EXCLUSION OF HEAVY SILT FROM CHANNELS BY VANED PITCHING.

By H. W. KING,

Executive Engineer, Lower Chenab Canal.

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Introduction.

The object of this paper is to make known a method, discovered by the author, of excluding heavy silt from channels.

Efforts have been, and are still being made to exclude silt at the heads of canals by means of raised sills, etc.; but though these efforts have, to a large extent, been successful, they have not been entirely so; and engineers, in dealing with the question, have generally accepted the presence of a large quantity of heavy silt in a canal as unavoidable, and have confined themselves to trying to keep this silt in suspension, in which effort Kennedy has been so largely successful.

Even Kennedy's discoveries, however, have not rendered possible the entire removal of the silt difficulty, and much labour and very large sums of money are still spent every year in silt clearance, regrading channels, changing outlets, etc. The proper point at which to attack this problem is the head of a canal, and there endeavouring by some means to exclude from the canal all silt which cannot be carried by even the worst designed minor, or by an average watercourse.

Silting in Branches.

It has long been an accepted axiom that the heavier silt in a channel is carried in the lower layers of water: that the water becomes more and more heavily silt laden towards the bottom, and that the heaviest silt is carried by rolling along the bed itself.

It has also been observed that, where a branch takes off more or less at right angles from its parent channel, especially just above a fall, which is the commonest situation for such channels, the branch takes a larger proportion of silt than the parent carries on, and this often in spite of the raised sills, etc., with which engineers have tried to combat the effect. A

good example is the Bhowani regulator on the Sirhind Canal, where the Bhatinda branch, taking off at right angles, silts heavily, while the direct Abohar channel tends to scour. Many engineers (the author included) have tried to cure this, but in vain.

There are three reasons for this silting of branches, of which the first and by far the most potent is that the offtaking channel draws its supply from water which has a certain velocity and momentum, and it is therefore obvious that the water adjacent to the offtake, which has the least momentum, will be drawn into the channel more readily than that with a higher momentum ; consequently the slow-moving water at the bottom, which contains most of the silt, is drawn into the channel, while the surface water, which has a higher velocity, is carried by its momentum along the direct channel. It follows from this that if the bed of the parent channel be thoroughly roughened, say with cellular pitching, upstream of the branch, so as to cause the heavy silt to be thrown up towards the surface, the offtaking channel would take in a proportion of silt more approaching its proper share ; but to ensure a fair distribution of silt, the roughening of the bed would have to be very severe.

The second reason can in the writer's opinion have only a slight effect in this direction, but nevertheless it is of considerable interest. It is explained by Professor James Thompson, in a note on the erosion of river banks at bends, where he shews that silt and debris travel towards the concave side of a bend in a stream. The third reason is the influence of the cross-currents towards the edges of a stream, described by Stearns.

The object then is to discover a means, either of causing only the surface water to be drawn off by an offtaking channel, or to remove the more heavily silt-laden water so far from the head of the offtaking channel, that none of it will enter, and both these effects are achieved by the method described below.

Silt Carrying Capacity depends on Roughness of Bed.

Mr. Stearns gives it as his belief that bodies of water are thrown upwards towards the surface of a stream by projections in the bed of the channel, while Dupuit's theory is that silt is carried in suspension as a result of the eddies caused by the difference of velocity of two contiguous horizontal laminae of water, and that the greater the difference in velocity, the greater the silt-carrying power of the stream. This really comes to admitting that silt-carrying power is due to roughnesses in

the bed, as asserted by Stearns ; for roughness in the bed would of course increase the difference in velocity of two contiguous horizontal laminae. It may thus be taken then as an established fact that the silt carrying capacity of water depends on the roughness of the bed.

From this it follows that if the bed of a channel be made smooth (say, pitched), silt, which would otherwise have been carried in suspension, will deposit, or will travel in lower layers of water than it would otherwise have done. Of this artificially deposited silt, the heaviest grains will roll along the bed in waves (provided the velocity in the channel is sufficient to move them,) while the next lighter grade of silt will move along with a saltatory motion, the height to which each particle is thrown at each leap depending on the roughness of the bed. Still lighter silt will be carried entirely in suspension, but also probably with a more or less saltatory motion, being alternately thrown up into the region free from upward force, and falling till it again comes under the influence of an upward throw. A smooth and level bed will facilitate the rolling onward of the heaviest silt, while the fact that it is pitched will prevent the formation of the deeper ridges and holes formed in a natural bed, so that, though the deposited silt will in some degree again roughen the bed, the roughness will not be as great as in the natural bed. Moreover this partial roughening will probably in some degree be counterbalanced by the greater velocity which the bottom layer of water would have, owing to the partial absence of roughness. This sounds like the chasing of one's own tail, but observation of pitched discharge runs has shewn that the cases are not entirely similar, while the re-roughening of the bed by deposited silt can be overcome by contracting the channel slightly in the lined reach, so as to induce a sufficient velocity to roll the heavier silt along.

Thus by putting a smooth lining into a channel, all heavy silt will be carried in a lower layer of water than in an unlined channel, and it now remains to deal with this silt.

Experiment with Guide Vanes.

After several experiments and failures the following experiment was carried out :—

A reach of two hundred feet of distributary channel was pitched, and at the downstream end ribs or guide vanes of 1/16th inch sheet iron, about eight inches high, were put in, as shown in Plate No. 1 ; the object being to cause the silt-laden water

to flow from right to left. At the downstream end of these ribs two exactly similar outlets were constructed at bed level in the distributary, each six inches square. Each outlet led to a long and deep pitched tank, the tanks also being exactly the same and similarly situated, and each having such an outfall that the working head of the outlets should be the same.

Particulars of the depth, width, etc., of the distributary and of the guide vanes are shown on the sketch. The two outlets were opened together, allowed to run for two days, and then closed at the same time. They were not allowed to run when the supply in the distributary was low.

The result was remarkable. The surface water, as soon as it arrived over the vanes, flowed rapidly across the distributary from left to right, and the effect of the vanes was to cause the water to rotate in the same way as a bullet in a rifle, the result of course being that the clean surface water fed the right hand and the heavily silt laden water the left hand outlet. (Theoretically there should have been enough outlets on the left to draw off all the silt-laden water as it arrived at the side, and enough on the other side to take the clear water, and in the absence of these, the silt-laden water was thrown with considerable velocity against the left bank, then up to the surface, and finally some of it across the stream again on the surface, but the length of the vaned reach was not great enough to allow the silt-laden water to get to the right hand outlet again, the silt having been carried downstream past the outlet by the time it arrived across the channel.)

When the tanks were dry the deposit was examined. In the left hand tank was a large heap of coarse silt, all deposited just in front of the outlet, while in the rest of the tank there was no heavy silt, but only about two inches of fine impalpable clay, practically evenly spread over the whole bed of the tank. In the right tank there was no silt heap in front of the outlet, but the whole bed of the tank, including the part in front of the outlet, was practically level and had on it a deposit of about two inches of fine impalpable mud similar to that in the other tank, being much finer than that found deposited in the beds of the smallest distributaries; the coarsest of it being so fine in fact that the grains were scarcely discernible.

It was found that the upstream ends of the vanes, being vertical, collected jungle, but this was overcome in later trials by not ending the ribs abruptly at their upstream ends, but

cutting them off at a gentle slope (*vide* Plate II) so that grass, sticks and rubbish coming against them would have no hold. When anything catches in a vane the effect is at once clearly noticeable by the boiling effect at the surface.

The circumstances of the above experiment were as unfavourable for the separation of silt as possible, and the result shows that all depositing silt, or as much as may be desired, can be excluded from a channel by the application of silt vanes.

There are two facts which will at once occur to one in this connection ; namely, that if silt be excluded from an off-taking channel it must continue in the parent channel, and that if too much silt be excluded from a channel, scour will result, probably with disastrous results, undermining masonry works, etc. The writer had thought these two facts too obvious to be put forward as criticism, even by one who had not specially considered the subject ; he found, however, that he was wrong ; and they are therefore mentioned here to save time. To comment on them is scarcely necessary.

Length of Flume.

To determine the length of flume required, it is necessary first to decide what grade of silt is to be excluded from the channel. Assume, as the limit, silt which falls through still water at the rate of 0·1 ft. per second, anything falling more rapidly being excluded. A flume must be of such a length that all such particles will have had sufficient time, before arriving at the vanes, to fall to the bottom. It is now necessary to make an assumption which, though it may not be accurate, will err on the side of safety ; namely, that it would take a particle the same time to travel from the bottom to the surface, as to fall back to the bottom if the propelling force were removed. (Neglecting the friction of the air, a projectile takes the same time to reach its highest point as it does to fall back to the level it started from.) A particle, on just entering a flume, may be projected upwards with sufficient velocity to reach the surface when it must have time to fall back to the bottom. If the depth of a flume be d feet, the particle will take $\frac{2\,d}{0{\cdot}1}$ seconds (*vide* above assumption) from the time of leaving the bed to fall to the bottom again. If the average velocity in the flume be V *f. s.*, the particle will have travelled $\frac{2\,d\,V}{0{\cdot}1}$ feet by the time it falls and this gives the length of flume necessary.

In practice, two-thirds or even one half the length of flume thus calculated will be found sufficient, probably owing to the factor of safety in our assumption.

Curvature of Vanes.

The curvature will have to be such that the obstruction to the flow caused by each vane will not be sufficient to cause the silt, which is to be excluded, to jump the vane, but our knowledge of the lifting effect of obstructions in the bed of a channel does not go far enough to enable us to calculate, with accuracy, the limiting radius necessary for a given velocity and grade of silt. Let u be the velocity with which the grade of silt to be excluded falls through still water. We must assume for want of definite knowledge that if a body of water is thrown upwards from the bottom of a channel, with a vertical velocity x, a particle of silt of the particular grade under consideration, contained in that body of water, will travel upwards with a vertical velocity $x-u$. This may be an unwarranted assumption, and it can only be settled by experiment, if at all.

It is then required to find the minimum curvature of vane, which will cause the water flowing round it to exercise sufficient pressure to throw a body of water upwards with such a velocity x, that an initial velocity of $(x-u)$ will carry a particle of heavy silt from the bed to a height not greater than the height of a vane. The author in calculating this obtained a result which was proved by experiment to be wrong : so he leaves it. By actual experiment it was found that a minimum radius of twenty-five feet was ample in a channel of 2·5 feet depth, and with the average velocity of water obtaining in our distributaries, the vanes being raised 0·65 feet above the pitching was sufficient to lead away all the silt likely to deposit in an average distributary.

There must be no trace of any boiling effect caused by water being forced up to the surface, anywhere above the vanes, as this would show that the curvature was too sharp. There should also be no boiling effect over the pitched flume upstream of the vanes, as this could only be caused by some obstruction.

Effect of Vanes.

The effect of silt vanes in a channel is very violent. Downstream of the vanes, if the bed and banks of the channel are unprotected by pitching, the lateral velocity of the surface water, together with the fact that the water is comparatively free of silt, has a very strong scouring effect on the side away

from which the vanes are turned ; and the heavy silt, having all been led to the other side of the channel, will, unless corrective measures are taken, cause a large silt heap to form on that side. It was found necessary, therefore, to extend the pitched flume for some distance downstream of the guide vanes, and to construct, downstream of the main guide vanes, another set of correction vanes to lead the silt back to its original place, or distribute it evenly over the bed (Plate II). Below these correction vanes again it may be necessary in some cases to have a set of straight guide walls, to stop lateral movement of the water (Plate II), and to perfect the design, the last ten or fifteen feet of pitching downstream of these guide walls should be roughened, or cellular, so as to throw the heavy silt up into the water again and give it a fair start.

The design will depend largely on whether or not there is a fall just downstream of the offtaking channel. If there is a good fall, it will have a mixing effect on the water and silt, and in some cases correction vanes will not be necessary. The plates attached to the paper give some designs which explain themselves and require no further description.

This system cannot be applied extensively on distributing channels for fear of silting up other channels, but there are many small distributaries, obstinate silters, from which, if all silt were excluded and retained in the parent channel, no harm would result, and the author has applied the system in five or six cases with success.

The chief thing to guard against in putting in these vanes is over-doing it. Vanes eight inches high, with a minimum curvature of twenty-five or even twenty feet, will be quite high enough for the average distributary of two and a half or three feet depth. If the vanes were made higher, the effect would be more violent, and scour would result in the offtaking channel.

It is advisable to construct the pitched flume at least six inches above the average silted level of the bed in channels of about two and a half feet depth, in order to make certain that the curved channels between the vanes will not get silted up. In some cases this is not enough and the channel has also to be contracted. The sides of the channel at and below the vanes must be pitched as well as the bed, to protect them against the powerful scouring action of the laterally moving water.

Conclusion.

If confined to distributaries the system described will have a limited value, but as already remarked, the proper point at which to tackle silt is the head of a canal, and the great question that presents itself in this connection is what would happen if the heavy silt at present entering a canal were sent down the undersluice channel. It has been suggested that the effect on the undersluice channel would be negligible, but the author thinks it might be considerable, and that special steps might have to be taken to cause the extra silt to be carried on down the river. The vanes principle would probably be too expensive for application to silting tanks, but for other purposes it might be useful in certain rivers.

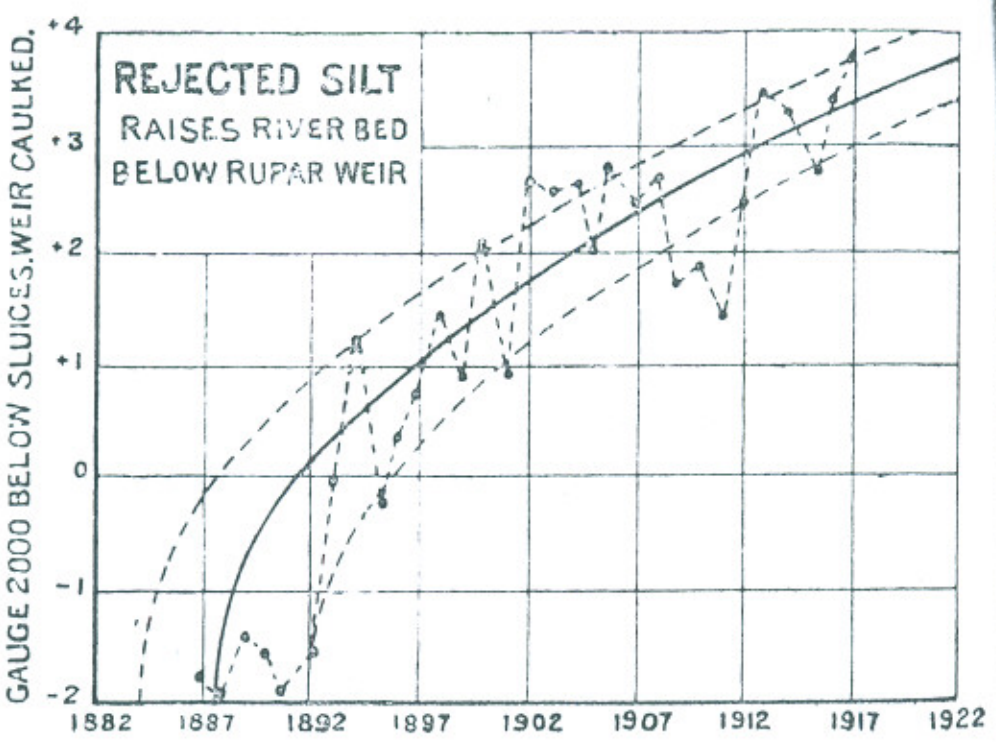
There are two corollaries to the arrangement discussed above, both methods of *regulating* the quantity of silt entering a channel. In neither are vanes necessary, and in the case of a headwork, or an inundation canal, they promise advantages over the vanes. The writer has not had the opportunity of testing them, but they will doubtless suggest themselves to any one who desires to continue the investigation.

DISCUSSION.

MR. KING, in introducing his paper, said that he had proved since writing it that the length of flume suggested in the paper and shown in the diagrams was far greater than was necessary in practice. The length of the flume depended on the depth of the channel, but it could not be calculated in the way suggested. In practice, a very short flume was found sufficient.

MR. NICHOLSON pointed out that, although the author's method of excluding silt appeared to have given satisfactory results on the particular distributary to which it had been applied, the problem required fuller investigation. So far as he knew there was trouble with silt on the whole of the Jhang branch, and if Mr. King's method were adopted on silting distributaries higher up, the silt would reach the Jhang Division in such quantities that it would not be possible to deal with it, and Mr. King would be the first officer to object to his cure for silting distributaries being carried out in the higher reaches. The cure proposed was like clearing up one's own compound by throwing the rubbish into the next, and such procedure would not benefit the community. The distributary head was the last place to deal with silt ; it should be eliminated from the water taken into the canal at the head ; but he wished to lay stress on the fact that eliminating silt from the water coming into the canal did not end all trouble. The silt rejected at the canal head remained in the river, raising the bed below the weir, and thereby lessened the effectiveness of the weir in controlling the river. He had prepared a diagram for the Sutlej* shewing the lowest water surface on the gauge two thousand feet below Rupar weir every year since the Sirhind Canal was opened. The water surface was recorded when the weir was caulked, as this gave the best indication of the river bed level, and an inspection of the diagram put beyond doubt that the river bed was rising in accordance with some physical law. The two dotted curves starting from 1884, when the canal was opened, and 1892, the last year of the acute silt trouble in the canal, embraced nearly all the points plotted. Objection might be taken to the points falling low in 1909-11, but these were accounted for by the fact that silt trouble had restarted in the canal owing to unintelligent regulation. The full curve in the diagram was a parabola and the rise in the river bed was equal to the square root of the number of years from 1887. Thus in 1912, after twenty-five years, the river bed had risen five feet and it would go on rising.

* See next page.



MR. E. S. LINDLEY noted that Mr. King had laid emphasis on the fact that the point where the silt trouble should be combated was at the headworks of a canal. Some past papers on the problem gave the impression that their writers considered it necessary only to distribute the silt in the canal as equally as possible and to pass it on to the water-courses; while it had also been stated that the total exclusion of silt was not desirable on account of its fertilising value, but he thought that this view was erroneous, as the silt that had any fertilising value was too fine to be excluded by any measure that was likely to be adopted. The silt which gave trouble in channels had no fertilising value, and could be greatly reduced by the application of knowledge already available The vaned pitching had been put forward merely as an idea, but Mr. King had not mentioned that vanes had been working for a year in several places, nor had the results of their working been given. He therefore put forward such figures as he had been able to obtain, to exhibit the conditions exising before the vanes were instituted as compared with the present state of affairs. He had made hydraulic surveys of the channels under discussion, and averaged the results obtained to compare them with similar surveys made before the vanes were constructed, with the re-

sults tabulated below. It should be noted however that no silt clearances had been made :—

Details.	Sultan Pakhra		Feeder		Mochiwala	
	1917	1918	1917	1918	1917	1918
Surface width between berms	31·5	31 5	30 3	30·3	17·1	17·1
Mean depth of reach in feet...	3·26	2·98	3·33	2·99	1·74	1·94
Discharge in cusecs ...	193	182	196	170	55	59
Mean velocity in feet per second	1·97	2·03	2·05	1·97	1·95	1·59
Mean slope per thousand ...	0·250	0·225	0·165	0·239	0·400	0·284
Value of Kutter's N ...	0·0230	0·0203	0·0183	0·0214	0·0192	0·0209
Reduction of gauge for equal supply	...	0·40	...	rise 80	...	0·40
Critical velocity ratio ...	1·10	1·19	1·13	1·16	1·60	1·24
Corrected critical velocity ratio	1·25	...	0·97	...	1·47	...
Silt index of head ...	...	2·71	...	9·47	...	9·80
Direction of vanes ...	<—from —>		<— to —>		<—from—>	

Scrutinising these figures, it was noticed that in the Sultan Pakhra, which was said to be getting less silt, the critical velocity ratio had risen appreciably ; if it were assumed that the higher value of Kutter's N for 1917 showed that the discharge was wrong, and if a correction were applied accordingly, the critical velocity ratio only rose to 1·25 as compared with 1·19 at present, which was no great difference. The Feeder was said to be getting more silt, but the critical velocity ratio had gone up very little, and if a similar correction were applied for Kutter's N as before, the critical velocity ratio went down to 0·97 as compared with 1·16 at present, which was a considerable difference, though some allowance must be made for the three outlets in the reach in question having been converted from the ordinary type into Kennedy guage outlets.

On the Mochiwala, the critical velocity ratio had been reduced from 1·6 to 1·24, and if a correction were applied

as before, the critical velocity ratio became 1·47, still leaving a large reduction, though it was impossible to say how much of this was due to the vanes and how much to the remodelling of the head, which had been carried out since the first observations. He also called attention to the very slight difference between the critical velocity ratio of the Feeder and of the Sultan Pakhra, whilst the latter had a silt index three-and a half times greater than the former. In conclusion, he thought that Mr. King had had an opportunity of supporting his ideas with facts and figures, but he had omitted to do so, while such facts and figures as he himself had been able to collect were hardly convincing.

MR. QUINN YOUNG was glad to see that Mr. King had gone to the bottom of the subject without theorising. Many theories had been advanced for silt exclusion from channels and some of them had by chance been successful, but he doubted whether Mr. King was correct in saying that a pitched channel was smoother than a natural or silted bed. It appeared to him that a sandy bed offered less resistance to the flow of water, as long as it was level, which it would be for the short lengths under consideration. He agreed with Mr. King that the exclusion of silt should be made at the head of the canal and he offered, as a solution to this problem, the suggestion that immense silting reaches should be taken up in swampy or poor ground, along the main lines, to absorb any undesirable silt entering at the head.

MR. KING pointed out, in reply to Mr. Nicholson, that he had stated on page 65 of his paper that there were two points which he had thought too obvious to be brought forward by any one as criticisms, one being that if silt were excluded from an off-taking channel it must continue in the parent channel. It was also emphasized that the proposed system could not be freely used in distributaries, but that the exclusion of silt must be at the head of a canal. Mr. Nicholson's diagram was very interesting and provided an answer to the question raised at the end of his paper. Regarding Mr. Lindley's remarks, he denied that either the case of the Feeder or the Sultan Pakhra was a fair test of the vanes, which in these cases had not been made as suggested in his paper. The depth of the parent channel was about five feet, if he remembered aright, while the height of vanes was less than half a foot, so that they could only be expected to have

the slightest effect, and were only designed with this expectation. The silting of the Sultan Pakhra had been very slight, and ceased entirely when the vanes were put in.

The Mochiwala was a better test, but had been vitiated by the fact that the head regulator had also been altered; there had been some silting, but slight scour began after the vanes had been put in. On the other hand the Dhaya minor had silted very heavily, but scoured so severely after the vanes had been put in that some of them had to be taken out again. None of these should be quoted as test cases. Regarding Mr. Quinn Young's remarks as to the smoothness of the bed, he thought it very probable that the vanes would be effective even without a flume at all. In conclusion, the diagrams attached to his paper were far more extravagant than was necessary. The silting of a minor of say twenty cusecs could be cured for about Rs. 300 or Rs. 400 ; and of a large distributary, like the Pauliani, taking off the Lower Gugera branch, for about Rs. 800, at the rates now obtaining on the Lower Chenab Canal. The investigation was still in its initial stages, but the potency of the vanes had been proved, although more detailed information was required.