PAPER NO. 211.

SILT EXCLUDERS

By

F. F. HAIGH, B.Sc., B.E., A.M.I.C.E., I.S.E.

1. Origin of the Silt Excluders.

The idea of the silt excluder must be credited to the late Mr. H. V. Elsden, whose paper, (I. B. Paper No. 25) published in 1922, first brought the idea of silt regulators before the Punjab Engineers. The basic principle on which silt excluders are designed lies in the fact that in a flowing stream carrying silt in suspension, the concentration of silt in the lower layers is greater than in the upper ones. Consequently if we can escape the lower water without interfering with the silt distribution, the water remaining will have less silt in it per unit volume, than the water upstream of the escape.

2. Elsden's proposals.

Elsden's design for effecting this, comprised a regulator divided into two portions by means of a horizontal diaphragm over which the upper water passed into the canal while the heavily silt laden lower water was passed through tunnels to waste. With modification in detail this form of construction is found in all excluders constructed to date.

Elsden also advanced the idea that the amount of silt entering the canal might be regulated by varying the supply passing through the lower tunnels. He also suggested the need of a hinged flap at the upper end of the diaphragm, in order that the line of separation of the two streams might be varied to permit the separation to take place without disturbance of the approaching water.

3. Proposals for Khanki.

To the great loss of the Engineering profession, Elsden died shortly after publishing this paper and for many years his ideas remained untested in practice. They were not lost sight of, however; Messrs. King and Oram prepared a very elaborate design for an excluder for the Headworks of the Lower Chenab Canal at Khanki, about 1926, which was based on Elsden's principles. The chief feature of this design was that the diaphragm was to cover half the undersluice pocket and a paved approach channel was to be provided.

A smooth approach channel is an important feature of silt excluder design. Elsden first pointed out the advantage to be secured by this, though the idea of paving the channel appears to have originated with King. Its object is of course to permit the silt to settle more effectively and hence to increase the efficiency of the exclusion.

Mr. King's design was not sanctioned by Government on account of its heavy cost (estimated at about 13 lacs) which was considered to be too great for an untried device.

4. The Khanki excluder.

Excessive silt continued to enter the Lower Chenab Canal and the problem of its exclusion continued to occupy the local officers. It was not until 1934, however, that a design acceptable to authority was produced, for which the late Mr. H. W. Nicholson, C. I. E. was responsible. In this design, illustrated in figure 1 the diaphragm is confined to the triangle between the face of the regulator and the first two bays of the undersluices. The escapage passes through tunnels parallel to the face of the regulator and is controlled by the undersluice gates.

5. Development on the Upper Jhelum Canal.

The construction of the first excluder at Khanki was followed by rapid development on the Upper Jhelum Canal, where Mr. Crump designed and built three extractors and two excluders. The distinction between an extractor and an excluder, it may be noted, is that the latter is at the head of the canal, and consequently excludes a proportion of the silt, while the former being placed at some distance down the canal extracts or ejects silt which has entered the canal.

6. Upper Jhelum Canal Extractors.

In the case of the extractors, which are situated at Kasba, Chak Sikandar and Dumbiwala, use was made of the cross drainage culverts, which are numerous on this canal. The escapage discharge was kept small and the diaphragm placed in close proximity to the bed. After separation from the canal supply the escapage was led through orifices in the culvert roofs to the culvert barrel and hence discharged back to the river *via* the culvert outfalls. In two cases the escapage discharge was regulated by individual valves on the roof orifices. In one case a portion of the culvert barrel was converted into a duct serving all the orifices, and the escapage is regulated by a single gate at its downstream end.

7. Upper Jhelum Canal Excluders.

The excluders which are situated on the Bhong and Jaba level crossings and exclude the torrent silt from the canal, follow the Khanki type more closely, but considerably more care is taken in the design of the tunnels and their orifices to secure uniformity of velocity of the escapage across the canal at the line of separation.

8. Madhopur River conditions.

Simultaneously with the works on the Upper Jhelum Canal an extractor was built at Madhopur on the Salampur Feeder of the Upper Bari Doab Canal. At the Headworks of the Upper Bari Doab Canal at Madhopur, of course, the River Ravi has a boulder bed and consequently the grade of silt entering the canal is very heavy. Prior to the remodelling of the regulator in 1925, boulders of considerable size used to enter the canal and the remodelling, which mainly consisted of raising the crest, only reduced the size of the material entering to three or four inch shingle. Again, the Ravi during the flood season carries a very large quantity of drift-wood. Conditions at Madhopur are, therefore, much more difficult from the point of view of excluder design than in the case of Lower Chenab and the Upper Jhelum. An excluder on the head was, and I think justly, considered impracticable in view of the danger of the tunnels being blocked by drift-wood. Recently experiments have shown that the construction of a cantilever slab at cill level will probably effect a considerable reduction in shingle entry, and this is, I believe, to be constructed. There is little doubt, however, that the grade of silt entering the canal will still remain very coarse.

9. Madhopur Canal conditions.

Shortly below the head the canal bifurcates into the Salampur Feeder and the Main Line, and it is not possible to obtain an adequate outfall for the escapage to the river from above the bifurcation. It was proposed, therefore, to construct an extractor on the Main Line head, escaping into the Feeder, and to have a second extractor on the Feeder, which would discharge the Main Line escapage together with the heavy silt of the Feeder's own water. The excluder which has been built at Madhopur, is the latter part of this scheme, it being intended to build the Main Line excluder at a later date. In the meantime, however, it has been decided to build the Ravi Beas link for supplementing the supply of the Sutlej Valley Canals. The water intended for this purpose will be passed down the Main Line for about two miles and then escaped *via* an artificial outfall to the Beas. It is now proposed, therefore, to use this outfall for the escapage of an extractor to be built at the head of the link, which will control the silt entering the Main Line.

10. The Salampur Extractor.

The design of the Salampur extractor follows generally the Upper Jhelum excluders. The diaphragm is, however, placed at a very low level and the velocity distribution at entrance is equalized by the multiple entrances provided to each tunnel. The tunnels themselves are of the same section and of different lengths. Hence they must draw more water from the right side than from the left.

11. Dadupur Excluder.

The only other excluder constructed in the Punjab, is that at Dadupur on the Western Jamna Canal, completed in 1936 and shown on plates III & IV. This is situated above the canal regulator, at the level crossing of the combined Somb and Pathrala torrents. Special features of the design are :—

(*a*) As the regulator is considerably set back from the torrent bank, it was possible to secure a straight approach channel about 500 feet long.

(*b*) Correct velocity distribution is secured by the use of curved vanes in the tunnel entrance, a method which was suggested by Mr. Crump and is claimed to be cheaper than the 'fan design', previously used.

(*c*) The head available for escapage being small, particular care was taken in streamlining the entrances and exits. The escapage is designed for a minimum head of 2 feet.

12. Design of excluders.

Having thus briefly narrated the history of silt excluders in the Province and described the works actually constructed, we will now consider the various points which have to be considered in their design.

13. Approach Channel.

The first point to be dealt with is the approach conditions. Undoubtedly the object should be to provide a long straight approach channel, in which the silt can settle into the lower layers of the water, and thus increase the efficiency of the extraction. Anything after the nature of a curve, which will displace the silt concentration to the side of the channel as well as reduce it, or any obstruction on the sides or bed which will set up turbulence and hence destroy the bed concentration, is to be avoided.

The great advantage that an extractor has over an excluder is that this approach channel can generally be secured without difficulty in the case of the former, while in the case of the latter it is usually necessary to turn the water through a right angle bend before separation is effected and in any case, the approach channel, which consists of a natural river bed, will probably have curves in it and will certainly have very irregular boundaries.

King proposed in his design for an excluder at Khanki to line the approach channel as he considered that this would improve the silt concentration at the bottom of the channel. That this would be the case is doubtful, however. Recent observations of silt intensities at different depths in lined and unlined sections of the Bikaner canal show that the concentration in the lower layers is greater in the case of the unlined channel. This is, of course, to be expected as the velocity in the lined channel is greater. It appears, however, that the best distribution can only be obtained when some of the silt is rolling along the bed and with this condition it would be immaterial whether the bed was lined or not. It is possible, however, that a narrow deep section would have a greater efficiency than a shallow wider one. The approach channel should of course be designed with the flattest slope which will suffice to carry the heaviest grade of silt, likely to approach the work.

The approach channel has to carry the escapage discharge as well as the canal supply and consequently is more expensive than the normal channel. For economical design, it is necessary therefore to keep it as short as possible and research is necessary to determine the minimum length required to produce normal distribution from any work by which turbulence has been created. At Dadupur, observations 700 feet below the rapid, showed a very considerable concentration in the lower layers, but whether this was normal distribution or not, was not determined. The length would of course, vary with discharge and silt grade, but probably 1000 feet would suffice for a 6000-cusec channel.

14. Proportion of escapage to canal supply.

The efficiency of an excluder may be defined as the reduction per unit of the silt intensity in the canal supply when compared with that of the water approaching the work. This, though the only practical standard, is a false criterion. The true measure of the efficiency of an excluder is unity minus the ratio of the silt entering the canal to that which would enter were the excluder not working. The point about this distinction is that the addition of the escapage discharge to the canal discharge increases the silt approaching the canal and increases it in a proportion greater than that of the discharge. It has also been demonstrated by Crump on the Upper Jhelum Canal that as might be expected from the general form of the curve of silt distribution with depth, that an increase of the escapage discharge is always accompanied by a marked reduction in its intensity. We must not therefore blindly accept the idea that the greater the escapage the greater the efficiency. Research is necessary to determine what is the optimum proportion, but in the meantime, I would work to a fairly low figure. Inspection of any silt distribution curve will show that there is a very heavy concentration near the bed in normal flow and I would suggest a figure of 20 per cent as reasonable.

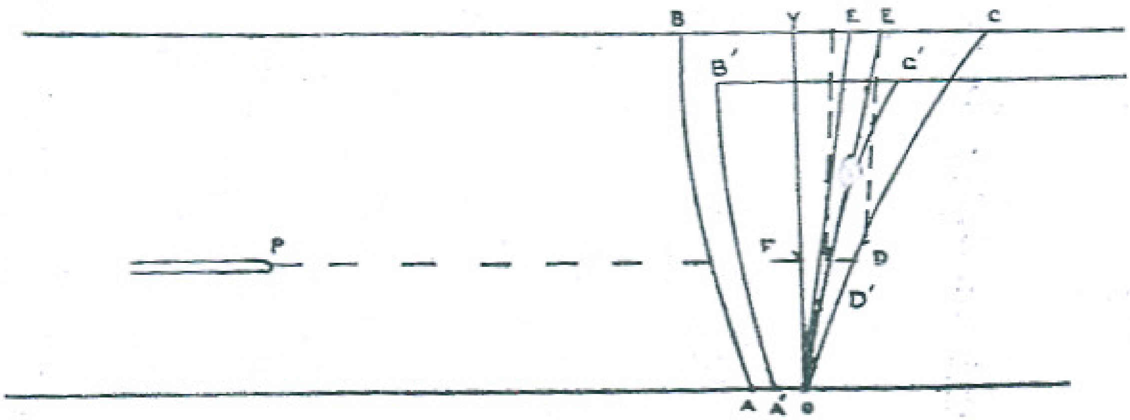
Actual procedure is as below :—

	Canal	*Escapage*	*Per cent*
Bhong	8000	1260	15·8
Jaba	8000	1500	18·8
Kasba	8000	200	2·5
Chak Sikander	8000	235	2·9
Dumbiwala	8000	108	1·3
Salampur	1800	700	39·0
Dadupur	6400	1400	22·0
Khanki	12000	4000	33·0

15. Separation of escapage from canal supply.

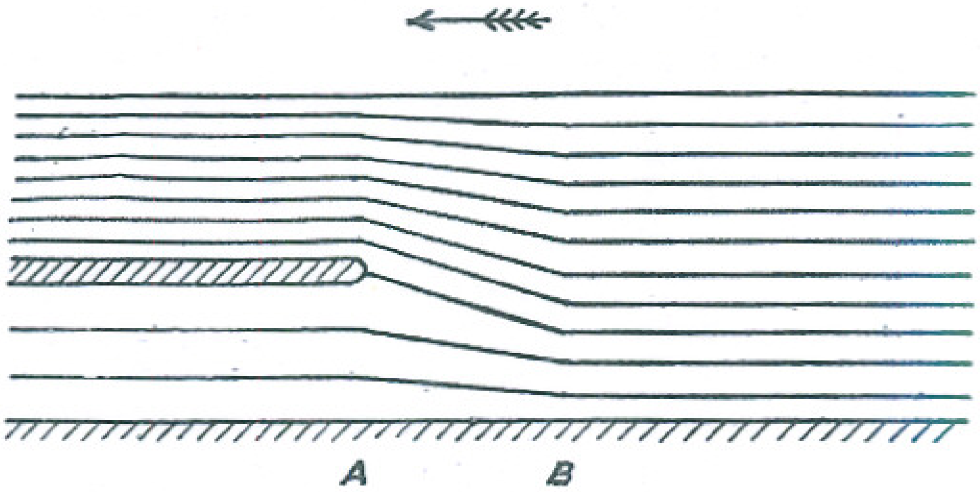
The separation of the escapage water from the canal supply at the edge of the diaphragm should obviously be arranged without disturbing the silt distribution. It is easy enough to arrange this for fixed canal and escapage discharges by placing the diaphragm at a height such that it divides the normal stream into the correct proportion. In practice, however, it is always necessary to vary both the canal supply and the escapage and if the height of the diaphragm is fixed it will generally not suit the proportions of the two.

The point may perhaps be made clearer by means of a diagram.



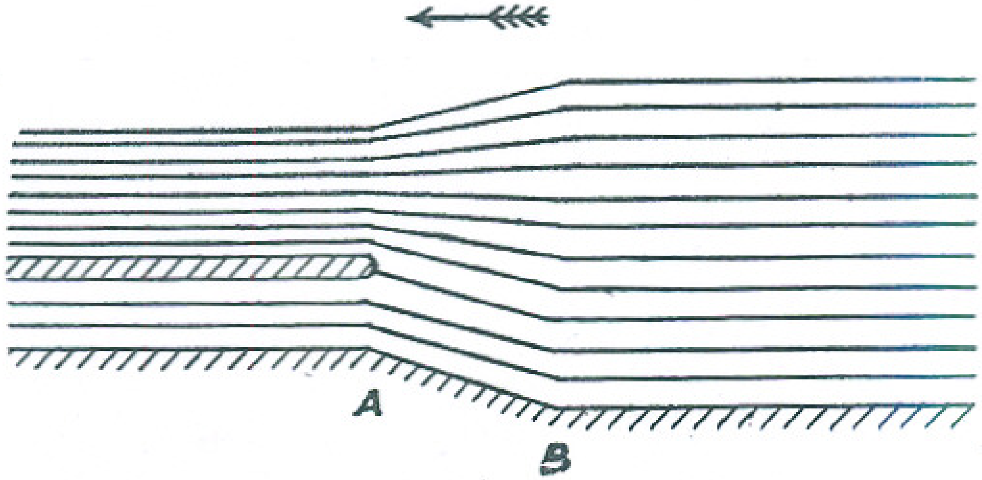
In this the line *AB* referred to the axis *OY* represents the velocity distribution for full supply conditions while *OC* represents the integrated discharge on a vertical. *YC* will be the total discharge and if

YE is escapage, and *EC* the canal supply, the diaphragm must be placed at a height *OF* above the bed if the flow of the stream is not to be disturbed. With any small supply which is diagrammatically represented by the figure *A′ B′ C′ O*, the position of the diaphragm will only be correct if the escapage is *YE′*. In this case as for full supply conditions the stream lines will be horizontal. If, however, it is required to run the canal supply full, while sufficient water is not available for the discharge escapage or if the escapage is run full when canal supply is low we shall have stream lines somewhat as below :—



In the region *AB* there may be a certain amount of turbulence set up which will cause a less favourable silt distribution. The question is, is this disturbance serious? That Elsden thought it would be, is shown by his proposal to have the height of the edge of the diaphragm variable. In practice this device has not been made use of and little attention has been paid to the point in the design of the Jaba and Salampur works. Personally, I doubt whether disturbance from this cause has any considerable effect. The point could easily be determined by model experiments in a glass flume and might well be done.

A device, which should minimize disturbance resulting from this cause, is to contract the stream in the reach *AB*; thus



This device is based on the principle that divergent flow is always associated with turbulence, while the reverse is the case for converging flow.

16. Tunnel entrances.

For economy and also to avoid any danger of silting, the velocity in the tunnels must be high. We have therefore to transform the comparatively low velocity of the escapage at separation to the high tunnel velocity in the entrances. This must be done without allowing the draw of the tunnels to affect the velocity distribution upstream of separation and in certain cases when escapage head is valuable a gentle transformation is necessary to avoid loss. The former point can always be secured by placing the entrances a sufficient distance downstream from the edge of the diaphragm, but this may involve an expensive cantilevered slab.

The methods by which this has been otherwise secured in various designs is shown in plates II and III.

The Khanki design is distinctly bad from this point of view. The draw of the tunnel must disturb the velocity distribution upstream of the point of separation resulting in a certain amount of top water being drawn into the tunnels, and a corresponding amount of bottom water entering the canal.

In the case of the Kasba and Chak Sikandar designs, the distribution is effected largely by the number of tunnels.

The various types of fan shaped approaches that have been used on the Upper Jhelum Canal and at Madhopur are shown in plates II and III, figs. 1, 4 and 5. The vane design used at Dadupur is shown in plate III, fig. 2.

17. Tunnel Design.

The tunnels themselves must be arranged to evacuate the escapage at a high velocity, not less than 10 ft. per second, say. They must also provide control of the discharge so that the same velocity is secured at the entrance to each tunnel. This may be done either by keeping the same tunnel dimensions and varying the width of canal served by each tunnel, or by keeping the widths served and hence the discharge the same, and varying the tunnel sectional dimensions to secure the same discharge with the varying tunnel lengths. The loss of head in each tunnel may be calculated by Manning's formula.

At Jaba, the widths served and the tunnel dimensions are the same and the discharges are equalized by a varying degree of contraction at the tunnel exits.

At Dadupur, the discharge of each tunnel is the same and the tunnel dimensions are varied. There is a control weir at the end of each tunnel, the crest levels of which are varied to suit variations in width.

At Khanki and Madhopur there appears to be no device for equalizing the tunnel discharges.

The tunnel roof should be designed to take the full water pressure above it with the maximum pressure which may occur inside it, assuming the entrance to be blocked. If the tunnels act as a weir for the canal supply, the possibility of uplift occurring with the tunnels closed at the downstream end, and a velocity depression over the roof should be studied.

The escapage if less than full supply is regulated by gates on the down-stream end of the tunnel. At Madhopur a surge chamber is provided at the down-stream end of the tunnels which serves to obviate any danger of water hammer. This arrangement also permits the regulating gates to be placed within the chamber and enables grooves, with only one face machined, to be used. At Dadupur, the gates are placed on the outer ends of the tunnels and the grooves are machined on both faces, the gates closing against the upstream face.

At Khanki, Bhong, and Jaba the existing undersluice gates were used to control the tunnel discharge.

18. Canal Flume.

The crest of the canal flume cannot be below the diaphragm level but may be above it. Also by varying the section of the canal the diaphragm level may be varied over a large range. The design of the canal flume will therefore depend largely on local conditions. At Dadupur where the head into the canal was ample and adequate protection against erosion downstream existed, the crest was placed as high as possible in order to reduce the cost of deep wet foundations. At Bhong and Jaba the work was built on an existing floor which probably controlled its level. At Madhopur, however, the crest is actually below the downstream bed evel and the conditions for approach to the diaphragm edge do not seem ideal.

When the canal flume forms a control point, it is necessary to remember that the downstream edge of the weir should be normal to the stream. The inclination of the upstream edge resulting from the triangular tunnel plan is immaterial except that the crest level must be varied to counteract the varying co-efficient of discharge, resulting from the varying length of crest.

19. Tail Race.

In some cases as at Dadupur, it is necessary to pass the escapage back to the river by a tail race of appreciable length. It might be expected that a steep slope would be necessary to carry the heavily silt charged escapage. The Dadupur Tail Race was designed with a slope of 1 in 1600 and a C. V. R. of 1·87. Actually, however, it is found to work with a flatter slope and with a C. V. R. which is much the same as that of the canal.

20. Trash Racks.

At Khanki and on most of the Upper Jhelum Canal excluders, no trouble is experienced from jungle blocking the tunnels, the exception being the Kasba Extractor where the small orifices at first became blocked with sodden driftwood moving along the bottom of the canal. This trouble disappeared when the Jaba excluder was constructed.

At Madhopur where it was evident that trouble would be experienced were it not provided against, trash racks were constructed at the head of the Salampur Feeder, which are effective in protecting the extractor.

At Dadupur, difficulty was not anticipated from this source. but in practice it was found that the tunnel entrances quickly became blocked with grass and light jungle carried in suspension near the bottom, The tunnel entrances are now regularly cleaned by men using grappling hooks, from a boat floated across the canal on a wire ropeway.

21. Use of Silt Excluders.

Up to the present, silt excluders have been applied in a rather primitive fashion. In each case, where a silt excluder has been built, silt entry has been affecting the regime of the canal to a dangerous extent.

In the case of Upper Jhelum Canal, the canal capacity had been reduced considerably and was still diminishing, as the result of silt entry. In the case of the Lower Chenab Canal, excessive silt entry at the head had caused the bed of the main line to rise, and was giving great trouble in the branches and distributaries. On the Upper Bari Doab Canal, there is a point about 17 miles below the head, above which the bed is composed of shingle. It has been observed that this point was advancing down the canal at the rate of about 1000 feet per annum. The beds of branches and distributaries are consistently rising and heavy maintenance expenditure is necessitated in consequence. On the Western Jumna Canal, no difficulty was experienced in the head reach, but the Main Branch had silted to such an extent that its authorized supply could not be put into it without expensive raising of the Main Line.

In all these cases therefore it was obviously necessary to exclude or extract silt from the canal as much as possible and the excluders were constructed as a method of effecting this; but in doing so, no attempt was made to consider what grade or quantity of silt was suited to the canal regime, and to regulate the silt entry accordingly. The excluder has always been designed to be as efficient as local conditions would permit at reasonable cost.

It is evident of course, that if the excluder was too effective and resulted in too rapid retrogression of the canal, it could be disused or worked intermittently and this has, I believe, actually had to be done in the case of the Bhong excluder, where the retrogression produced endangered masonry works in the canal.

22. Silt Regulation.

No attempt has, however, so far been made to regulate the silt at entry to a grade or a quantity suited to the slopes for which the canal has been designed, but such regulation must be the aim in the case of an established canal syatem. How this aim as to be achieved, however, is by no means clear. To regulate silt we must have some standard for measuring it which can be readily observed. The most generally accepted standard for silt grading is Lacey's 'f' which cannot be defined more clearly than to say that it is a characteristic which relates silt grade to discharge and slope in a regime channel. 'f' has not yet been accurately correlated with the physical properties of silt, either on the bed, or in suspension, and, though research is in progress to determine such a relation, or a new factor which can be related on the one side with the physical proporties, and on the other with slope and discharge, the solution is not yet in site. The difficulty of the problem is increased by the fact that 'f' varies throughout a canal system, under the influence of such factors as attrition and the unequal silt extraction of off-takes, and before we could regulate to a given 'f' at the head we should require to relate that 'f' with those of the canal as a whole. There does not therefore seem to be much prospect of silt regulation in the immediate future.

23. Effects of Excluder on Canal Regime.

On the Upper Jhelum Canal the effect of the excluders so far has been to stop the progressive silting up of the canal which was in progress, and to restore its capacity to that designed. On this canal the capacity is ruled by a maximum gauge of 11·3 at Jaggu. The discharges given by this gauge in different years are as given below :—

1934—7695. 1935—7875. 1936—8160.

In 1937 the gauge of 11·3 was never attained. In January of that year a gauge of 11·25 gave a discharge of 8385 cusecs which appears to have been the maximum run.

Fig. I of plate V shows the average depth of silt on the bed of the canal from R. D. 125,000 to 254,000 from April 1935 to October 1937.

On the Lower Chenab Canal the canal bed fell from January 1934 to May 1936, an average of 1·56 in the reach 0 to 40,000 and 0·93 from 0 to 140,000. This effect is now stated to have progressed as far as the head reach of the Gugera Branch.

On the Upper Bari Doab canal the effect on the Salampur feeder is not so noticeable, as might be expected from the fact that the bed of this channel consists of heavy shingle. Surveys carried out in September 1936 and October 1937, however, show an average retrogression of 0·113 throughtout the channel.

On the Western Jumna Canal it is improbable that the effect of the excluder on canal regime will be evident for some time to come. The case of this canal is different from that of the others in that its head reach is excavated through heavy grade shingle while only medium grade silt enters it. The object of the excluder here is to provide retrogression, not immediately below the head, but about 40 miles down, where the silting of the Main Branch has made its command by the Main Line Lower impossible. There will undoubtedly be a considerable time lag before this effect is achieved. An increase of capacity of about 4 % for the same levels in the Main Line Lower is reported, however, for 1937 as compared with 1936. Similarly on the Upper Bari Doab Canal the object is to control the regime of channels some distance below the head; and considerable time must elapse before this object is attained, even when the whole supply is decanted. It would be interesting to endeavour to estimate the time which this process will take. We know for instance that the shingle berm at present travelling down the Upper Bari Doab Canal has taken about 80 years to travel 18 miles. Also the progress of the silt waves on the Lower Chenab Canal branches is very slow. The speed of silt movement must, however, be effected by the gradient of the channel and by increasing it the movement can be accelerated.

24. Regrading as a means of eliminating time lag.

When the silt contents of a stream running in a bed of self-borne material is reduced the deficiency will to a certain extent be made good by the water picking up additional material from the bed, as a consequence of which there is no immediate effect on the silt contents at the tail. This supplementing of the silt contents of the water from the bed of course will result in retrogression of the bed and a flattening of the slope, which will continue until a new regime is established suited to the new conditions of silt entry. The extent to which such retrogression may take place is very limited, as the slope is controlled more by silt grade than quantity and a small flattening of the slope is generally sufficient to render the stream powerless to move the grade of bed silt associated with the former regime. The question has been investigated by Mr. Crump whose tentative conclusions were that it would amount to about 4 % of the slope in the case of shingle and might extend up 20 % in the case of fine silt.

The delay involved in this process can be eliminated by artificially regrading the channel to a flatter slope when the movement of bed material will be restricted in the reach regraded and the effect of the reduction of silt content at the head will be at once apparent at the tail. Such regrading may be necessary in any case, as otherwise the retrogression may effect the safety of masonry works, etc.

Regrading has been proposed in the case of the Western Jumna Canal, though in this case the problem is complicated by the fact that the Main Line Lower is an old river creek which has never been properly graded and the case is therefore equivalent to the design of a new channel.

25. Observation of silt contents.

In order to study the working of excluders it is usual to observe periodically the discharges and silt contents of the water passing them. For this purpose the canal discharges will generally be available from routine observation, but it may be necessary to calibrate the work to obtain the escape discharges or to have these specially observed.

The silt contents will be obtained from silt intensity observations which may be made in the approach flume, in the canal or in the escape. Observations at any two of these sites are sufficient to enable the silt distribution to be determined, but observations at all three are advisable to obtain a check on the work.

26. Units of Intensity.

The silt contents are observed by taking samples of the water and measuring it and its silt contents. The ratio of the silt to the water is the silt intensity. This intensity or the average of several samples is then applied to the discharge to obtain the total silt contents.

The intensity may be expressed in several ways. That favoured by the Research Institute is the ratio of the weight of silt in ounces to the volume of the water in cubic feet. Since one cubic foot of water weighs 1000 oz., this is equivalent to parts per thousand by weight and to obtain parts per thousand by volume all that is necessary is to multiply by the specific gravity of the silt which is approximately two.

The writer prefers to express intensity as parts per 1000 by volume and this unit is consequently used at Dadupur.

At Khanki the unit of intensity adopted is the silt contents by volume of a cusec-day from which of course the silt entering the canal daily can readily be obtained. This unit is 86·4 times the intensity expressed as parts per thousand by volume.

27. Grading of Silt.

In addition to the intensity of total silt, the quantities of silt coarser than certain grades are also observed. These are :

Fine silt—which is all silt above 0·075 mm. in diameter and

Coarse silt—which comprises all silt above 0·20 mm. in diameter.

As it has been established that only the latter silt is harmful to canal regime, coarse silt intensities are those principally studied in connection with the working of excluders.

28. Method of sampling.

Silt observations may be made in one of four ways which are listed in order of efficiency :

(*a*) Trapping the whole silt of the stream for a period.

(*b*) Sampling from turbulence.

(*c*) Sampling from the normal stream from points spread over the section horizontally and vertically.

(*d*) Sampling from single points on verticals.

In this case the point is so selected that the silt is representative of the average of the vertical.

Of these methods that at (*a*) undoubtedly gives the most correct results, but as it can only be applied under specially favourable circumstances it is more useful as a check on other methods than for routine work.

Sampling for turbulence is an efficient and practical method provided that certain precautions are taken. In the first place the turbulence must be adequate. It has been found in practice that a head of four feet is necessary to ensure that the turbulence produces a reasonably uniform silt distribution and if this head is not present the results of sampling from turbulence can be very misleading. Eddies and whirls which are of a continuous nature, such as those which occur downstream of bridge peirs, are apt to collect silt out of proportion to their volume and sampling from such sites cannot be relied upon.

If suitable turbulence is not available recourse must be had to sampling from the normal stream. The simplest way to do this is to take samples from a single point on a vertical at a fixed proportion of the depth, usually 0·6 depth, but the method is not very satisfactory. It has been established that sampling in this way is on the average representative of the total silt in suspension in certain streams, but it is very improbable that the same is true when dealing with silts of a certain grade; in fact examination of the curves of silt distribution with depth of different grades show that the same ratio cannot apply. It is possible, however, that when this method is used for comparing intensities at two sites the error involved is not great as though the actual intensities will not be correct they will both be in error to the same degree.

The best method of sampling in the open stream appears to be to take samples from a number of points distributed over the sections both vertically and horizontally and the greater the number the greater the accuracy which may be expected. The points should be distributed according to the discharge, and not according to the area of the sections. Again, it is found that the silt intensity at any point in a stream varies considerably with time, and thus to get a representative sample the sampler should be filled slowly. Also care should be taken that no silt can enter the bottle after it is once filled—which means that either the bottle should be removed or closed immediately it is filled—or the entrance should be so arranged that silt cannot enter unless water borne. A narrow tube on the orifice terminating horizontally will effect this, while it is not easy to judge the exact time for closing or removing a sampler.

Whatever method of sampling is used when observing silt intensities for the purpose of calculating the efficiency of an excluder, it would seem advisable that it should be the same at all the sites. Accurate results cannot be expected if the turbulence method is used for the escapage and single point observation taken in the canal.

Actual methods of observation in use at different sites appear to be as below :—

At Khanki. Observations are taken in the turbulence below the canal regulator in each bay in the wave, and downstream of the undersluice gates. The former observations are satisfactory but the latter are doubtful. A comparison of the silt contents of the wave with a few experimental observations in the jet issuing below the gates show the intensities in the latter case to be greater. Routine observations at the latter site are impracticable, however.

Upper Jhelum Canal. Observations are made in the canal upstream and downstream of the works by the single point method, depths of 0·8 and 0·9 depth being used. They are also made in the turbulence of the escapage.

Madhopur. The single point method at 0.6 depth is used in the canal upstream and downstream of the extractor. The silt extracted has also been observed by trapping on various occasions.

Dadupur. The multi-point method (fifteen points, five on each of three verticals) is used at all three sites.

29. Accuracy of results.

In spite of the thought and care that has been given to the observation of silt intensities, it is evident that the present methods are still far from satisfactory. The variations between individual observations are very great and a comparsion of the results from the three sites shows considerable discrepancies. For example the average coarse silt above the Dadupur excluder for a ten days period in August of the year from the flume observations was 2,330,000 cubic feet. From the total of the canal and escape observations, however, the silt passing the work was only 1,450, 000 cubic feet, a difference of 38 % on the upstream figures.

Efficiency of silt excluder. There has been some doubt in the past as to the best method of calculating the efficiency of excluders.

That now in general use gives the reduction of silt intensity in the canal water as compared with that of the approach flume. On the Upper Jhelum Canal, however, it was formerly customary to take the ratio of the total silt escaped to that of the approach flume as the efficiency, and this method is also employed at Madhopur.

If Q, I and S are the discharge, intensity and total silt contents the suffixes f, c and x denote the approach flume, the canal and the escape respectively, the efficiency is given by

$$E=\frac{I_f-I_c}{I_f}=1-\frac{I_c}{I_f}$$

If observations of the approach flume are not available, the efficiency may be obtained from the canal and escape observations by the formula

$$E=\frac{Q_x(I_x-I_c)}{I_cQ_c+I_xQ_x}$$

According to the second method referred to above the efficiency is given by

$$E'=\frac{S_x}{S_f}=\frac{Q_xI_x}{Q_fI_f}$$

$$= \frac{Q_x I_x}{Q_c I_c + Q_x I_x} \qquad \frac{Q_f I_f - Q_c I_c}{Q_f I_f}$$

$$\textit{whence } E' = E + \frac{Q_x I_x}{Q_f I_f}$$

It is clear from this that the latter method gives a greater value of the efficiency than that calculated by the method recommended. It may also be noted that if the excluder efficiency is nil, i. e., if the intensities in the two downstream channels are the same as that upstream the atter formula would still show a high efficiency $\frac{(Q_x)}{(Q_f)}$ while the former would correctly give a *nil* value.

30. Factors affecting Efficiencies.

In comparing the efficiency of excluders it must be remembered that the greater the proportion of the supply escaped, the greater will the efficiency be. As has been pointed out above, however, the efficiency will not vary directly with the escapage. Since the intensity decreases rapidly with depth, additional escapage will increase the efficiency but slowly.

Another point to be borne in mind in this connection is that the efficiency must be affected by the grade of material carried by the water. Since that grade has been found to cause trouble in practice, efforts are made to exclude everything larger than 0·2 mm. diameter, and efficiencies are calculated on material of coarser grade than this. The proportion of the total silt which is greater than 0·2 and the relation of the coarsest silt carried to this grade will, however, vary at different sites.

The same excluder may be expected to work more efficiently where the proportion of coarser silt is greater than where it is small, but on the other hand, the coarser the heaviest grade of silt carried, the greater the slope and velocity will be, and consequently the less the concentration of silt in the lower layers. It seems probable that the coarser the silt present, the greater the efficiency would be when based on the same grade, but this is by no means proven by our present knowledge of the subject.

31. Actual observed efficiencies.

With this word of caution, the figures of efficiencies observed in practice are presented in the attached statement. In this all the efficiencies are calculated by the method recommended above, cases where this method is not in use at the site having been recalculated. Intensities are all in parts per 1000 by volume. Where only figures of parts per 1000 by weight are available, these have been doubled to give the corresponding volume relations.

√

Commenting on these figures in detail :—

Jaba. The variation of efficiency with escapage discharge is clearly shown. The high figure for 12-6-37 is very doubtful. The canal observation site is some distance below the work and it is probable that silt entering during a flood, which this condition represents, deposits on the bed temporarily, and is not apparent in the canal observation.

Kasba, Chak Sikander and Dumbiwala. The high efficiencies for the low escapage discharge are very significant. Doubts might be experienced concerning their reliability in view of the small number of observations, but the Kasba observation is the most careful experiment of this type which has been made in the Province. Observations of silt and velocity were made at every 0·1 of depth on six verticals and the total silt below the work checks up very accurately with that observed upstream.

Comparing *Khanki, Madhopur and Dadupur*, it would appear that the two latter are more efficient as might be expected from the better approach conditions and the heavy silt. As stated above, however, there is some doubt regarding the observations downstream of the Khanki tunnels and the probability is that the efficiencies are actually greater than those reported.

32. Acknowledgements.

The author's acknowledgements are due to Messrs. Giles, B. K. Kapur, Wells, and D. D. Jaini for the help they have given in supplying information regarding the excluders in their charge. Also to Messrs. Crump, Khosla and Dundon whose notes on the subject have been most helpful and freely made use of by the writer.

Statement showing figures of intensities, discharges and efficiencies of excluders.

		APPROACH FLUMES.		CANAL.		ESCAPE.		
Period.	No. of observations.	Intensity in parts per 1000 silt above 0.2 mm.	Discharge.	Intensity.	Discharge.	Intensity.	Discharge.	Efficiency %.
Symbol.		I_f	Q_f	I_c	Q_c	I_x	Q_x	E
				Jaba.				
1—15-4-37	11	..	..	0·114	6368	0·578	250	13·4
16—30-4-37	13	..	..	0·120	7547	0·604	358	15·8
1—20-5-37	16	..	..	0·114	7561	0·492	350	13·4
8—30-6-37	18	..	..	0·110	7503	0·732	492	23·9
4—24-7-37	17	..	..	0·108	6658	0·512	482	20·1
2—31-8-37	23	..	..	0·104	6498	0·595	450	22·3
1—22-9-37	16	..	...	0·104	7299	0·511	450	26·9
12-6-37	1	..	..	0·064	7932	1·492	1300	75·8
				Kasba.				
30-7-36	1	0.048	7359	0·029	7159	0·731	200	39·5
				Chak Sikander.				
31-8 & 8-9-35	2	..	..	0·091	6293	2·431	100	30·4
				Dumbi Wala.				
Do.	2	..	..	0·146	6293	3·933	108	30·6
				Khanki.				
21—31-5-37	7	..	..	0·038	10571	0·088	2791	25·3
1—10-6-37	6	..	..	0·037	10709	0·104	2874	28·3
11—20-6-37	6	..	..	0·033	10866	0·088	2697	29·4
21—30-6-37	10	..	..	0·083	10976	0·476	5024	48·1

Period.	No. of observations	Approach Flume.		Canal.		Escape.		Efficiency %.
		Intensity in parts per 1000 silt above 0·2 mm.	Discharge.	Intensity.	Discharge.	Intensity.	Discharge.	
Symbol.		I_f	Q_f	I_c	Q_c	I_x	Q_x	E
1 -10-7-37	9	..	..	0·068	10718	0·215	4935	39·8
11—20-7-37	10	..	..	0·070	10998	0·232	3519	31·5
21—31-7-37	8	..	..	0·164	9364	0·448	4224	32·0
1—10-8-37	10	..	..	0·161	10881	0·535	4892	42·1
11—20-8-37	10	..	..	0·067	11142	0·241	4745	45·8
21—31-8-37	11	..	..	0·145	11272	0·313	2835	20·0
			Madhopur.					
20—30-5-37	8	0·486	..	0·232	1933	..	709	50.7
1—15-6-37	5	0·302	..	0·117	2075	..	709	61·7
10—22-7-37	3	0·337	..	0·187	1929	..	709	45·9
5—14-9-37	3	0·457	..	0·213	1927	..	709	48·7
			Dadpur.					
1—15-4-37	5	..	..	0·012	4345	0·167	755	65·0
16—30-4-37	5	..	..	0·011	5188	0·129	954	59·3
16—30-5-37	11	..	..	0·006	5902	0·102	1088	48·8
1—15-6-37	5	..	..	0·003	5502	0·102	969	71·0
16—30-6-37	12	..	..	0·030	5623	0·205	949	40·8
1—15-7-37	9	0·254	4218	0·143	3299	0·246	917	65·7*
16—31-7-37	10	0·212	4745	0·137	3671	0·360	1074	44·5*
1—15-8-37	8	0·261	5668	0·120	4828	0·383	840	54·3*
16—31-8-37	14	0·202	7165	0·101	6315	0·273	850	47·1*

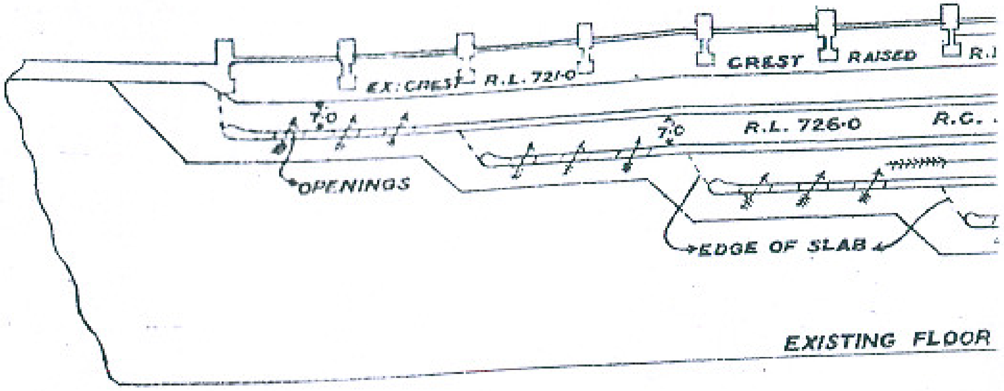
* Efficiencies based on Flume and Canal observations.

Discharge.
Q_x
35
19
24
92
45
35
09
09
09
09
55
54
88
69
49
17
74
10
50

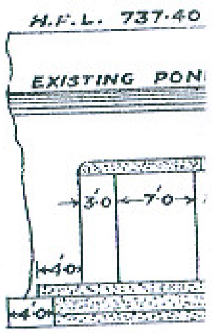
KHANKI E

PLAN OF

SCALE



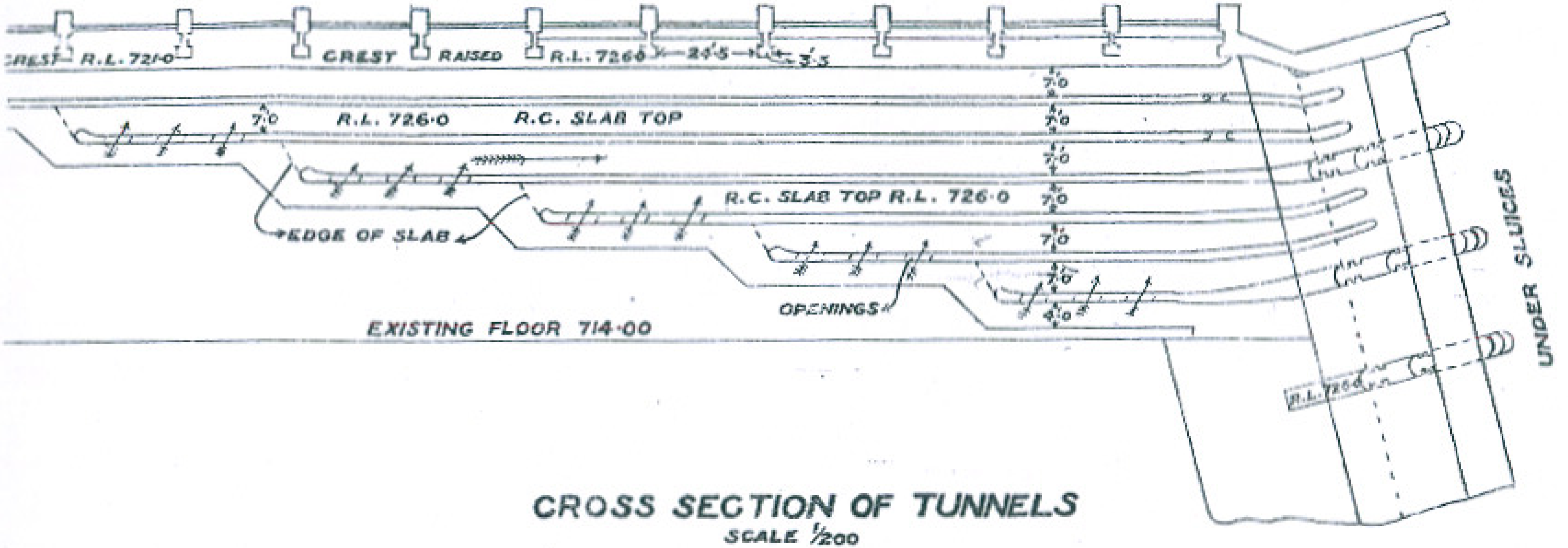
C



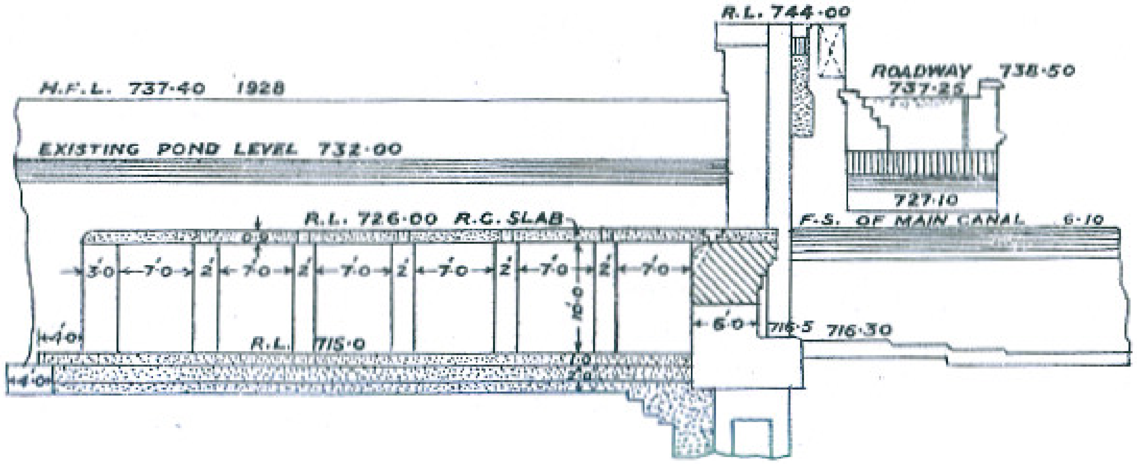
KHANKI EXCLUDER

PLATE I
PAPER NO. 211

PLAN OF TUNNELS
SCALE 1/500



CROSS SECTION OF TUNNELS
SCALE 1/200



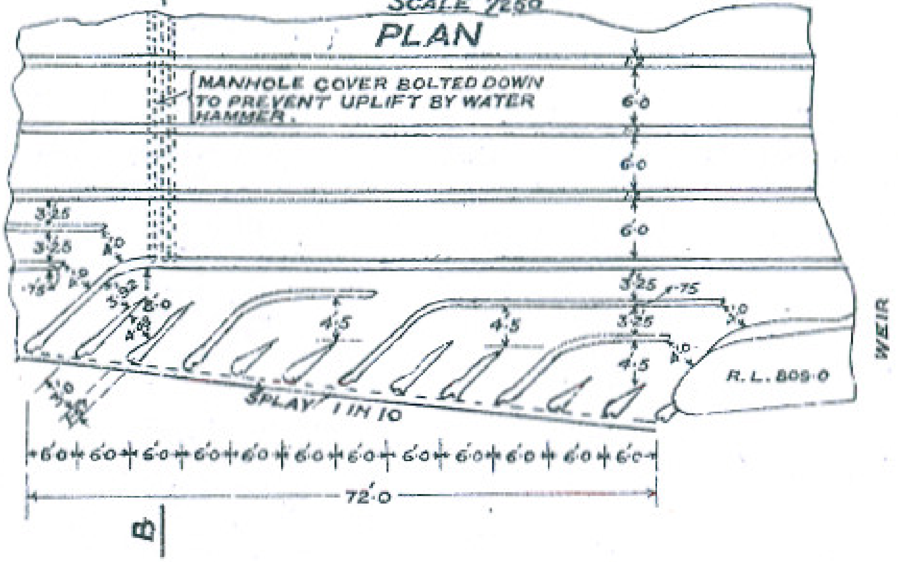
PUNJAB ENGINEERING CONGRESS
1938

FIG. 1

JABA SILT EXTRACTOR

SCALE 1/250

PLAN



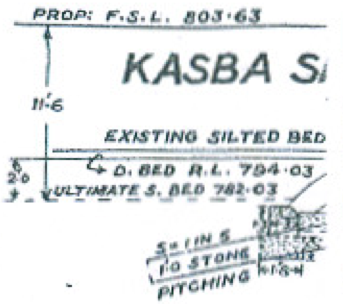


FIG. 2

SECTION ON B.B.

SCALE 1/100

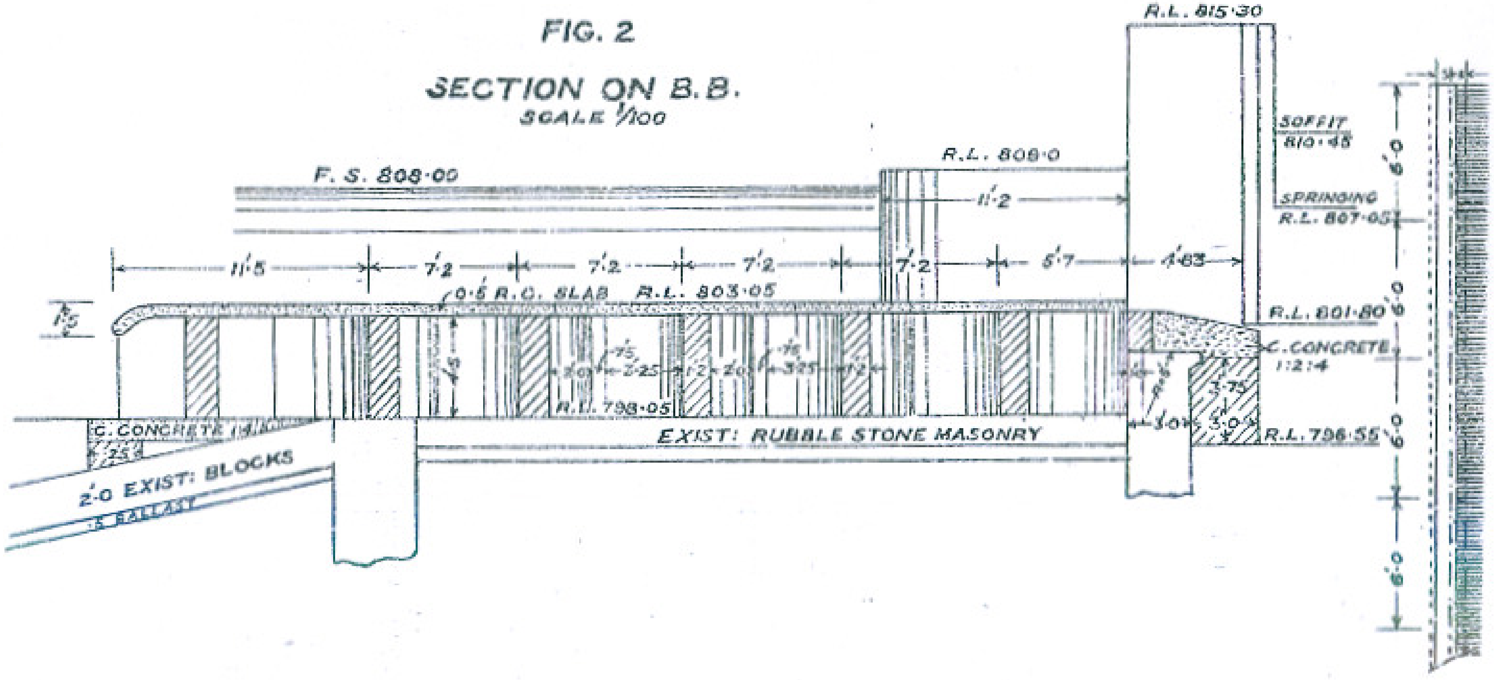


PLATE II
PAPER NO. 211

RACTOR

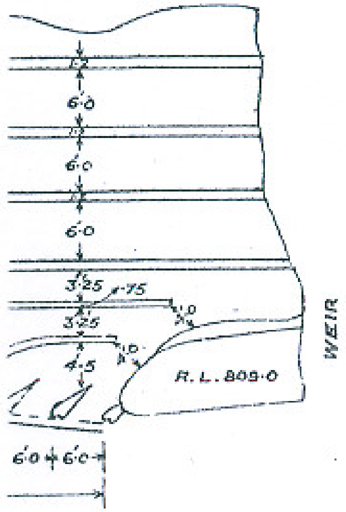
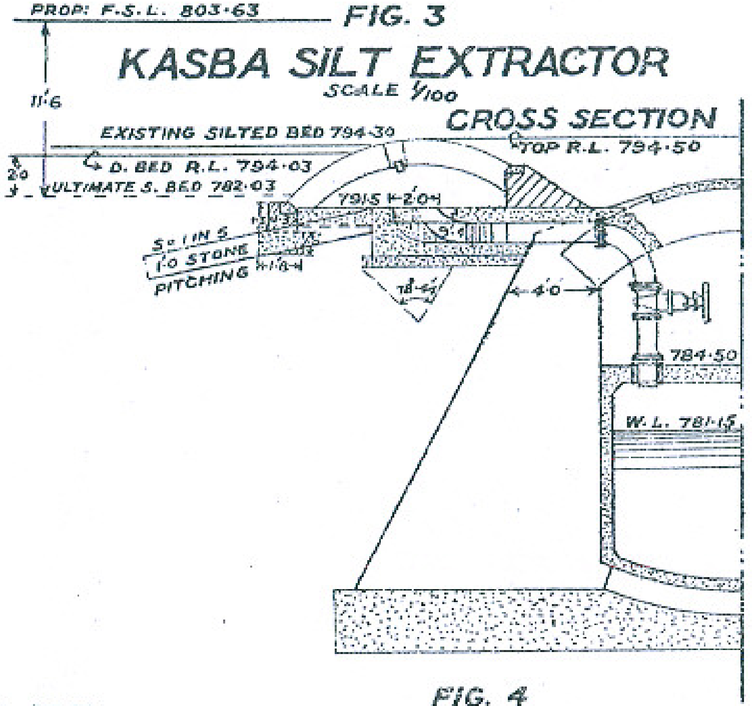


FIG. 3

KASBA SILT EXTRACTOR

SCALE 1/100

CROSS SECTION



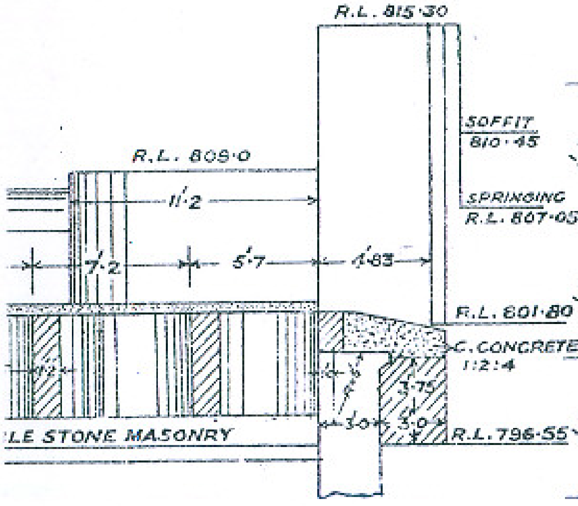


FIG. 4
PLAN

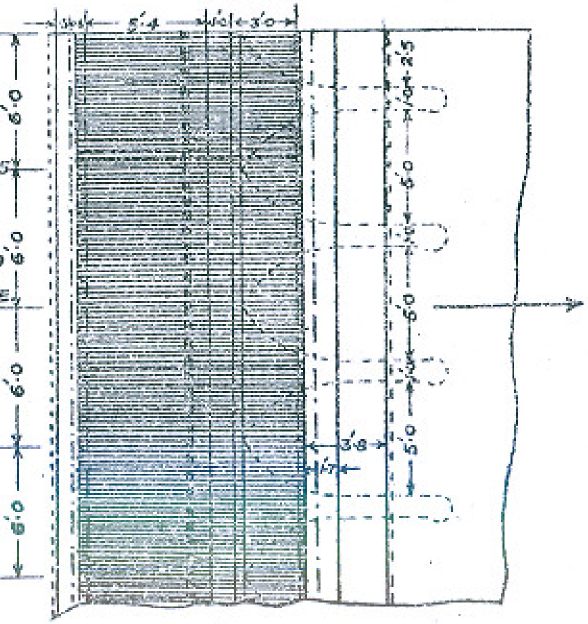


FIG. 5

DUMBIWALA SILT EXTRACTOR

SCALEL 1/100

PLAN

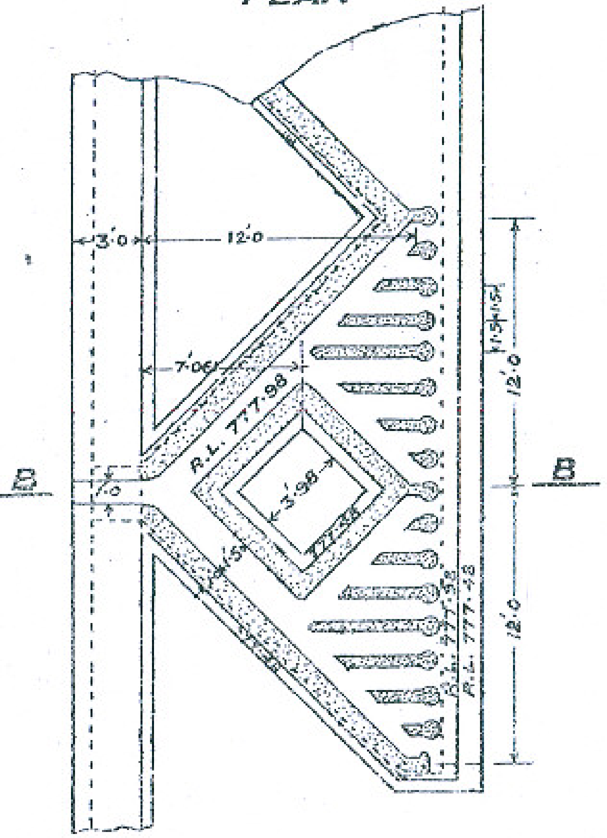
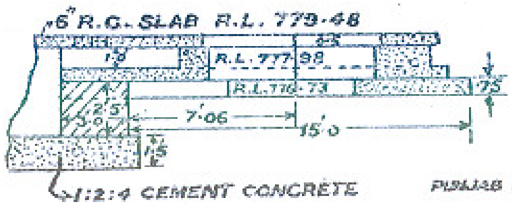


FIG. 6

SECTION ON B.B.



PUNJAB ENGINEERING CONGRESS
1938

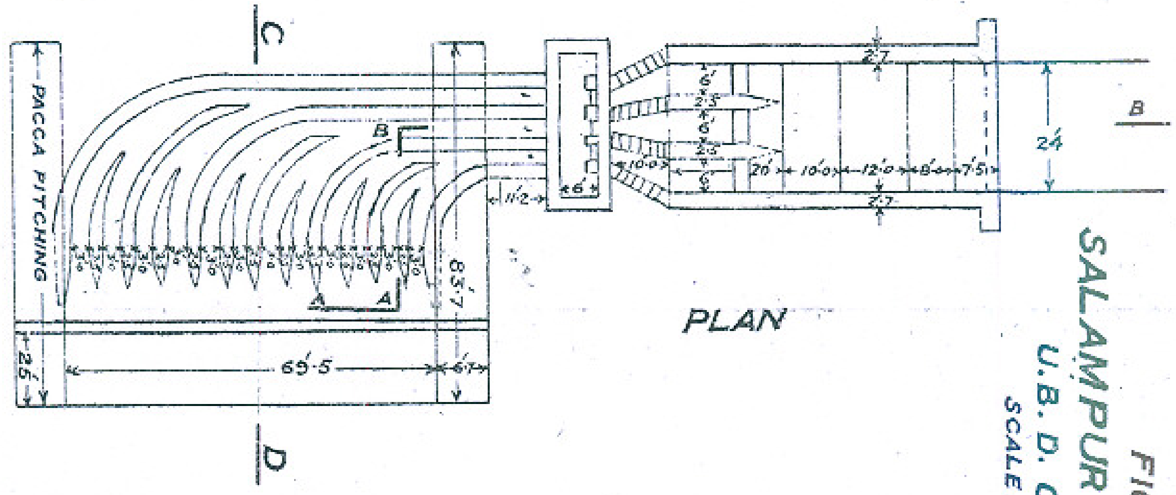
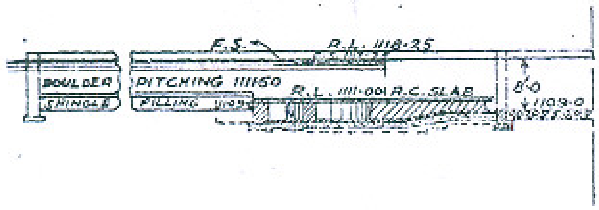
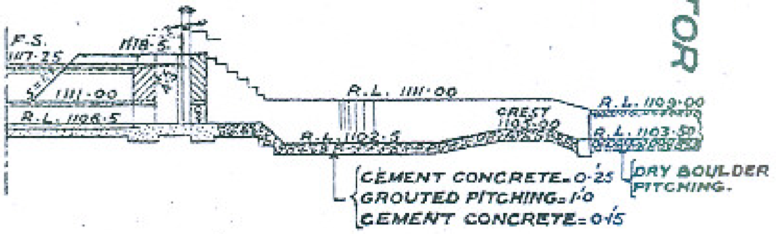


FIG. I
SALAMPUR EJECTOR
U.B.D. CANAL
SCALE = 1/400

SECTION ON C.D.



SECTION ON A.B.



SECTION OF D/S END OF TUNNELS
SCALE = 1/200

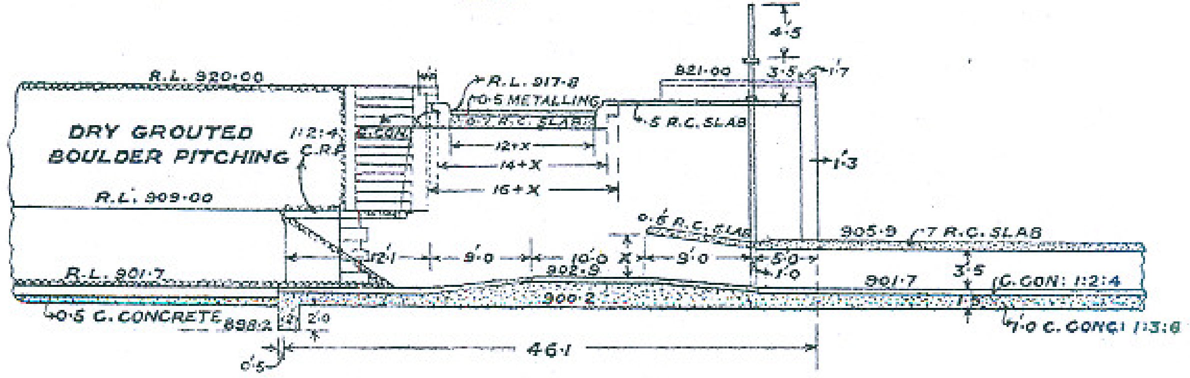


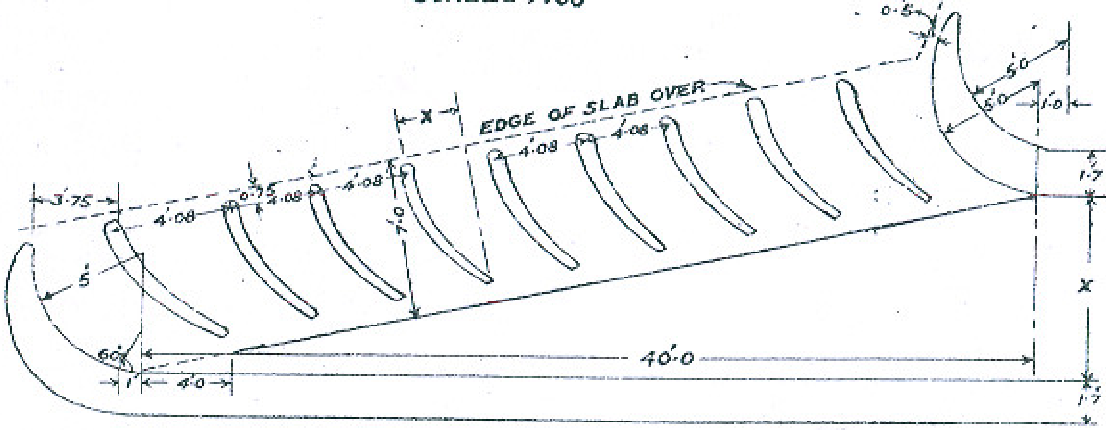
PLATE III
PAPER NO. 211

FIG. 2

DADUPUR SILT EXCLUDER

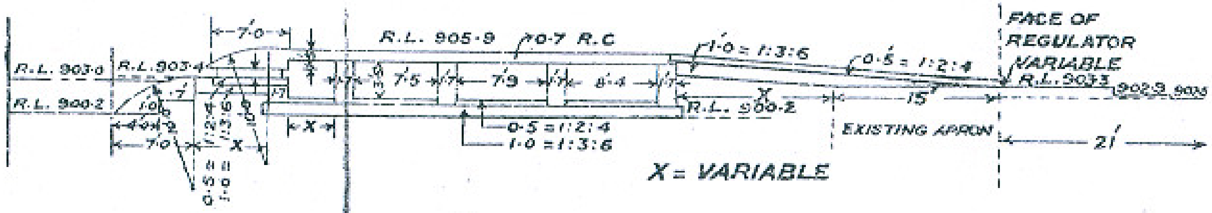
DETAIL OF VANE LAYOUT

SCALE = 1/100



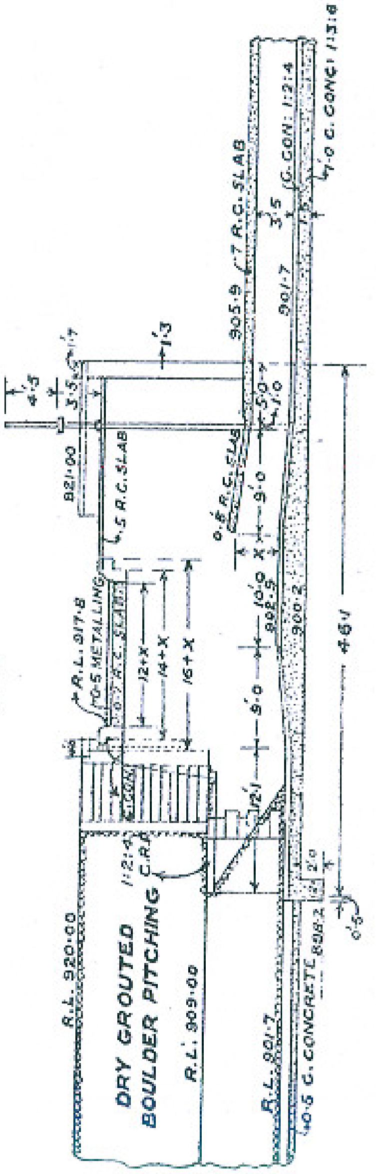
CROSS SECTION OF TUNNELS

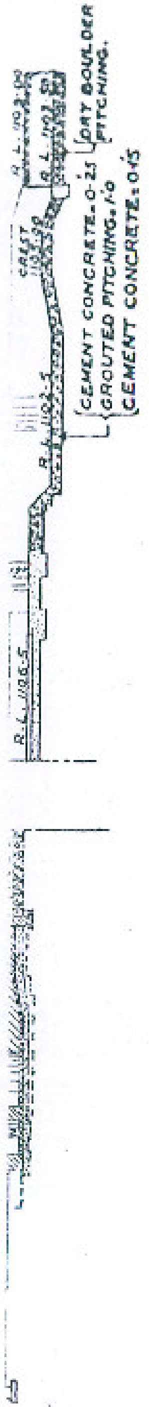
SCALE = 1/200



SECTION OF D/S END OF TUNNELS

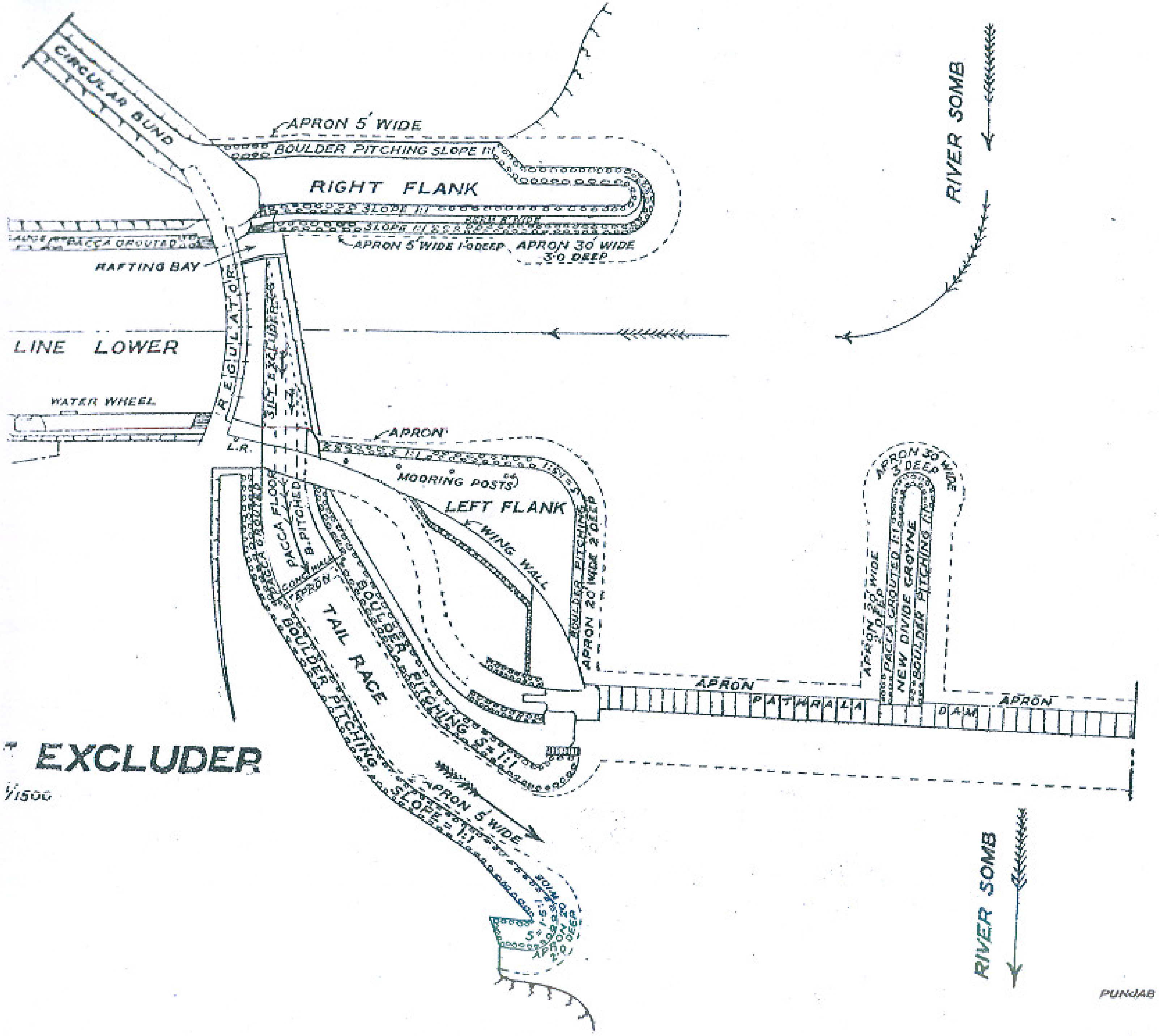
SCALE = 1/200





PUNJAB ENGINEERING CONGRESS
1938

PLATE IV
PAPER NO. 211



EXCLUDER

1/1500

PUNJAB ENGINEERING CONGRESS
1938

DISCUSSION.

The Author in introducing the Paper said that in the table at the end of his Paper he had given values of the efficiencies of different works calculated on a uniform basis. It was interesting to plot these figures against the ratio of the discharge escaped to that passed into the canal, since the relative efficiency of any extractor must be dependent on the water used for escapage. This had been done on the curve (Plate V) and from this the following points might be observed.

The efficiency was much greater in the case of the groups shown by dots, i.e., the Upper Jhelum Circle extractors, Dadupur and Salampur, than in the case of those shown by open circles, *i.e.*, Jaba and Khanki. This, he thought, was a clear indication of the value of a straight approach channel, since this feature was present in the case of the former works but not in the latter.

From the point of view of indicating the relation between efficiency and escapage ratio the graph was not very conclusive.

Mr. Crump had suggested that, since the observations represented by black dots referred to works of similar types, they might draw a curve such as *A B* as representative of this relation, but in view of the different grades of silt present in the three canals he (the Author) would hesitate to accept this. On the other hand the Khanki observations were sufficiently dispersed to indicate that the relation might be represented by the line *C D*. The line *A B* would indicate that the relative efficiency, *i.e.*, the efficiency divided by the escapage ratio, was very high for small escapage; while *CD* indicated that it was almost constant. In view of this, it might be concluded that while the relative efficiency was certainly greater for small escapage than for large, the data presented was not sufficient to estimate the extent of the variation.

If the former conclusion was correct it was obvious that if a given discharge was available for escapage, a greater total efficiency could be obtained by multiplying the extractors and dividing the discharge between them.

Members, he was sure, would like to know what was being done about extractors on the Haveli Project. Briefly, it was proposed to provide a river excluder to each canal head, together with one or more extractors in each canal. The excluder for the Rangpur Canal would be of the Khanki type, but for the more important Haveli Canal it would consist of a diaphragm covering four bays of the undersluices and extending well upstream of the regulator. An excluder of this type which closely followed Elsden's original design and King's design for Khanki, had been designed by R. S. Kanwar Sain for the Headworks of the Thal Project at Kalabagh. In subsequent discussion it had come to be known as the Kalabagh type. A straight approach was to be secured to this excluder by providing a divide wall about 350 feet long upstream of the edge of the diaphragm.

While the details were not then finally settled it was probable that the Rangpur Canal would have one extractor at about R. D. 2,000 with an escapage of about 30% while the Haveli Canal would have two at R. Ds. 1200 and 2000 with escapages of about 20% each.

Dr. **Bose**, referring to the Author's statement that the basic principles on which silt excluders were designed lay in the fact that in a flowing stream carrying silt in suspension, the concentration of silt in the lower layers was greater than in the upper ones, said that not only was the concentration greater but the grade of silt was much coarser at the bottom than in suspension. This fact was utilized in excluding silt from any canal system either before it could enter it, *i.e.*, by excluders in the river pocket itself; or immediately after it had entered the canal, *i.e.*, by ejectors carrying it back to the river, or by silt skimmers before it could enter any distributary.

Another basic principle that must be borne in mind in the design of ejectors or excluders was the fact that any particular grade of silt would remain in suspension or roll on the bed, depending on the velocity and degree of turbulence of the stream. What was bed silt with a certain velocity would be picked up and be floating when the velocity or the turbulence increased. This fact made the functioning of excluders in the river pocket less satisfactory than that of ejectors in the canal. Conditions in the river pocket could not be maintained as smooth as in a canal in spite of a rigid still-pond system, a long divide wall and the most recent device of having tunnels all throughout the pocket. This device known as the Kalabagh Type of excluder was being constructed in the pocket of the Trimmu Weir. A model of this had been built at Malikpur. It showed that with 5000 cusecs running into the canal and another 5000 cusecs through the tunnels a velocity of between 3 to 4 feet per second could be expected at the upstream end of the excluder where the vertical velocity distribution was uniform. It had been found from experiments on the lined reach of the Bikaner Canal that this velocity of 3 to 4 feet picked up all silt up to a diameter of 0·35 mm. which was the same as was to be found in the river bed at Trimmu. Thus it would appear that it would be very difficult to keep down velocities—much less turbulence in rivers. This could be comparatively easily attained in a canal. An ejector seemed to be a better proposition than an excluder.

The Author said that Lacey's *f* was a characteristic which related silt grade to discharge and slope in a regime channel. It was evident that the Author had the following relation of Mr. Lacey in mind :—

$$S=\frac{f^{\frac{5}{3}}}{1{\cdot}788\,Q^{\frac{1}{6}}}$$

but it was not clear how he connected silt grade with f in this relation. The only relation given by Mr. Lacey that connected f with silt was :—

$$f=8\sqrt{d}\ ,$$

and this relation was not correct so far as Punjab data were concerned. Unless Mr. Lacey could connect f with silt in a more satisfactory way he was afraid the Author would have to use the following formula proposed by the Research Institute

$$S\times10^3=2{\cdot}06\,\frac{m^{0{\cdot}86}}{q^{0{\cdot}21}}.$$

The Author had rightly observed that unless they knew how silt grade varied along a canal system from its head reaches to the tail there did not seem to be much prospect of silt regulation in the immediate future. But for the Main Line in any case it was possible to regulate silt at the Headworks with the help of the above formula, which would show what grade of silt could be carried by the available discharge and slope, so that any silt coarser than this would have to be excluded. This had been done in the case of the Haveli Project. About branches and distributaries the problem was more difficult as it was complicated by unequal extraction of their offtakes. Unless offtakes were standardized and their silt exclusion capacity was known the problem of silt exclusion in branches and distributaries would remain subject to trial and error only.

Mr. **Montagu** felt that any comments he might make on the Author's paper must be rather theoretical, because he had not had the opportunity to construct any silt excluders. But he desired to make two corrections before proceeding to comment on the paper.

On page 55. He was informed on good authority, that the Salampur Feeder silt ejector was designed a year before the Upper Jhelum excluders.

On page 61. The silt ejector at the Salampur Feeder had three gates in the surge chamber which give absolute control over the three groups of tunnels.

He had been associated with Mr. Oram in the original design of the excluder for Khanki, referred to on pages 53-54, by orders of

Chief Engineer, Mr. Sangster. While holding charge of the Madhupur Division, he had had the opportunity of observing the working of both the small excluder on the Kot Karm Chand Distributary, and also the larger one on the Salampur Feeder. He had also been associated with the experiments on this subject carried out at the Malikpur experimental station.

Also he had prepared two designs and estimates in detail for the proposed Main Line excluder as well as preliminary steps for a third design. Before attempting these designs he had secured blue prints from Mr. Haigh of his designs on the Western Jumna Canal which had proved most instructive.

As a result of the experience so gained, he had formed certain tentative conclusions upon which he would be grateful for the Author's comments.

Ordinarily speaking, maximum silt was inducted into a canal during the summer months, when there was ample supply in the river to work the ejector or excluder to full capacity.

Consequently, if the roof slab of the ejector was designed as to height, to afford minimum disturbance to the stream lines at that discharge, any slight disturbance at other states of discharge was not of vital importance.

The Speaker felt that the actual proportion of total discharge to be ejected would depend on the volume and grade of silt to be removed. This would be determined most simply by actual experiment and subsequent regulation of the ejected discharge in the prototype.

The design of the approach and departure channels was really a difficult matter. There were three discharges to be considered, *viz*:—

(*i*) the discharge approaching the ejector,
(*ii*) the discharge passed on down the canal,
(*iii*) the discharge ejected.

The Speaker favoured a smooth approach of comparatively short length, and of velocity and depth just appropriate to move the silt in the stream.

The canal discharge should be passed on, at the velocity and depth appropriate to the silt remaining in the water. The combination of these two sets of conditions leads to some curious design and is the reason for the apparently low roof slab at the highly efficient Salampur Feeder ejector.

The tunnel discharge should enter smoothly, of course. On page 60, the Author stated that the velocity in the tunnels should be not less than 10 ft./sec. The Speaker suggested instead, that provided there was a progressive increase in the velocity from entrance to exit, there would be no fear of silting in the tunnels. This increase, moreover, need not be very great.

The tunnels themselves might vary in depth and width until at the exit end the proportion was attained which was most economical of gates and superstructure.

The Speaker was strongly in favour of the provision of a surge chamber at the exit end of the tunnels, in which the regulating gates should be fitted. These gates were an important part of the design as they permitted precise regulation of the discharge from individual tunnels.

There was one point on which the Speaker differed from other designers. The Speaker deprecated the use of hyper-critical velocities or velocities even approaching the critical, for the following reasons :—

(*a*) a trifling miscalculation as to the amount of friction would either prevent the desired discharge passing (calculation too low) or else create a free surface in the tunnels with a higher velocity of exit (calculated friction too high) ;

(*b*) in the latter event any attempt to reduce the volume of discharge by using the exit sluices would cause a standing wave to form at once. As the discharge was even slightly reduced, there would come a point where a change of stage would occur. The consequences would be, a violent and sudden increase of pressures throughout the length of the tunnel and a marked falling off in discharge. (These pressures were not susceptible to calculation, but were true "water-hammer" pressures and were very high) ;

(*c*) for the above reasons, regulation of volume of discharge with any accuracy, was impossible: wear would be very great and maintenance costs in a shingle stream, very high.

In conclusion the Speaker referred to the Author's remark on page 64 to the effect that the shingle had advanced only 18 miles in 80 years, in the Main Line of the Upper Bari Doab Canal.

The bare statement, though correct, was misleading. The shingle node was advancing slowly, owing to the number of falls in the head reach which must be eliminated before the full effect would become apparent, and this would take another century or two, unless steps were taken to remove the cause. The real trouble on the Upper Bari Doab on the quality of silt present in the bed of a channel in any particular reach, otherwise it would be impossible to account for the absence of coarse silt in the head reach of the Lower Chenab Canal and its existence lower down.

It had been observed that heading up of the pond level at Khanki to its maximum limit during the flood days was highly conducive to the non-silting of the canal. Similarly, he believed, was the experience at some of the other headworks. In fact the Upper Chenab Canal with distinctly coarser grades of silt at Marala was working satisfactorily with somewhat flatter slopes.

It would therefore appear that the principal factor in keeping canals free of silt at their heads was the method of regulation, and if silt excluders helped in improving the regime of channels, their effect could only be secondary.

Observations made at Khanki showed that the mean velocity in the approach channel varied from about 3·0 ft./sec. in a low river to over 6·0 ft./sec. when the river was high. With low velocities in the approach channels, it was observed that although the silt excluder might not be working, the canal remained clear of silt. His observation was that up to slopes flatter than 1 in 5000 in the approach channel, no silting of the canal occurred irrespective of whether the silt excluder was working or not and with slopes steeper than 1 in 5000, which only happened in a high river, the canal invariably had a tendency to silt up although the silt excluders might be fully working. He therefore took 1 in 5000 as the critical slope of the river at Khanki below which the canal remained clear of silt and above which it began to silt up.

Recently the pond level at Khanki had had to be temporarily lowered by 6″ to facilitate execution of some work and it had been observed that the canal began to silt up rapidly ; but as soon as the pond level had been brought back to its original level, the canal had begun to scour again. The silt tunnels had not been working on either of these cases.

This showed the sensitiveness of the canal to even slight variation in the river slope in the immediate vicinity of the canal head.

As regards the actual efficiency of the silt excluder it was obviously most important to exclude silt where the river discharge and silt intensity were high, but unfortunately in a high river, the coarse silt was diffused in the entire mass of water due to high velocity and was not confined to the bottom layers.

The working of silt excluders was based on the assumption that coarse silt particles were all concentrated in the bottom layers, and as this assumption did not hold in a high river with high velocities, silt excluders obviously could not be effective, when they were most needed.

An example of the ineffectiveness of silt excluders was furnished by the condition at Khanki on the 2nd of August, 1935. The discharge of the left arm of the river had been 65,000 cusecs and the river slope 1 in 5000, the velocity of coarse silt entering the canal was 35 cubic feet per cusec-day, while that passing through the excluder was 42 cubic feet per cusec-day, the efficiency being only 4%. It would therefore appear that in low river where they could conveniently flatten the river slope, silt excluders were not needed. In high river where they could not appreciably flatten the slope, and when silt exclusion was most needed in order to keep the canal clear of silt, they were practically ineffective.

Mr. **N. D. Gulhati** said that the Author's paper had not come too soon, and the thanks of the profession were due to him for giving, in this lucid Paper, all the known factors that govern the design and working of silt excluders.

As Sub Divisional Officer at Khanki he had watched the working of the silt excluder at that place for the last two summers. This being the first work of its kind to be built it had naturally the most to teach; and the few remarks he had to make would, he trusted, be of interest to the Congress.

The Speaker said that he would divide his remarks into two parts, firstly on the subject of silt excluders as a whole, and secondly with particular reference to the Khanki excluder.

A silt excluder was a mechanical separator of the upper comparatively silt free water from the lower water with greater concentration of silt. This mechanical separation postulated, that the approaching stream was flowing in what might be called stream-line or laminar flow, and the more nearly this condition was fulfilled, the greater the efficiency of the excluder. This point was of particular importance in silt excluders of the Khanki type, that is, those which were built in the river bed, where laminar flow in the flume could only be obtained at a very great expense, if at all. During the summer (and that was the only period when a silt excluder could function) the conditions of flow at the nose of the Divide Groyne were anything but stream-line. According to the observations made at Dadupur, mentioned in para. 13 of the Paper, the length of the flume required for a discharge of 10,000 cusecs would be at least 1500 feet, which would mean an otherwise unnecessarily long Divide Groyne. Inside the flume itself, according to the present design of canal regulators, built at an angle to the weir line, the stream must turn through this angle, and this change in direction entirely upset the silt distribution. In view of the difficulties in obtaining a good approach channel in the river bed, he desired to emphasize the very great advantage, as pointed out by the Author, that an extractor had over an excluder. Before another silt excluder was built at the head of a canal, it should be a question of first rate importance to consider, whether it could be replaced by an extractor in the canal itself.

The seclection of a site for a silt extractor was, however, very important, and the Author had not touched this subject in his Paper. A natural outfall is of course essential. A point of greater importance was, however, the fact that to work a silt extractor it was necessary to escape a certain amount of water; and except in a few cases where the water escaped could be utilized lower down, there was no supply available for escapage from about the 15th of September to the beginning of the following summer. It was a well known fact that the silt that entered a canal during the monsoon deposited in the head reach, and slowly moved down in a series of waves. Observations made on the L. C. C. showed that the silt that entered the canal at head during July and August, did not reach Chenawan—8 miles away—until about December. So an extractor at Chenawan would be of no use in dealing with the annual influx of silt, as there was no water available for escapage when the silt reached that place. It appeared therefore that an extractor to be of real use should be built in the first mile of the canal.

Referring to para. 14 of this Paper, a few experiments conducted at Khanki in June 1936 had shown that other conditions remaining the same, a reduction in the escapage had actually reduced the quantity of silt going into the canal. In view of the fact that the efficency as exhibited by the calculations showed the excluders to be more useful than they really were, it was imperative that the optimum proportions of escapage should be determined by experiments for each site. Meanwhile a limit to the escapage might be placed by keeping the velocity of water at the entrance to the tunnels equal to the mean velocity of the approaching stream.

In para. 17, the Author advocated a high velocity in the tunnels of not less than 10ft. sec. In view of the remarks in para. 19, this appeared to be rather high, and a lower velocity might usefully and more economically be allowed.

The problem of regarding the channels, as discussed in para. 24 of the Paper, was in his opinion very closely related to that of silt regulation in para. 22. The fact that the silt that really mattered was all fed into the canal at the head in a period of about four months every year, should also have an important bearing on the problem and was not to be lost sight of.

To produce adequate turbulence as described in para. 28 of the

Paper, it was not only necessary to have a certain minimum head, but in the case of escapage through an orifice under a gate, experiments at Khanki showed that the height of the opening relative to the depth of water on the downstream floor was a very important factor in silt sampling. With small openings the highly silt laden water shot past the bed with high velocity, and did not mix in the turmoil until a good distance away from the gate.

To come to the Khanki excluder the approaching stream entered the flume in anything but laminar flow, the flume was barely 200 feet long; there was a change in the direction of flow in the flume itself, and on top of all this, as pointed out by the Author in para. 16 of the Paper, the design of the tunnel entrances was distinctly bad. The mean velocity in the flume was about 4 feet/sec. The velocity in the tunnels was as much as 16 feet/sec. When this velocity of 4 feet/sec. had suddenly to jump to 16 feet/sec., it would certainly throw up eddies and bottom silt. How was it then,

(1) that the excluder had an efficiency of as much as 40% ?

(2) that it had been possible to exclude so much silt at the head that the realtively silt free water had picked up one foot of silt in the first 28 miles of the canal and passed on this load of 4 crores cubic feet of silt into the channels below, without making them any worse ?

As regards the first, this high efficiency could be wholly attributed to the method by which it was calculated, and did in no way represent the actual usefulness of the excluder.

As to the second it had to be remembered that the construction of the silt excluder at Khanki more or less coincided with introduction of the still pond method of regulation, the division of the river above the weir into two channels, and the study and maintenance of optimum conditions of the approach channel immediately outside the flume. It was to all these changes that the amelioration of conditions on the L.C.C. should be attributed. The Speaker did not contend that the excluder was no use at all, but to credit it with all the good done on the canal was to deceive themselves as to its usefulness.

Lastly, the Speaker said, he had to suggest a slight alteration in the Khanki excluder to improve its efficiency. Due to the change in the direction of flow in the pocket, the top water got on the outside of the curve and forced the bottom water to take a sharp turn. As a result of this, the silt concentration in the flume gradually decreased from upstream down. The results of daily silt analysis showed that the silt ejected by the tunnels from opposite the six downstream bays was insignificant as compared with that ejected by the tunnels from opposite the six upstream bays. The alteration proposed had been shown in Plate VI and consisted in extending the three lower tunnels so that they also took off in the area of high silt concentration. Incidentally this would also considerably improve the entrance to these tunnels. He would be glad to know what the Author thought of this proposal.

Mr. **W. P. Thompson** said that reference had been made in the Paper to certain observations on the distribution of silt intensities in the lined and unlined sections of the Bikaner Canal, and as a result of these observations he was given to understand that a lined section was not as useful as an unlined section for an approach channel to a silt ejector.

It was necessary to clarify their ideas on the subject by a process similar to that applied to the silted water of the canal.

The desired condition of flow in an approach channel to the silt ejector had been well stated and this was one which caused the concentration of the silt in the lower layers of the water about to pass the ejector.

The proposal advanced by Mr. King and other designers to have a smooth outline for the approach channel to an ejector in order to obtain concentration of the silt in the lowest layers was reasonable.

The object to be achieved was stream-line flow as contrasted with turbulent flow. Stream-line flow or flow with uniform velocity in a straight line might be compared to a state of rest and as in water in a state of rest there was precipitation of the particles to the lowest layers—hence there was the attempt in devising stream-line flow to obtain this concentration of the silt load in the lowest layers.

Experiments had been conducted to show that a smooth bed induced stream-line flow whereas even a small irregularity in the bed created eddies of sufficient momentum to carry to the upper layers matter suspended in the flowing water.

The lined section of the Bikaner Canal was designed to carry the water at a high velocity in a minimum section.

Such conditions were the reverse of those required to produce stream-line flow and the experimenters had selected the wrong environment for the experiment to compare flow in a lined section with flow in an unlined section to discover the effect of lining.

In order to have comparable sections it was necessary to brick-line a section of the same dimensions as the unlined sections and then to discover if there was a difference in concentration between the two sections.

In order to obtain a separation of the silt load resulting in a concentration of the heavy silt in the low layers, time was obviously necessary in the same manner that some time was required for a turbid fluid to precipitate its load in an ordinary vessel.

This meant that the length of the approach channel had to be sufficient to allow the precipitation to take place.

In the design contemplated for the silt ejector in the Main Line, Upper Bari Doab Canal at Madhupur a short approach channel was inserted and he had pointed out in the report that the time taken by the water to flow through this section was too short to enable any settlement to take place.

On the Upper Bari Doab Canal, however, the load of heavy material in the water was concentrated in the low layers on account of its great density and the approach channel there had been of secondary importance.

In the neighbourhood of Haveli, however, it could well be supposed that the efficiency of an approach channel would materially alter the efficiency of an ejector as a whole and sufficient length should therefore be allowed—the length to be in proportion to the velocity of flow in the channel.

Mr. **Madan Lal** complimented the Author on his careful analysis and brilliant digest of all that had been done towards silt exclusion by silt excluders and ejectors since the publication of Mr. Elsden's Paper on the subject.

He considered the main object of a silt excluder to be to obtain a non-silting channel. With the slopes permissible in the country it was possible to determine a suitable silt grade for the whole system from Lacey's regime channel formulae. Any silt coarser than the grade adopted was bound to deposit in the channel and its elimination from the canal was essential.

Before discussing the comparative economy of silt exclusion at the headworks and silt extracting in the canal, the Speaker felt inclined to review the older method of still pond silt regulation. He asserted that the system had proved fairly efficient wherever it had been adopted as far as reduction in silt entry was concerned. Its efficiency with reference to the grade of silt excluded depended on the general grading of the silt throughout the depth of the approach channel. At Headworks on the lower reaches of a river, where the coarsest silt at the bottom was not very much coarser than the permissible grade, he believed that still pond regulation was bound to prove successful. After all the still pond system of silt regulation consisted in just tapping off the decantated surface water of the river, which could be charged only with the fine grade of silt. The efficiency of silt excluders of the Khanki type which did not cover the whole width of the pocket at headworks on the lower reaches of a river was doubtful.

On the other hand the silt excluders of the proposed Kalabagh type which covered the whole width of the pocket depended for their efficient working on the length of the approach channel flume. Constructing excluders of this type meant stimulating canal conditions in a river which could be done though at great expense. He pointed out that the superficial area covered by a silt excluder in a river was much greater than that of a silt ejector in a canal. Another factor responsible for the excessive cost of a silt excluder, he thought, was the loading for which its slab had to be designed. The cost of the slab was a function of the loading. The loading for tunnel roofs of an excluder would ordinarily be much greater than that of the slab of an ejector since the depth of water in the pocket would generally be two to three times the depth of water in the canal in the head reach. Again, the cost of a slab was a function of the width of the tunnels. In a river the width of the tunnels had of necessity to be kept greater than that of the ejector tunnels from the considerations of catching jungle. Thus the slab of an excluder would be more costly than that of an ejector, all other things being equal. Hence he considered that an ejector in a canal was an economical proposition and for its efficient working had more favourable conditions than an excluder of the headworks of a canal.

He would like to consider the loading for which the slab of a silt excluder should be designed. There would be two cases :

(*i*) when the tunnel ran full bore,
(*ii*) when there was atmospheric pressure underneath the slab.

In the first case, besides the submerged weight of the slab and the silt deposit on it, provision had to be made at any point for the pressure head lost at entrance plus the head lost due to friction up to the point, minus the velocity of approach head if any as shown in the loading curve, below.

h_a = head due to velocity of approach,

h_e = head lost at entrance,

h_f = head lost due to friction.

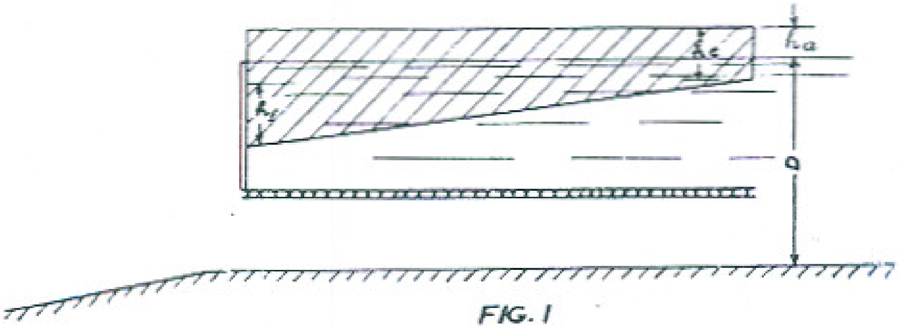


FIG. I

Since the frictional resistance was proportional to the square of velocity, the severest conditions would be obtained when the pond was maintained at the same R.L. and the tunnels discharged full bore in unsubmerged conditions.

It had been the practice in the past to design the slab for the maximum depth of water on it and in consequence the spans of tunnels had been kept small. The trouble of catching jungle would necessitate large spans and hence the importance of investigating the maximum depth of water that would just make the tunnels run full bore.

If H=depth of water in feet at any point,

E=total energy of flow in feet of water,

V=velocity of water in feet/sec,

q=discharge in cusecs per foot width,

$$\text{then } \frac{V^2}{2g}+H=E \qquad (1)$$

$$\text{Now } V=\frac{q}{H}$$

$$\therefore\ H^3+\frac{q^2}{2g}-EH^2=0$$

$$\text{or}\quad q=H\sqrt{2q(E+1)}. \qquad (2)$$

For q to be a maximum with the minimum energy of flow,

$$\frac{dq}{dH}=0$$

$$\text{or}\quad H=\tfrac{2}{3}E$$

$$\text{or}\quad E=\tfrac{3}{2}H. \qquad (3)$$

Substituting the value of E in terms of H

$$q=H\sqrt{2q(\tfrac{3}{2}H-H)}=H\sqrt{qH}$$

$$\text{Now } q=VH=\sqrt{gH^{3/2}}$$

$$\therefore\ V=\sqrt{qH}.$$

Hence at any point in the tunnels where the pressure under the slab becomes just atmospheric,

$$E=\tfrac{3}{2}H$$

$$V=\sqrt{qH}.$$

If H is uniform, E and V would also be constant. For the total energy E at any point, the total energy at the entrance as shown in Fig, 2 would be

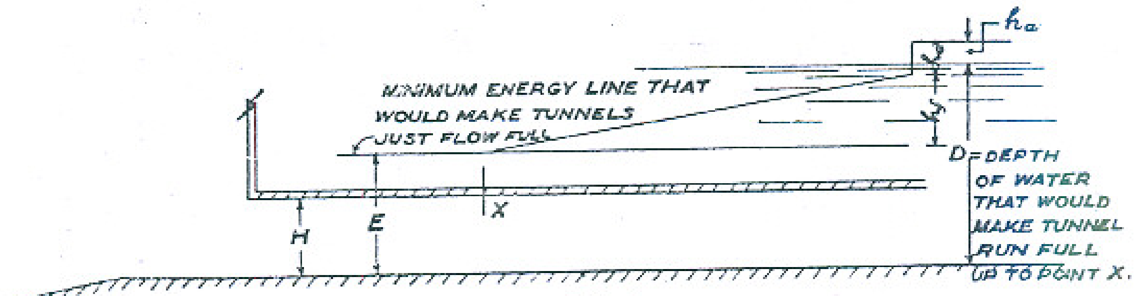


FIG. 2

$$E+h_f+h_e=h_a+D$$

$$\text{i.e. } D=(E+h_f+h_e-h_a).$$

Now the maximum depth of water, D, that would just make the tunnel flow full bore would be a maximum at exit where head lost due to friction h_f would be a maximum and the maximum depth D would be a minimum at entrance where $h_f=0$.

The loading curve is shown in Fig. 3.

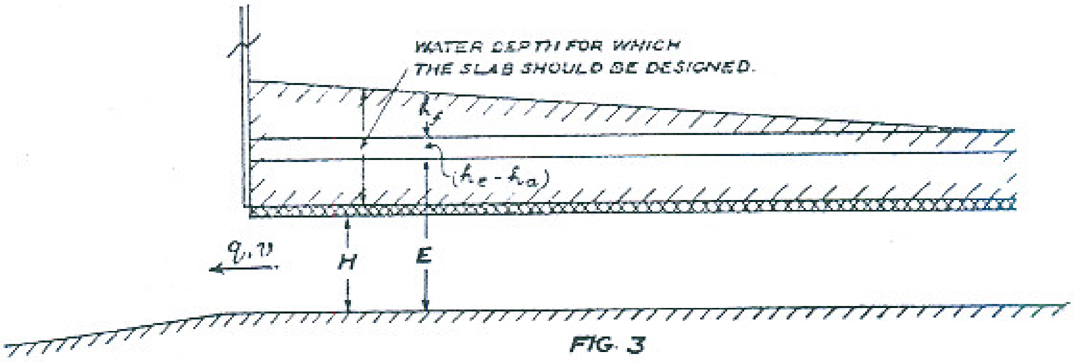


FIG. 3

Mr. **R. K. Khanna** said that the Author's Paper which, he must say, was very frank and ingenuous, freely admitting all the limitations of the usefulness of silt excluders and silt extractors, might be divided into two portions—the scientific design of silt excluding devices, and their function and usefulness. There could be no two opinions about the perfection of the scientific design of these devices, but having devised the most efficient silt excluders and silt extractors, and conceding that they took away the heaviest grades of silt in suspension, the real problem as to the effect of silt exclusion on the regimes of channels still remained unsolved. They had fixed a size of 0·2 mm. of silt particle as being injurious to the regimes of channels, and any silt excluding device which removed all these fatal particles, he must regard as the acme of perfection in the silt excluder. But this theory fell to the ground when he saw channels drawing 2-inch or even larger silt particles, completely immune from silt troubles, and channels drawing 0·02 mm. particles, sorely beset by this trouble, so much so that they would not flow for a single season without heavy silt clearances. Irrigation engineers were familiar with examples of both these types of channel. All the canals offtaking from near the foot of hills were examples of the former type, and silting canals and channels situated anywhere in flat country, such as the Lower Chenab Canal and its numerous offtaking channels, with which irrigation engineers were only too familiar, might be cited as examples of the latter class. This was not all. Of two channels taking off from the same river and the same spot, one might be a silting channel, and the other might be completely immune from silting. Some of the canals taking off from the Ravi at Sidhnai were silting channels, whereas those immediately adjoining showed no signs of silting. And yet all the silt at Sidhnai was perhaps much finer than the prescribed 0·2 mm. grade. Recently he had read in an interesting paper from America; that there was serious silt trouble on certain irrigation canals, and the delinquent silt particle had been no larger than 0·1 mm. There was the case of the Fazal Shah Canal taking off from the Ravi at Sidhnai, which, for discharges varying from about 200 cusecs at head to about 40 cusecs at the trifurcation at its tail at the 11th mile, had a surface slope of 1 in 10,000 and except for the very infrequent silt clearances of a mile or so in its head reach, it had been flowing for sixty years without any silt trouble. In its tail reach, where the discharge was only 40 cusecs, the slope was, if anything, flatter than 1 in 10,000, and the cross sections if anything, showed scour in the bed.

He had mentioned all these discrepancies from the accepted notions of the behaviour of silt in suspension in water to show that the grades of silt had nothing to do with most, if not all, silt troubles, and that therefore the silt excluding devices, even if perfect, would not solve the problem of silting channels. Serious silt troubles had been successfully solved in the past without recourse to silt excluders on the Sirhind Canal and the Upper Chenab Canal, and probably elsewhere also. The remedial measures adopted to combat the silt trouble on the Sirhind Canal in the nineties, which have proved so successful ever since, were, the Speaker said, well known to us all. Mr. Handa had remarked that the system of still pond regulation on the Upper Chenab Canal had proved so successful that the regulator protection in the canal had to be watched for scour. It had been observed, he said, that the following factors were conducive to silt exclusion at Marala :—

(1) The maintenance of a rigid still pond,
(2) Watching the approach channel for turbulence and boils,
(3) Raising the pond gradually to its maximum limit and maintaining it steady in summer,

(4) Suitable manipulation of shutter bays to keep the main stream of the river on the right, so that supplies in the canal ran parallel to the river, allowing decantation opposite each open bay,

(5) Extension of the virtual pocket by having weir bays Nos. 1 and 2 almost always closed while the canal was running.

Of these five factors the only one which was really responsible for the so-called silt exclusion from the canal was the raising of the pond to its maximum limit in summer. Mr. B. K. Kapur, criticizing one of his recent short articles on silt and slopes of artificial channels, made somewhat similar observations about the regulation at Khanki and had described the maintenance of a high pond level as the most effective way of keeping the canal bed clear of silt. And this maintenance of a high pond level was nothing more or less than artificially flattening the slope of the river and making it difficult for the heavy silt particles to flow down to the weir. Or in other words he might say that for a considerable distance above the weir the river had been canalized, or the virtual head of the canal had been shifted higher up the river, and the silting reach of the canal which was formerly the first few miles of the head reach of the canal had been shifted to the head reach of the newly canalized portion of the river some miles above the weir.

It was thus that they ensured immunity from silting of the head reaches of canals by providing a flat sloped approach of a river to the canal regulators. It was possible or rather it was likely that immunity from silting of the head reaches of canals, though not to the same extent, might be obtainable by providing effective silt excluders at their heads. But here the usefulness of silt excluders ended.

There was no rational basis for supposing that by excluding heavy silts at the head of any canal they would improve silting conditions scores of miles lower down the canal. These grades of silt which caused silt trouble lower down would always continue to flow in the canal. So the expectations that as the result of silt exclusion at the heads of Western Jumna, Upper Bari and Lower Chenab Canals, the beneficial effects would travel down to the branches and distributaries were never likely to be realized. Some bed scour had taken place in the first twenty miles or so of the Lower Chenab Canal, and similar though less pronounced scour might take place on the Western Jumna Canal and the Upper Bari Doab Canal. But that would not solve the real silt trouble on any of their branches and distributaries. In the words of the Author, it had taken 80 years for the shingle berm of the Upper Bari Doab canal to travel 18 miles; and it would perhaps take 160 years for the shingle berm to travel back 9 miles. The microscopic observations of retrogression of 0·113 feet, correct to three places of decimals, on the Salampur Feeder as the result of several years working of th : silt excluder at its head should warn them against placing any dependance on these devices. So soon after the construction of the silt excluder at the head of the Western Jumna Canal, the Author himself was beginning to make pessimistic speculations about the time it would take for the effect of the excluder on the canal regime to be at all evident, and had suggested increasing the gradient of the channel for speeding up the effect. They knew from experience that channels with steep gradients were invariably lined with heavy silt particles. So, instead of speeding up the effect of silt excluding the steepening of the canal gradient would tend to neutralize whatever effect it might otherwise have.

Mr. **L. D. Gupta** wrote to say that as he was intimately connected with the design of the Salampur excluder he would like to put forward the following remarks :—

On paragraph 15, page 59, it was stated that in the design of the Salampur ejector little attention had been paid to the disturbance caused by keeping the edge of the diaphragm at various heights. The fact, however, was that they had been in the very lucky position of having a small model of the ejector at Malikpur, on which they had tried the effect of keeping the edge of the cantilever at various heights by tilting it at various angles. This had been tried, but as it had made no appreciable difference in the efficiency, the diaphragm had been made level with the rest of the roof. Nevertheless it had been made in precast pieces, bolted down on the tunnel walls, so that it could be easily raised or lowered subsequently if found necessary.

In paragraph 17, page 61, under tunnel design, the Author had given two devices for securing the same velocity at the entrance to each tunnel,

(1) either by keeping the same tunnel dimensions and varying the width of the canal served by each,

(2) or by keeping the widths served the same and varying the tunnel sections,

and in page 61 he had remarked that " at Khanki and Madhopur there appears to be no device for equalizing the tunnel discharge".

At Madhopur, Mr. Gupta said, there were three main tunnels and each tunnel had a separate surge-well with a regulating gate so that any amount of fine adjustment of discharge entering each tunnel could be very easily effected. In the plan of Salampur ejector, on Plate III of the Paper, the walls separating each surge-well from the others had been omitted and it appeared that this omission had caused the Author to believe that there was no device for equalizing the tunnel discharge at Madhopur. He suggested that separate surge-wells with gates was a third device and in some cases easier and better than the two others.

In paragraph 18, page 61, it was stated "at Madhopur, however, the crest is actually below the downstream bed level and the conditions for approach to the diaphragm edge do not seem ideal".

The following history of the work would show how this happened and that it did not in any way affect the conditions for approach to the diaphragm :—

There had been a Rapid just below the excluder. If this had been allowed to remain as it was, there would have been a rapid falling off in the water surface level and the resultant draw off would have caused the silt particles to jump over the diaphragm edge. To avoid this a raised crest with an arrangement for needles had been built on the Rapid (its exact height being determined on the model at Malikpur) so as to cause no drop in the water surface. It had been the intention to carry the slab roof level up to this crest but as the crest level was much higher than the roof, and to avoid the extra cost of dismantling and rebuilding the old boulder pitching which was only 0·5 foot higher than the roof level, the roof had been smoothly joined with the old boulder pitching of the Rapid. The level of this pitching was 1111·5 and that of the roof 1111·0 and this gave one the idea that the roof of the ejector was below the downstream bed ; but this was done simply for the sake of economy and in no way impaired the conditions for the approach. On the other hand it had been found by actual observations that if needles were put on the raised crest, the efficiency was slightly increased. In the Speaker's opinion, if the excluder roof was not used as a crest, but a separate raised crest was built slightly below the excluder as has been done at Madhopur, it went to increase the efficiency of the excluder.

In paragraph 23, page 64, it was metnioned that "the effect of the ejector on Salampur Feeder is not so noticeable". He would say it was very noticeable. In the very first year of the working of the ejector the downstream aprons of Rapids which were buried for years in shingle, had been exposed and the conditions below Rapids No. 7 and 8 had become so threatening that staggered blocks had had to be put in to safeguard them against further scour.

The **Author**, replying to the discussion, said that he entirely agreed with Dr. Bose's remarks that extractors were preferable to excluders, since in the latter case good approach conditions were difficult to secure. Excluders, however, had the advantage that

(*a*) they excluded sunken debris which might choke an extractor ;

(*b*) if built in conjunction with undersluices and a paved pocket their cost was small, while a high escapage discharge could be obtained ;

(*c*) they would undoubtedly exclude any heavy silt present, thus enabling extractors to function more efficiently ;

(*d*) their escapage did not have to be provided for in the capacity of the canal regulator.

The Khanki type of excluder was the cheapest way of securing these results. The Kalabagh type, which was being constructed more or less experimentally in the left pocket at Trimmu, was considerably more expensive but with its straight approach was likely to be more efficient. Whether the extra money would have been better spent in extra extractors or not would be seen by the results in due course.

If $f=8\sqrt{d}$ was substituted

in $S = \dfrac{f^{\frac{5}{3}}}{1\cdot788q^{\frac{1}{6}}}$, the result was

$$S\times10^3 = 4\cdot47\,\frac{m^{0\cdot83}}{q^{0\cdot17}}$$

which, as Mr. Lacey had pointed out, was very similar to Dr. Bose's formula. The relation $f=8\sqrt{d}$ might not be very accurate but the relation between f, s and q was well established and generally accepted.

The Author was not able to dispute Mr. Montagu's assertion that the Salampur Feeder ejector was designed before the Upper Jhelum excluders.

The distribution of discharge in the tunnels of the Salampur extractors could, it was true, be controlled by the downstream gates. The Author suggested, however, that a design which gave equal distribution automatically, *i.e.*, with the gates fully open, was to be preferred. If one or more tunnels had to be throttled down when in use it followed that their capacity was too great and the design was consequently uneconomical.

He agreed with Mr. Montagu that the roof slab should be set to suit maximum conditions but did not think their knowledge of silt movement was sufficient to permit them to attempt silt regulation with any confidence.

He considered that high tunnel velocities were advisable in the interests of economical design and did not think that water hammer was a serious danger in view of the slow movement of the control gates and the cushioning effect of the air in the standing wave which must be present under the conditions visualized by Mr. Montagu. No difficulty in this respect had been experienced at Dadupur which was designed for hypercritical velocities. He agreed, however, that where there was serious danger of excessive wear resulting from high velocities the fact should be considered in the design.

He was not clear in what way his statement regarding the rate of advance of the shingle bar in the Upper Bari Doab Canal was misleading. Had there been no falls on the Upper Bari Doab Canal the progress of the shingle would have been slower.

The Khanki officers, Messrs. B. K. Kapur and Gulhati, had both expressed the opinion that the improvement in the canal at Khanki was due to improved river control and regulation methods more than to the silt excluder. They instanced the improvement which had taken place at Marala where canal improvement had been effected by river control only and they might also have cited the classic instance of Rupar. It was always unfortunate from the point of view of the scientific investigation when the effects of one factor on the experimental results were liable to be obscured by those of another, and it could not be denied that the improvement was partly due to the causes suggested. Equally, however, the fact that improved river control had been in force did not make it impossible that some improvement was due to the excluder, and the routine silt observations and calculated efficiencies were definite proof that this was so; which cause was of primary importance was at present a matter of opinion.

The Author did not accept Mr. Gulhati's remarks regarding stream-line and turbulent flow. Actually there was no stream-line or laminar flow in canals or rivers except in the convergence from infra-critical to critical conditions. All open channel flow was turbulent and silt distribution was a function of the degree of turbulence.

Mr. Gulhati's idea regarding the uselessness of constructing an excluder at Chenawan was new to the Author and seemed to be sound.

His suggestion for the improvement of the Khanki excluder also was interesting. It appeared that the change of direction of the stream approaching the work and the righthanded spiral motion set up brought the bottom water to the top upstream of the point of separation on the inner side. This being so it might be an improvement to extend the tunnels on the upstream side as he suggested or to shut off the canal waterway over one or two tunnels on the left side.

The Author agreed generally with Mr. Thompson's remarks except that he had not intended his observations regarding the Bikaner Canal experiments to imply that a lined section was not as useful as an unlined section. He had stated in the Paper that the poor distribution obtained was due to the high velocities and had not attributed it to the lining. The observations had been spread over a few thousand feet of the lined canal and practically no improvement of distribution with distance had been observed. At any rate it was clear that any good effect of the lining was very much outweighed by the increase in velocity.

Mr. Madan Lal's observations were interesting but he appeared to have neglected in his calculations the fact that the pressure under the slab was less than the total energy by the velocity head. With the upper waterway closed and the tunnels fully open for unsubmerged conditions the pressure under the slab was atmospheric at the downstream end and the full head of water above the slab must therefore be provided for. At any point upstream the head to be provided for was reduced by the frictional losses in the tunnel stream, and if this was appreciable, as it would be in the case of large works working under a high head, a reduction in the load on this account might be allowed for.

Mr. R. K. Khanna took exception to the standard of 0·2 mm. silt which had been taken for the purpose of silt observations. He should not, however, take the statement that this grade of silt must be excluded as harmful to canal regime, too literally, however. If silt of this grade were present there would certainly be difficulty about berm formation, but if ample slope was available a channel might be made to work fairly satisfactorily with higher grades of silt, and if the country was flat and command difficult, finer silt might give trouble. The 0·2 mm. grade silt was taken as the grade which was likely to give trouble under average conditions, a standard being necessary for the comparison of silt at various sites. The Author would not introduce a silt excluder at the head of a canal such as the Sirhind Canal which was working satisfactorily without it. To do so would be to cause trouble in the maintenance of the canal owing to the alteration of regime which would follow. Where, however, the silt entering a canal was too heavy for the existing slopes as was evidenced by the silting up of channels, a reduction of silt entry was obviously desirable and would reduce maintenance costs—and this was true whether the trouble was at the head, or some distance down the canal as in the case of the Western Jumna Canal, though in that case the results would be delayed. An excluder reduced the entry of silt of all grades though the proportion excluded at any site was higher in the case of coarse than fine silt.

A channel carrying silt of a certain grade could not be made to maintain any slope other than the regime slope corresponding with that silt, except by mechanical means and it was useless to flatten the slope of such a channel unless its silt burden was controlled also.

Mr. Khanna appeared to have misread paragraph 24 of the Paper. The Author's suggestion for quickening up the effect of the head excluder lower down the canal was to flatten the slope, not to steepen it.

Mr. Gupta's remarks regarding the trial of an adjustable edge to the slab in the model of the Salampur ejector confirmed the Author's view that this was an unnecessary refinement.

His remarks regarding the gates were covered by the Author's reply to Mr. Montagu. The Author admitted, however, that from the drawings of the work supplied by the local officers he was under the impression that the surge chambers were interconnected.

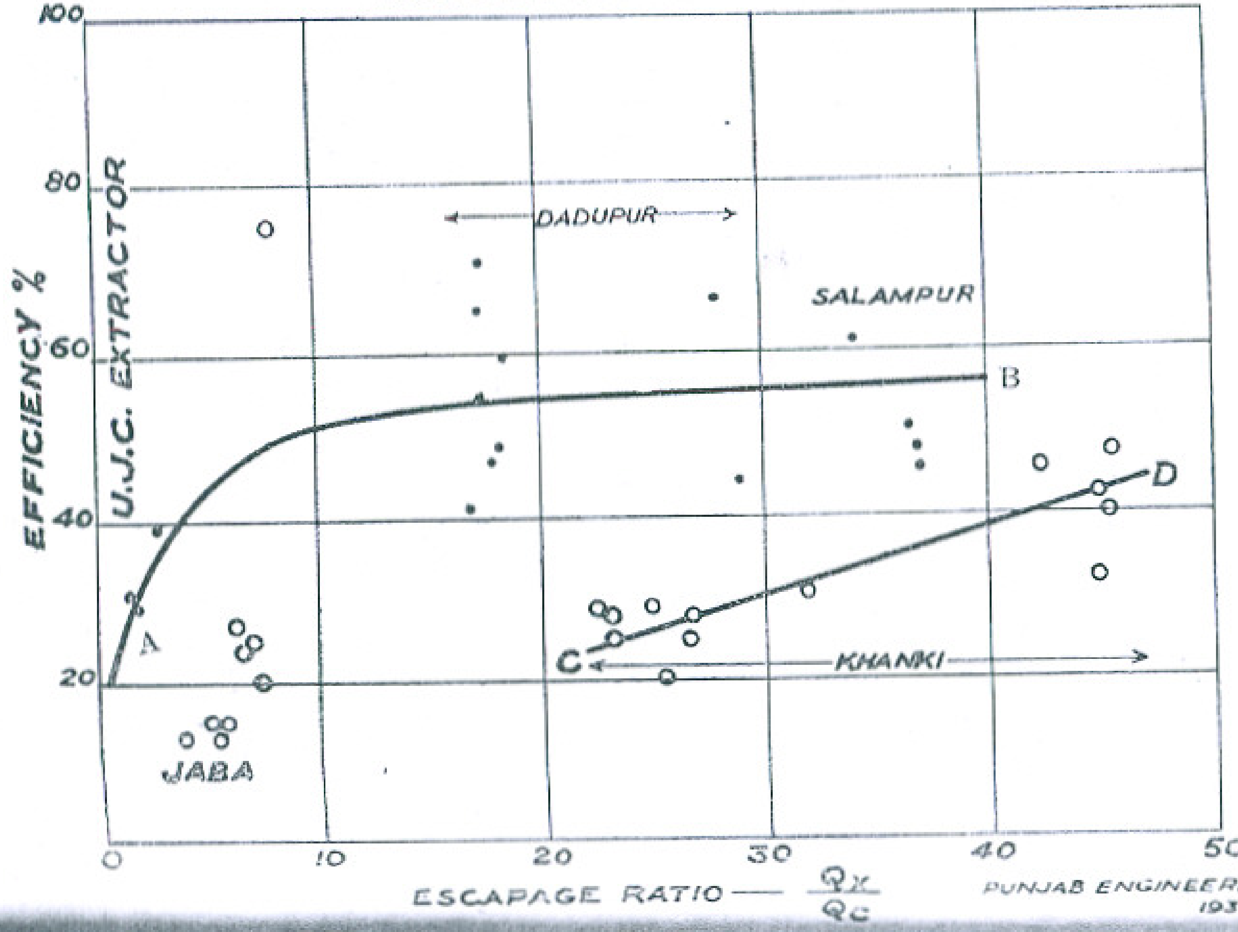
Where head was available he would certainly prefer to use the tunnel roof as a control point and he considered separate control downstream of the work as an unnecessary and wasteful refinement.

The retrogression reported in the Paper for the Salampur Feeder was all that the local officers had any record of. Admittedly, however, it applied only to the year 1937. Previous retrogression had not been kept under observations by reading actual levels and hence could only be a matter of opinion.

PLATE V

PAPER NO. 211

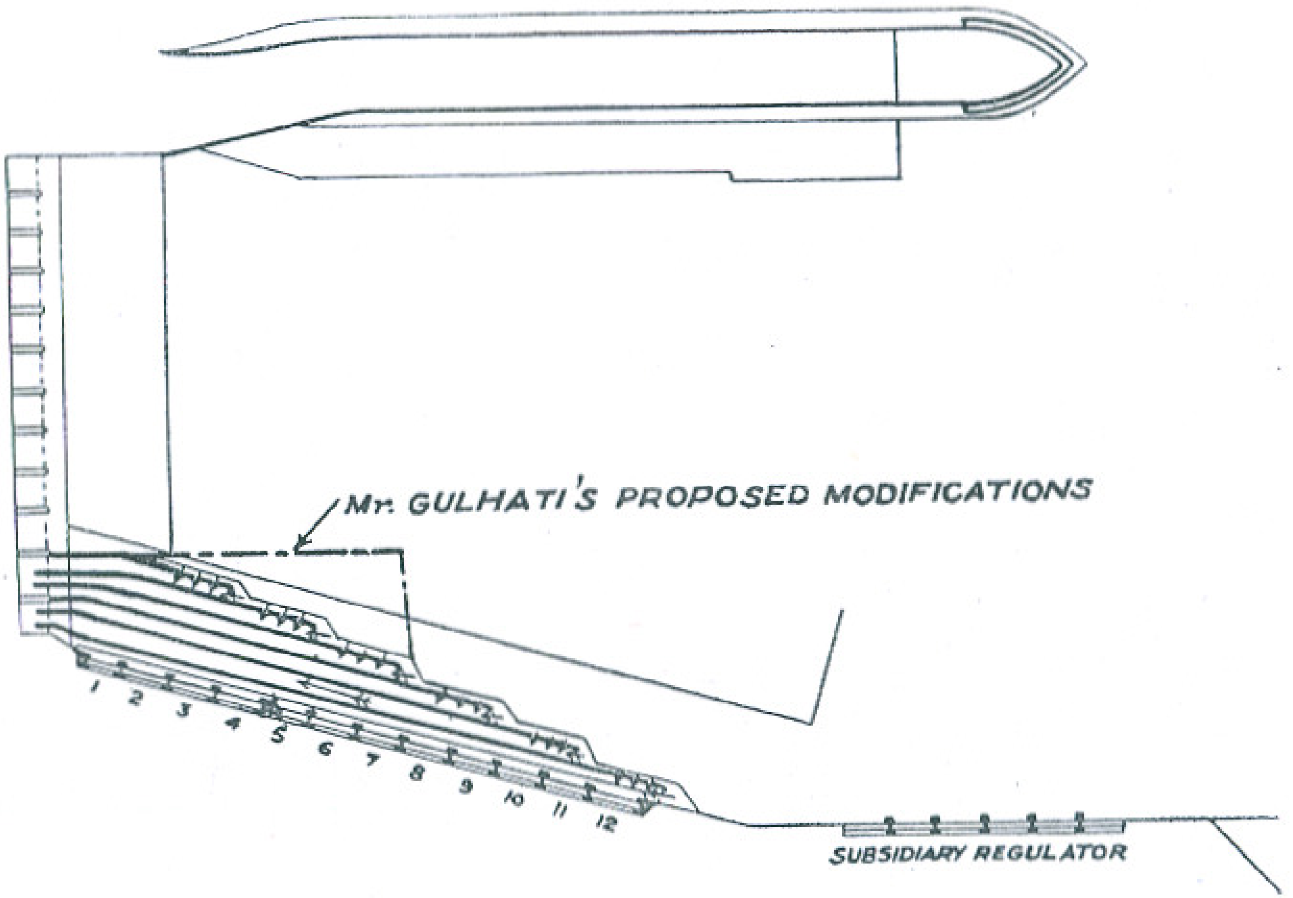
COMPARISON OF EXTRACTOR EFFICIENCIES WITH ESCAPAGE RATIO.



PUNJAB ENGINEERING CONGRESS
1938

PLATE VI
PAPER NO. 211

SILT EXCLUDER, KHANKI HEADWORKS.



PUNJAB ENGINEERING CONGRESS
1938