the motions of the head and tail of the vortex would be reversed. A little sugar at the bottom of the glass would be tossed up to whichever side the tail of the vortex went, indicating that the movement was a powerful one. The action only took place while the glass was actually in process of being tilted, as only then was the couple continually applied. The experiment was very rough, but was sufficient to indicate what happened.

Before finishing he wished to point out that when Mr. Kennedy was collecting data for his silt diagrams he begged the whole question of silt distribution at distributary heads, because he assumed that all the channels he dealt with had the same silt charge. That meant assuming that Mr. Elsden's ideal condition already existed in fact. They were all now agreed that with distributary heads as at present existing on canals that assumption was very far from true, and accordingly Mr. Kennedy's results seemed to require modification.

Finally he would like to ask Mr. Schönemann to explain more clearly why he labelled Fig. 9* of his paper a "mistaken device," when according to his theory, it was very nearly

* Page 107.

right ? Mr. Schönemann had not made it clear why he considered it wrong to have an undershot gate behind the sill. If the gate were twenty feet downstream of the sill would it still be a "mistaken device"? The advanced sill illustrated in Fig. 9 seemed a logical conclusion of Mr. Schönemann's line of reasoning, and the fact that this class of sill often failed to exclude silt, seemed to be direct evidence that Mr. Schönemann's theory was either unsound or at least incomplete.

MR. HADOW, introducing the third paper on behalf of Mr. Elsden, who was prevented by illness from being present, said that he had not been commissioned by Mr. Elsden to do so, and consequently could not give the Congress the benefit of what his remarks would have been. He was however confident that Mr. Elsden would have said that his paper was far from complete: he had not originally intended it for publication as it stood, and he had meant to amplify or rewrite it in the light of experiments ; but as he had not been able to undertake these, the paper remained incomplete, which was a matter for regret, as it put forward some original ideas.

MR. CARNE opened the discussion on Mr. Schönemann's paper by saying that the author, after discussing the hydraulics of canals, put forward a design for distributary head regulators which presumably he believed fulfilled the functions laid down on the first page of his paper* as being necessary. The design was that of a regulator with a gate rising behind a fixed masonry sill, the idea being to take in only top water from the canal. Admitting that this design fulfilled functions (*a*) and (*c*) what about function (*b*) ? In what way did the design fulfil this function of silt flow regulation ? In actual working the rising sill gate would be raised or lowered for the purpose of regulating the flow of water into the distributary, but that supply would only be drawn from the upper strata of the supply in the canal.

Designers of distributary head regulators aimed at providing means to limit the amount of silt entering a distributary, or in other words to prevent the distributary from taking more than its fair share of silt, or to enable it to take in more silt than it was formerly taking, or to take its share of silt. It was premature to say that one of the functions of a distributary head was to regulate the amount of silt entering a distributary, though this was a function that they would all like to see it capable of performing.

* Page 91.

The design put forward only satisfied a condition that was comparatively seldom attained, *viz.*, more or less unlimited working head, and did not appear to be adapted to fulfil the function of causing the distributary to take its fair share of silt.

In defining a regulator as intended to control the flow of silt laden water* had the author not forgotten that his design was also intended to include the function of silt flow regulation ? and might they not conclude that the author had failed to arrive at a design of head regulator having the much desired function of being able to regulate the flow of silt from the trunk to the branch channel ?

Regarding the author's criticisms of Mr. Kennedy's theories of silt transportation, they surely were never intended to understand that the silt carrying or transporting capacity of a channel depended only on the depth of the supply. In Mr. Kennedy's diagrams, the curves turned backwards at the bottom, noticeably in the $1 \cdot 1\ V_o$ and $1 \cdot 2\ V_o$ curves, where, for a given bed width, there were two limiting depths of supply, each giving the same critical velocity ratio, or in other words the same silt transporting power. Between these two limiting depths the transporting power exceeded that at the limits beyond which the transporting power decreased. Thus it was impossible to indefinitely decrease the supply depth without altering the width, or silting would occur ; as, although, the silt transporting power of the stream varied inversely as some function of the depth, it also varied directly as some function of the velocity, which in turn varied as the square root of the hydraulic mean depth, on the assumption that the slopes were constant. Hence it was obvious that above and below the limiting depths the section became less efficient. It was obviously quite possible to have the condition of a very wide and shallow channel (due to allowing the bed to rise by silting) with a less silt transporting power than the originally designed section.

In the case of a channel silting up as described and illustrated by the author † was it not due to an inefficient section, which silted up each time, after silt clearance, to a section sufficiently economical to transport the silt ? By an efficient section was meant one in which there was a balance between the gain in silt transporting power due to low depth and the loss in velocity due to a reduction in the hydraulic mean depth.

* Page 91.
† Pages 96 and 97.

The cases quoted by the author, particularly that of the scour in connection with the Amipur regulator at the tail of the Jhang Branch of the Lower Chenab Canal, called to mind the case of the scour in the combined branch above the Bowani regulator, which was the head regulators of the Abohar and Bhatinda branches of the Sirhind Canal. This scour began when the diaphragm wall was removed some years ago. The wall was replaced with larger openings, but was again removed early last year, and some karries were kept in the grooves, with the result (as Mr. Colbourne had just informed him), that the combined branch had become silted to a depth of about $1\frac{1}{2}$ feet, while there was a nasty scour in the first mile of the Abohar Branch. On the 10th August three karries were removed, and by November there had been a slight improvement. One more karri was then removed from each bay—leaving three, and sections taken in December showed that the combined branch bed was slightly above designed bed level, while the scour in the Abohar Branch had nearly filled up. The sections taken in January and February showed that the beds of the Abohar Branch and the combined branch were approximately at the designed levels. The Bhatinda Branch levels were also normal. So far during the cold weather there had been no trouble in getting full supply with the Abohar Branch, without topping the feeder gates, and a karri to raise the height of the feeder gates had not been necessary.

With reference to Mr. Gibb's paper he thought that those who were, and had been, in the Lower Chenab Circle would be able to form their own opinions as to the effect Mr. Gibb's valuable investigations had on the design of distributary head regulators. Nowadays no engineer, on open canals, ever followed the printed type plans.

Many distributary head regulators had been rebuilt or remodelled on the open canals on types, which more or less embodied the arrangements of intake with advanced sills, which, he believed, had first been proposed by Mr. Gibb. So far as he was aware the usual design embodied the following :—

(*i*) An advanced sill usually in the same plane as the inner, *i. e.*, the below water slope of the canal, and having the same slope on the canal side.

(*ii*) The upstream canal water wing curved, and its face changing in slope from that of the inner slope of the canal to vertical.

(*iii*) Unsymmetrically cut pier noses to facilitate free entrance of the supply.

(*iv*) The downstream canal water wing wall produced in the line of the abutment and ending off as a profile to the inner slope of the canal below the offtake, which was reduced in bedwidth from this point as necessary on account of the offtake.

(*v*) The height of the advanced sill was usually calculated to give the full supply in the distributary under the condition of minimum working supply in the canal.

When the bed of the distributary was high above the bed of the canal the sill did not need to be raised above the floor level of the regulator. This arrangement of calculating the height of a sill was apparently adopted with the idea that as much silt as possible should be excluded, the intention being that the regulator should always be capable of passing the necessary supply under ordinary working variations of supply level in the canal. Depending, therefore, on the working head available, the silt transport regulation would vary in each design. The idea no doubt was to make sure of being free from silt troubles, forgetting that, if each distributary did not take a fair share of the silt, there was likely to be trouble at some future date towards the tail of the canal.

Turning to Mr. Elsden's paper, he thought that the arrangement of offtake proposed was undoubtedly novel, but one that no doubt others like himself had often wished they could have adopted. This idea of offtake occurred to him years ago when in the Upper Sutlej Inundation Canal Division, particularly for the purpose of replacing distributary heads forming open offtakes at right angles to the canal, where the working head was often the absolute minimum ; there being neither gates nor karries in use to regulate the flow. The only provision for regulation was a wooden platform or bridge across the span or spans and a set of grooves in each span in which karries could be placed.

His idea of the style of head put forward by Mr. Elsden was to avoid loss of head or velocity due to the sudden change in direction of flow in the water on its way from the canal to the distributary. This arrangement would be most useful in cases of inferior working head between a canal and an offtake,