Mr. Gordon went on to make his own proposals as follows :—

"The exclusion of heavy silt from the main canal has now become a pressing necessity. On the Sirhind Canal one of the measures by which this object was attained was the construction, during 1893-94, in the canal regulator, of a raised sill seven feet high above the floor of the undersluices, with a movable sill capable of rising still higher, so that only topwater would be taken into the canal. Mr. Jeffery, Superintending Engineer of the canal from 1893 to 1899, was of opinion that the high sill had been the means of saving the canal. Mr. Bird and Lala Baij Nath, from personal observations as to the movements of the silt, have no doubts as to the good effect of the sill, and their views are in accordance with my own experience. *In any case a subsidiary regulator is required to admit of the existing regulator being strengthened and repaired. This should be done with the least possible delay. The present condition of the work is not what it ought to be, considering the enormous interests which depend on it.*"

The portion of the above quotation which I have italicized indicates a lack of confidence in the silt remedy advocated, and well illustrates the uncertainty of expert knowledge on this vital problem of the causation of silt deposits.

Mr. Gordon proposed to raise the height of the canal head sill by three feet, thereby reducing the waterway of entry by $234 \times 3 = 700$ square feet ; and to compensate for this he proposed to lengthen the sill from 234 to 416·5 feet, thereby furnishing $182{\cdot}5 \times 6{\cdot}8 = 1241$ square feet of additional waterway up to river low-water level.

The lengthening of the sill of the canal head from 234 feet to 416·5 feet was recommended on the ground merely that increased waterway was needed to compensate for the raising of the sill, and for the increase of discharge from 10,700 to 12,000 cusecs. Nothing was said about the effect of the operation on the *velocity of entry* into the canal ; but incidentally the design proposed had the effect of reducing the mean velocity of entry to $29 \div 6{\cdot}8 = 4{\cdot}3$ feet per second ; with a maximum of, say, *six or seven feet per second, acting at a level of about nine feet above river bed.* This was a very different condition of affairs to that which, as I have shown above, caused the silt trouble in the lower Chenab Canal ; *viz.*, a maximum velocity of fifteen feet per second, acting at a level only six feet above river-bed.

To compensate for the raising of the sill by three feet, an extra waterway of only 700 square feet was needed ; or, allowing for the increase of the discharge from 10,700 cusecs to 12,000 cusecs, an increase of 800 square feet of waterway would have sufficed. Mr. Gordon's design increased the waterway of entry by 1,241 square feet and it is difficult to understand why this was done, if not in order to reduce the velocity of entry. The length of sill in the Rupar case was increased by forty per cent. ; but Mr. Gordon added eighty per cent. to the length of sill at Khanki.

The author has no doubt but that Mr. Gordon's remodelling of the Khanki Canal Head will diminish the silt difficulties in the Lower Chenab Canal ; but it will be deplorable, if the precise operation which effects the cure be not clearly recognized. The heavy expenditure which may result from the present guesswork practice in canal headworks administration is well illustrated in a recent report by an officer, who had had considerable experience of river training works, both at Madhopur and at Khanki. He had noticed, in the early days of the existence of the Lower Chenab Canal, from 1892 onwards to 1900, when the canal did not suffer seriously from silt deposits, that large shoals, or islands of silt, were in existence in the river upstream of the Khanki weir ; and that latterly these shoals had disappeared. He inferred that they had been swept into the canal, to form deposits therein ; and, in order to keep the canal free of silt in future, he proposed to reproduce those shoals artificially in the river, and then protect them from scour by means of stone revetments! He wrote as follows :—" From 1892 onwards, a certain amount of silt regularly entered the canal during the silting season, but up to 1900 it was insufficient to cause any inconvenience. Thereafter it has varied in quantity ; but gradually increasing, until, from 1909, it has been so great as to cause at times the gravest apprehensions as to the uninterrupted supply of the canal. The silt brought down (by the river) settles into shoals, which have no character of permanency, but which yield readily to the indraw of the canal. "

These views are typical of what may be called the Madhopur school of river training works which seeks to cure silt troubles in a canal by training the parent river instead of by improving the canal entrance. If we agree that the indraw of the canal scoured away the Chenab river shoals, it would seem simpler to remedy matters *by modifying that indraught*, than by fortifying the shoals. The great increase

of indraught into the canal, to which allusion has already been made, is well illustrated in the following table :—

Year	Number of days in flow from 1st April to 31st October.	Average summer discharge (cusecs).
1892-93 ...	177	1553
1895-96 ...	177	2403
1897-98 ...	183	4242
1900-01 ...	175	8794
1902-03 ...	180	9303
1905-06 ...	172	9653

When we bear in mind that the discharge into the canal was quadrupled in the ten years between 1896 and 1906, whilst the orifice of entry remained unchanged in waterway, it is easy to find in the increased velocity of entry the cause of the great indraught of silt in excess of the transporting capacity of the canal current.

The Lower Jhelum Canal.

After the Lower Chenab Canal, the next great perennial canal undertaken in the Punjab was the Lower Jhelum Canal, with its head works at Rasul, about fifty miles from the Himalayas. This work was opened for irrigation in the year 1901. The declivity of the river Jhelum at Rasul was about 1 in 3400 ; implying a greater distance from the Himalayas, and a lighter bed-soil, than existed at any of the other canal heads in the Punjab, except that of the Lower Chenab Canal at Khanki, where the declivity of the river was about 1 in 3200 and the distance from the Himalayas also about fifty miles.

The weir across the Jhelum at Rasul was designed to be as nearly as possible at the mean bed level of the portion of the river occupied by it. Major Ottley, who designed it in the year 1887, justified the design in these words :—

" In the present case it seemed that, if the undersluices could be made sufficiently large to pass (without heading up) the volume that naturally comes down the deep channel, up to a level of 709·5, we should not only secure abnormally large undersluice power, but we should interfere as little as possible with the existing regime of the river. "

Major Ottley seems to have overlooked the fact that sluice-power, by which must be understood scouring-power, varies, notwith the width of the waterway, but with the degree of afflux set up. It was a mistake to suppose that great sluice-power could be attained " without heading-up. "

The Rasul Head Works.

The Rasul weir was actually built with its crest level at 707·5 on the left flank, and rising to a level one foot higher on the righ flank. The floor of the sluices was counter-sunk to a level of 701·0, which was also the floor-level of the canal-head, and the bed-level of the canal. The sill of the canal head was built up to 704·0, and the full supply level of the canal was put at 708·0. The sluices were regulated by means of "needles" instead of the usual iron gates. Mr. H. J. Johnston, C. I. E., who built the Rasul Works, wrote of the weir as follows in the year 1902 :—"The work might be termed a 'bar', as its function is not to raise the level of the water, but to keep the bed of the river almost exactly at existing levels".

The Head Works of the Lower Jhelum Canal have experienced troubles precisely attributable to the inadequate height of the crest of the Rasul weir. In the year 1908 Mr. H. V. S. Baker, the Superintending Engineer, reported as follows :—" In the years 1904-06, during the months May to August, when the river is most heavily silt-laden, the difference of level above and below the weir was on the average only 0·25 foot, and could not be increased by erecting the shutters, because until September the level of the river was too high to admit of this being done. In 1907 when a quarter of the length of the weir was fitted with six foot shutters, which remained erect almost throughout the flood season, the average afflux was 0·35 foot. Silt is deposited below the undersluices, and gradually the undersluice channel, and the space between the canal head and divide-groyne, becomes silted up and cannot be scoured out. The depth of silt has sometimes been as much as eight or nine feet above the floor, and as there is no means of checking the flow in front of the canal head by closing the undersluices, and forming a comparatively still pond, silt is freely carried into the canal. The canal head has a fixed cill three feet high, which is further raised by ten-inch planks, as many of these being left in each bay as is compatible with the required supply being passed into the canal, but a raised cill has little or no effect in keeping silt out of a canal unless supplemented by undersluice gates which enable the still pond to be created."

Mr. Baker's Report showed also that in the flood season, when the afflux at the weir was only a quarter of a foot, or so, the head of pressure through the canal-head was about 3·5 feet. From this it may be inferred that there was a greater draught towards the canal than through the weir-sluices ; and this would account for currents highly charged with silt entering the canal, at a low level, whilst there was little or no scour through the weir-sluices.

The Executive Engineer, in charge of the Rasul Head Works in the year 1911, also reported that :—" floods which cease flowing suddenly often leave a deposit of over two feet of silt and gravel on the weir-shutters (in their prone position) which requires to be removed by hand-power before the shutters can be lifted." These are some of the results of building a weir, which is not a weir, but a "bar".

The full supply water level of the Lower Jhelum Canal at its head is now about 708·0. The masonry sill at the canal head is at a level of 704·0 ; but it is now the practice to add a temporary sill, consisting of planks, up to a level of 708·0 or 708·5 during the flood season. Under these conditions the inflow through the canal head has a " free " overfall. The length of the sill is 156 feet, and the full discharge is 4,000 cusecs, which can be passed by a free overfall 3·9 feet deep, which is obtainable when the river water surface is at 711·9. The entire length of the weir is now fitted with shutters six feet high, which can hold up the river to 713·5, or any lower level. Hence the command over the canal is ample. With free overfall the mean velocity of inflow into the canal is 6·5 feet per second ; and the maximum is about ten feet per second at a level seven or eight feet above river bed.

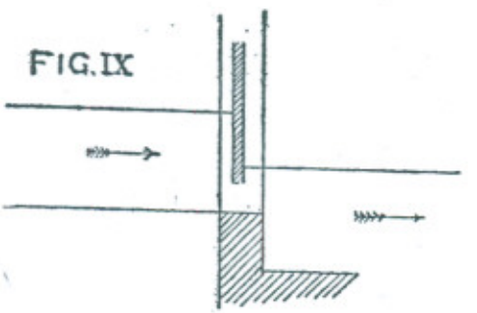
A peculiar condition in the case of this canal is that in its first five miles it is graded at 1 in 4,348, whilst in the next thirty-five miles it is graded at 1 in 6,666. Owing to some difficulty in excavating the foundations of the canal head, it was built at a level two feet higher than originally intended (and hence the abnormally steep gradient in the first section). As a result of this the bed of the canal is now scoured into holes in this five mile head reach. Formerly there were silt deposits in the canal, even in this head reach ; and the gauge in the canal, at below its head used to read in consequence about two feet higher than the gauge at the fourteenth mile ; but now the position is reversed ; the former gauge reads much lower than the latter, and there is no silt deposit in this part of the canal.

The change of condition is due to the fact that formerly in the flood season there was only a very slight afflux at the weir in the river. The river water surface in summer was relatively low, and could not be raised by means of four feet high hinged shutters, as these were not workable in the flood season; and in consequence of the relatively low river water level the sill of the canal had to be kept as low as possible. This resulted in a greater head of pressure, and hence of velocity of flow into the canal, than through the weir sluices; and hence also there was an excessive draught of silt into the canal.

Since then hinged shutters six feet high have been affixed to the weir, in place of the old four foot shutters; the new shutters are more generally workable, and the result is that the water can always be passed into the canal with a "free" discharge over a sill 7·5 feet high, and a mean velocity not exceeding 6·6 feet per second. There is no knowing, however, how long the efficiency of the six foot shutters will last; for at Khanki, on the River Chenab, six foot shutters have proved ineffective, and it has been decided to replace them by still higher shutters.

At the fortieth mile of the canal also, where it bifurcates, it discharges into its branches over falls which have no raised sills, thus :—

FIG. IX



The effect of this is to scour the main line of the canal; as is proved by the silted condition of the branches and of all distributaries downstream of the bifurcation.

The uncertainty of high professional opinion on the causes of silt troubles at canal head works is well illustrated by the

following notes recorded by Mr. (now Sir) John Benton after an inspection of the works at Rasul in October 1910 :--

" What has already happened at Khanki is being repeated here, and there is no reason to suppose that the following evils, experienced at Khanki, will not also result in this case in the course of a few years :—

(a) No surface fall over the weir.

(b) Impossibility of scouring through the undersluices.

(c) River bed silt rolled into the canal.

The great interests involved at Khanki necessitated the adoption of immediate drastic measures as follows :—

(1) Contraction of the width of the river channel downstream by the construction of spurs. The object of these works is to cause lowering of the silt deposits, and the formation of a deep gullet to cause scour.

(2) Construction of an additional canal head with a high sill level so as to exclude sand, and the subsequent raising of the sill of the existing canal head.

(3) Raising of the crest level of the weir by two feet in three out of eight bays.

It is possible that the execution of the works (1) above might have sufficed without the works (2) and (3), but as certainty of action is essential to ensure the vast interests at stake, all three remedial measures are being undertaken."

We see here that Sir John Benton was not quite sure in the year 1910 whether the correct remedy was a contraction of the river channel downstream of the weir, or the construction of a high sill to the canal head, or the raising of the weir crest, but in order to make quite sure he ordered all three remedies to be applied.

At the Simla Irrigation Conference of 1904 Sir John Benton agreed with Mr. Kennedy that it was most desirable to take off from a comparatively slack water pool in the case of canal head works, though he did not think it would be advisable to dispense with a high sill in the canal head ; but in the year 1910 we find him relying on the contraction of the river channel downstream, ignoring the still-pond idea, and doubting the efficiency of the high sill. At Khanki we find Mr. W. B. Gordon in the year 1910 pinning his faith to the high sill, and

discrediting the still-pond and shutter-regulation devices ; whilst in the year 1912 we find Mr. Bates, Superintending Engineer, attributing the existent troubles there to that very downstream contraction of the river channel which Sir John Benton thought in 1910 would be an all-sufficient cure.

Finally, though Mr. Baker in 1908 asserted that a high sill " has no effect in keeping silt out of a canal unless supplemented by undersluice gates which would enable a still-pond to be created ;" we now find conditions radically changed, although there is no still-pond at Rasul, the undersluice gates being kept open at the bottom for scour during the silting season.

One of the remedies advised by Sir John Benton at Rasul in October 1910, was the raising of the crest of the weir by two feet in three out of its eight bays.

Presumably this was a recognition of the fact that the weir crest was too low ; but it is not easy to see why the crest should be raised in three-eighths, only, of its length, at the centre, and not uniformly throughout its length. It was recommended on the analogy of similar work done at Khanki; but in the Khanki case Mr. Gordon advocated the raising of the weir crest in the following words :—

"The raising of the crest in the three bays will have no appreciable effect in increasing the afflux above what it was in the big flood of 1903 when at least three bays were masked by islands."

If the raising of the crest was not calculated to increase afflux, why was it done at all ? It is hardly advisable to alter the crest profile of a weir, merely to suit the contour of accidental shoals upstream, which may vary after every flood. As a matter of fact calculations shew that raising 1,500 feet of the length of the crest of the Khanki weir by two feet would probably increase the afflux in high flood by nearly a foot.

Full Discussion desirable.

In the interests of scientific progress the author would urge the threshing out of details of canal head works designs by a full discussion. When we find such eminent authorities as Sir John Benton and Mr. W. B. Gordon admittedly uncertain as to the real cause of the empirical cure of the Sirhind canal silt troubles at Rupar twenty years ago, and trying various expedients, by process of trial and error in each case dealt with, it is surely an indication of the necessity of some more systematic and scientific

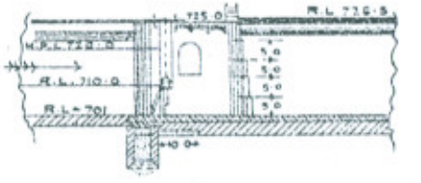
HEAD WORKS

FRONT ELEVATION OF HEAD REGULATOR

SCALE- 1/1600

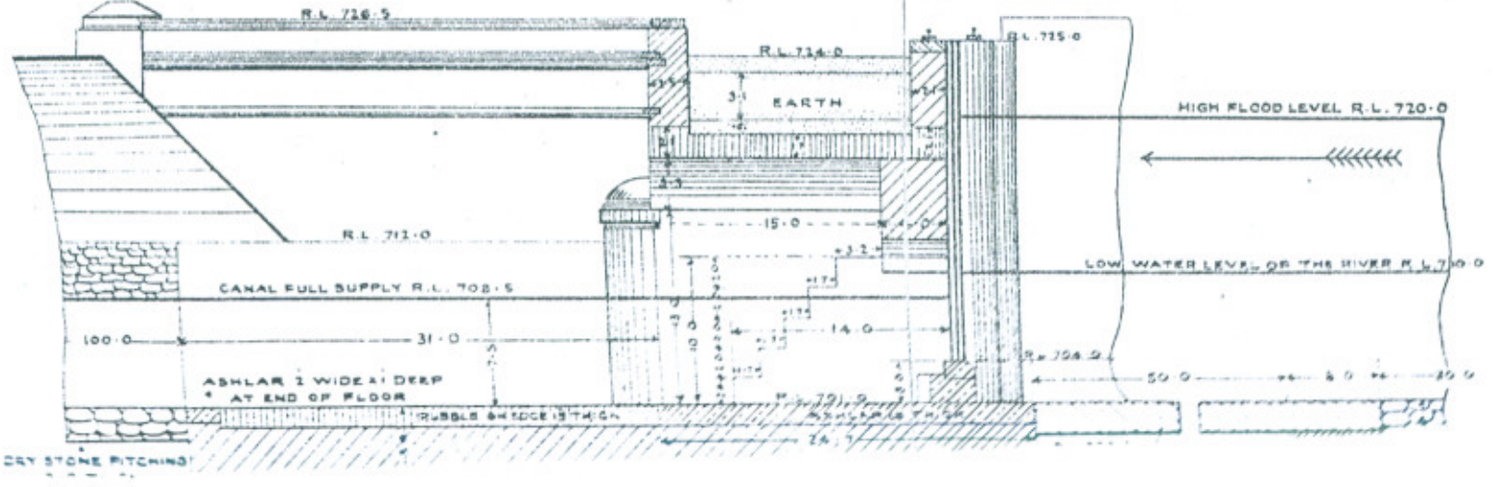


CROSS SECTION OF UNDERSLUICES



CROSS SECTION OF HEAD REGULATOR

SCALE- 1/400



investigation of the most important problem that Punjab Irrigation Engineers have to face.

If the theory set forth in this paper does not find general acceptance as a reasonable explanation of our canal and river silt phenomena; it will at any rate have served its purpose if it leads, by discussion, to some surer system of canal head works science in the future.

Declivities of Canals and Rivers.

The following table, which exhibits the respective declivities of various canals and rivers at the offtakes of some of our principal perennial canal heads, may be of interest :—

River.	Site.	Canal.	Declivity of river one foot in	Declivity of canal one foot in
Jumna ...	Tajawala. ...	Western Jumna.	300	400
Ravi ...	Madhopur	Upper Bari Doab.	300	1,250
Sutlej ...	Rupar ...	Sirhind ...	2,500	8,000
Chenab ...	Khanki ...	Lower Chenab ...	3,200	6,250
Jhelum ...	Rasul ...	Lower Jhelum ...	3,400	4,348

In the case of the Western Jumna Canal Head any o
standing on the bridge can hear the rumbling, and fe
tion, of boulders and shingle rolling over the floor
but, as the declivity of the canal is nearly the sa
the river, no trouble ensues in the canal. In t
Canal the declivity, though steep, is only one quar
the river, and serious deposits result on the canal of the Sirhind
Sirhind Canal, where such startling silt deposits occ nt in scouring
clivity of the canal was less than one-third of that t ; there must
whilst in the Lower Jhelum Canal we find scour wh ill not cause
slope is nearly the same as that of the river. y to the crest
e stream.

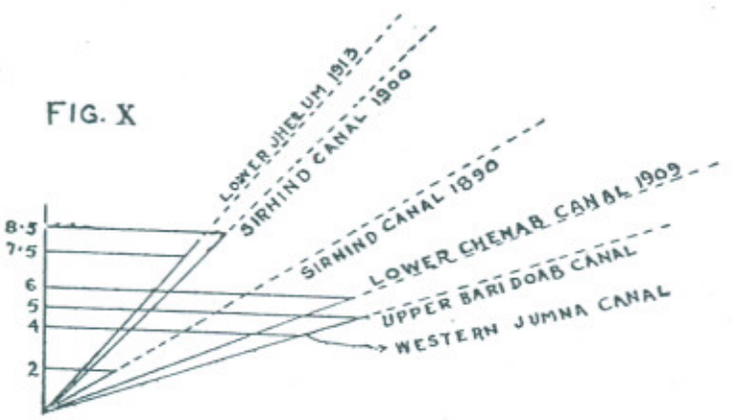
Theory Illustrated.

It has been already mentioned,* that the maxim
of inflow into the heads of the Western Jumna and
Doab Canals are twelve and fifteen feet per second, a level is shown
and five feet, respectively, above the bed of the river, er them with-
of the weir sluices being regarded as the virtual b in measurement
river at the canal heads. It has also been indica e faced without
ressure is to the

* Pages 62 and 69. † Page

corresponding data in the case of the Lower Chenab Canal head, before its enlargement in 1910-11, were fifteen feet per second at a level six feet above river-bed. It can further be shown that the conditions of inflow into the Sirhind Canal, were 3.3 feet per second over a sill two feet high, in the days of its silt troubles ; and about 8·5 feet per second, over a sill seven to ten feet high, when its silt troubles began to be cured and the diagrammatic comparison of all these various conditions of inflow instructively illustrates the author's views as to their effect in the matter of silt-transportation :—

FIG. X



:al line of the diagram represents, to a scale of 1-150, f the sills of the various canal heads, while the ·s represent the maximum velocities of inflow to a foot-one hundred feet per second ; and the radial conventionally the chords of the curves of velocities of approach in the vertical plane of flow. These re- ordance with the theory that the silt-carrying power : greater the divergence of the velocity curve from n the vertical plane of flow, as may be seen by e radial lines representing the conditions of the .l in 1890 and in 1900 respectively, and also by a ›etween the inclination of the shingle-carrying lines rn Jumna and Bari Doab Canals, with that of the ›wer Jhelum Canal.

Canal Heads.

iples of design here advocated can also probably ied to the case of the heads of inundation canals, in flow during the high stages of rivers, but

nothing has been suggested which would prevent a river from changing its course and leaving stranded, high and dry, the head of a canal unprovided with a weir across the river at the point of offtake. In cases like that of the original project of the Lower Chenab Canal, where there was no question of the river changing its course, but where the canal became choked with deposits of silt to a level higher than the water surface in the river at its low stages, a properly-designed head, excluding silt from the canal, might enable the canal to work successfully without the help of a river weir. The case of the project of a great canal to offtake from the Indus at Sukkur may be one in point, but though the author knows nothing definite as to the merits of this project, he understands that the Indus cannot change its course at Sukkar, and that the only question is whether a canal offtaking there can operate successfully without the help of an expensive weir.

Sluice-Power.

The depth below the weir-crest of the undersluice-floors of the principal head works is as follows :—

Upper Bari Doab	...	6·5 feet (originally only 3 feet)
Sirhind ...	...	9·5 feet.
Lower Chenab	...	7·2 ,,
Lower Jhelum	...	6·5 ,,

The deepest sluices, relatively, are those of the Sirhind Canal, and these have also proved the most efficient in scouring power. But mere *depth* of sluice is not sufficient ; there must also be afflux in order to produce scour. Sluices will not cause scour, no matter how deep they may be, relatively to the crest of the weir, if the weir itself creates no afflux in the stream.

Afflux at Weirs.

That our river-weirs are generally at too low a level is shown by the fact that the greatest floods have passed over them without greater afflux than about two feet in mean measurement right across the river, and greater affluxes could be faced without fear, seeing how necessary a great head of pressure is to the efficiency of the undersluices.

The barrages across the River Nile, at Asyut and at Esna, consist of a series of sluiceways, similar to our Indian weir sluices, stretching across the whole width of the river, and resting on a simple slab of concrete and masonry about ten feet thick. They are not founded on wells, although their bed-soil is pure sand much finer than that of the Punjab rivers ; and yet they work under affluxes amounting to as much as from five to eight feet, for long periods of time. The Okhla Weir, across the River Jumna near Delhi, is constructed on the surface of the river-bed, in " micaceous sand almost as fine as flour " with no foundations below that level. Yet it passes floods to the extent of 1,50,000 cubic feet per second, with a depth of six feet and a velocity of 9·3 feet per second over crest, successfully ; and sustains a head of ten feet of water pressure without injury.

The weir across the River Kistna in Madras is built on sand, with its crest sixteen feet above the summer level of the river, and from twenty to twenty-five feet above the deepest bed level of the river. Floods in this river, before the weir was built, used to rise from thirty-five to thirty-eight feet in height ; and the velocity over the crest of the weir has amounted to sixteen feet per second in a depth of twenty feet of water.

Many other cases might be cited, of weirs of great magnitude, the experience of which indicates that the design of the Punjab river weirs has been governed in the past, *qua* afflux, by far too great timidity ; and, as a greater afflux is necessary for the better working of the sluices, the case for a display of more enterprise in this direction, needs no further demonstration.

Calculation of Afflux.

We have before us sufficient data for calculating approximately the theoretical afflux which might be expected to occur in high floods passing over the principal canal headworks and the following calculations by formulæ, agree as well as can be expected with the affluxes of actual floods on record.

At Madhopur, before the construction of the weir, the cross sectional area of the highest flood of the River Ravi (see Plate III) was recorded as 14,200 square feet, and if the discharge of that flood was 2,00,000 cusecs its mean velocity would have been four feet per second.

The construction of the weir and sluices reduced this waterway, up to high flood level, to 11,480 square feet ; which, by calculation, indicates an afflux of 1·67 feet. After the undersluices had been destroyed by floods, and the weir

breached, the floor of the sluices was lowered by 3·5 feet, and this, by calculation, would have the effect of reducing the afflux of a 2,00,000 cusec flood from 1·67 feet to only one foot.

If the discharge of the maximum flood were only 1,42,000 cusecs, instead of 2,00,000, the calculated afflux would be only 0·8 foot before, and 0·6 foot after the floor of the sluices had been lowered.

At Rupar, on the Sutlej, the maximum flood waterway was 25,600 square feet before the construction of the head-works, which reduced the waterway to 17,900 square feet. For a flood discharge of 2,80,000 cusecs this would imply an afflux of two feet.

At Khanki, on the Chenab River, the corresponding data would be :—

Maximum flood waterway ..	1,17,000 square feet.
Mean velocity ...	... 5 feet per second.
Waterway reduced by works to ...	48,500 square feet.
Afflux	... 2·2 feet,

At Rasul, on the Jhelum River the corresponding data would be :—

Maximum flood waterway ...	1,06,000 square feet.
Mean velocity ...	... 5·5 feet per second.
Waterway over works ...	53,000 square feet.
Afflux... ...	... 1·65 feet.

At Marala, on the Chenab River :—

Maximum flood waterway ...	87,000 square feet.
Mean velocity ...	... 6 feet per second.
Waterway over works ...	40,000 square feet.
Afflux	... 2·5 feet.

Weir Shutters.

In the past it has been sought to make good deficiencies in the design of the weirs by affixing hinged shutters to their crests ; shutters which can hold up the river's flow when low, and which can be dropped out of the way, on the approach of floods.

On the Rupar weir shutters four feet high were first employed, which later gave place to shutters six feet high. On the Khanki weir the original idea was to have shutters only 2·5 feet high ; this was increased first to four feet, and then to six feet ; whilst now a further increase of height is contemplated.

On the Rasul weir the height of the shutters has recently been raised from four feet to six feet ; and no one can say where the process of increasing the height of the shutters will end.

Would it not be better to make the masonry crests of our weirs comparatively higher in future ; even if we cannot altogether dispense with the help of the hinged shutters for storing up low supplies ?

It is not as though the hinged-shutters principle of design were entirely on the side of safety. The worst accidents to our Indian river weirs have occurred, not as the result of floods, but at low stages of the rivers concerned, and were directly attributable to the hinged shutters on the weir crests. The damage to the Khanki weir, in January 1895, which necessitated nearly doubling the dimensions of the weir, was due to the shutters holding up water four feet higher than weir crest, and if there had been no shutters on the weir crest this accident would not have happened. The damage to the Narora weir on the Ganges, in March 1898, was due to the shutters holding water two feet above the crest. This cost six lakhs of rupees to repair. The damage to the Rasul weir, in the year 1904, was due to a flood overwhelming the work before the shutters on the weir crest could be laid flat. This danger is always present, and involves great anxiety and watchfulness wherever shutters are used.

The Cost of Head Works.

The expenditure on the principal perennial canal head works in the Punjab, down to the end of the year 1911-12 has been as follows :—

Canal.	Expenditure (Rupees) debited to		
	Capital Account.	Revenue Account.	Total.
Western Jumna	,,03,007	19,29,984	24,32,991
Upper Bari Doab	7,77,450	46,66,071	54,43,521
Sirhind	13,69,229	11,47,656	25,16,955
Lower Chenab	51,85,409	18,19,740	70,05,149
Lower Jhelum	31,76,590	8,60,569	40,37,159
Upper Chenab	72,01,822	Work unfinished.	

The steady increase in the capital cost of the more recently built works is very noticeable, and calls for critical scrutiny. The total cost of the Upper Bari Doab works is more than double that of the Western Jumna or Sirhind works ; the excess being mainly due to the superfluous and ill-devised river

training works at Madhopur. Had these training works never been undertaken, and time and money devoted, instead, to the improvement and strengthening of Col. Crofton's original design, a saving of at least thirty lakhs of rupees might have resulted.

The eighteen lakhs of expenditure debited to the Revenue Account of the Lower Chenab Canal has largely been due to the disastrous effect of the hinged-shutters device for making the Khanki weir fulfil its functions.

The Lower Jhelum Canal Head Works were avowedly constructed on cheap lines ; and it is probable that further heavy expenditure thereon will become necessary hereafter ; especially when it has to hold up the entire winter flow of the river, after the opening of the Upper Jhelum Canal.

The capital cost of the Upper Chenab Head Works at Marala, still under construction, is likely to be fifty per cent greater than that of the similar works at Khanki on the same river ; and it remains to be seen what further expenditure must be incurred in making good its defects during the next twenty years.

Concluding Summary.

In this paper the author has confined himself practically entirely to the design of Canal Head Works from the point of view of the exclusion of silt from a canal, and in conclusion would suggest the following procedure in the design of future head works :—

(*a*) Given the highest level of the land to be irrigated by a proposed canal ; the latter should be graded upstream, and proportioned, as to width and depth, in such a manner as is best calculated to prevent it from either silting or scouring.

(*b*) The alignment of the canal, so graded, will usually have much latitude of choice in the point of offtake from the river ; as the declivity of the river is generally much greater than that of the canal. It will thus be usually possible to select, within a considerable range of choice, the site that is best suited to engineering considerations.

(*c*) Having selected the point of offtake, a cross section of the river channel, up to maximum flood level should be carefully surveyed, and the length and crest-level of the weir fixed with reference to the

greatest permissible afflux. This afflux should be much greater in future designs, than that experienced at existing works; and might be put at not less than four feet, under the maximum probable flood.

(*d*) The afflux can be obtained in two ways; *viz.*, either by a relatively long weir at a high level, or a relatively short weir at a low level. The latter is the type of the Nile barrages in Egypt; and would imply, in an extreme case, the extension of what we call undersluices throughout the length of the weir. But the conditions of our Punjab rivers would probably be met more suitably by a high weir, affording a draught towards its sluices at the canal end. We should rely on drawing the perennial flow of the river towards the canal head by means of the design of our weir and sluices, rather than by means of training works, spurs, groynes, or guide-banks in the river upstream, and it ought to be possible to attain this end, without hinging shutters to the top of the weir.

(*e*) In the design of undersluices it should be borne in mind that what is wanted is high velocity and great erosive power, rather than great waterway and great discharging capacity. Sluices should, therefore, be relatively narrow and deep in waterway, relying for their draught and velocity on the afflux set up by the weir; and their discharging capacity need not be very much greater than the full capacity of the canal at the low stages of the river.

(*f*) The sill of a canal head regulator, or intake, should be fixed, if possible, at a level equal to, or higher than, the full supply level of the canal, so as to ensure conditions of "free" overfall at all times; and the length of the sill, or the width of the waterway of entry to the canal, should be so great, as to ensure such a low velocity of entry, as will not have greater silt-carrying power than the canal itself, at the low-water stage of the river's flow. As the water-surface of the river rises in flood, the permanent sill of the canal head should be supplemented by movable sills of gates, which, by rising from

below and passing the inflow over their tops, will keep the velocity of entry, or inflow, as low as necessary. Exceptionally high floods of the river must be kept out of the canal by closing the canal-head gates from above.

(*g*) The river training works should, as a rule, be restricted to such marginal embankments as may be necessary to contain the river in its proper channel; and to prevent such damage to riverain properties as may fairly be attributable to the influence of the canal works.

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DISCUSSIO...

MR. SCHÖNEMANN said he felt that as his paper was so lengthy he would have to be very brief in presenting it to the Congress for discussion. Part of the lengthiness was due to a feeling that it would be more interesting to describe past experience and the past history of the various perennial Punjab Canal Head Works, and the opinions expressed thereon by eminent engineers in the past, than to merely content himself with expressing his own views on the subject. Of the seventeen thousand words contained in the paper, no less than ten thousand were descriptive of these Head Works and their past history; and only a comparatively small portion was devoted to his own opinions.

MR. R. E. PURVES said that a day or two before the printed papers reached him, he was informed that his old friend Mr. Schönemann had taken a lot of trouble to write for this Congress a paper on the design of Canal Head Works. He knew that a paper on such a subject from this writer would immediately arrest attention, and would be complete and interesting. He felt almost certain that there would be an illuminating exposition of the old subject in a new aspect, and that the subject would be treated in a manner quite apart from the methods of ordinary contributors. Those who had read Mr. Schönemann's paper must have noted that these anticipations had been amply fulfilled.

The first striking aspect of the paper was the forceful manner in which the opinions, views, and designs of their predecessors for the last forty years had been introduced to their consideration. There was nothing more prominently treated or brought forward, time after time, and nothing that was so clearly on the surface. It should cause most of them to be thankful that they had not born at the same time as their predecessors. There were *awful duffers* in those days! Those worthy gentlemen, it would appear, went on blundering from work to work, making the same stupid mistakes without knowing it, and without realizing that some day they would be having a gay old time at their expense. Their intellectual vision was clouded with some of the silt that enters the canals, and they do not appear to have understood the question one little bit. They just copied their own mistakes in designing important works. There was only one redeeming point in their favour, and it was this, that they succeeded somehow in overcoming the silt troubles, although,

according to the writer, without knowing how it all came about. This was how the case for their predecessors had been presented to them, and the speaker could not help giving expression to a pious wish that some day, one or other of their successors would deal as kindly with them, when they were not there to fight for themselves. He did not hold a brief, however, for their absent and revered predecessors, and would return to the paper, and select one more striking aspect of it.

As beneath the surface of the turbid waters of a swiftly flowing stream were to be found the strong under currents that kept it turbid and carried it forward, so underlying this exhibition of their predecessors' mistakes and stupidity would be found the root idea of the paper, running from end to end. The paper would have been without interest, but for the propounding of a hitherto little known theory of the silt-transporting power of a current, which had now for the *first* time been so clearly put forward, and which appeared to be in accord with the theory as stated by Dupuit. Around this great central idea was found the history of the Punjab Canal Head Works, the river hydraulics, the silt troubles, and the errors of design, which marked the work of a long series of ignorant engineers. In fact the essence of the paper was in the theory of silt-import, which was intended to establish for all time a great advance in their knowledge. If the theory was sound and true, a new system of designing was urgently needed, and a lot of money was required to alter all existing works. If, however, the theory was erroneous, then the whole fabric of conclusions based on it fell to the ground like a pack of cards.

In the diagrams which the speaker had prepared with a view to ascertain if possible what ground there was for a belief in the top-water theory, which was supported by some excellent hydraulic engineers, the full lines in both figures were intended to represent a series of velocity curves, at regular and equal intervals of time, advancing towards the canal head regulator orifice. The dotted curves were intended to represent the gradual descent of pieces of solid matter from the surface of the stream to the bed, unaffected by vertical eddies and only acted on by the horizontal velocities. If there were no motion in the stream such particles of specific gravity greater than water, would descend vertically. For the sake of simplicity he had taken the liberty to assume that these heavier than water particles dropped equal distances through the water in equal intervals of time corresponding with the velocity curve time intervals. The assumption was arbitrary

TOP WATER THEORY

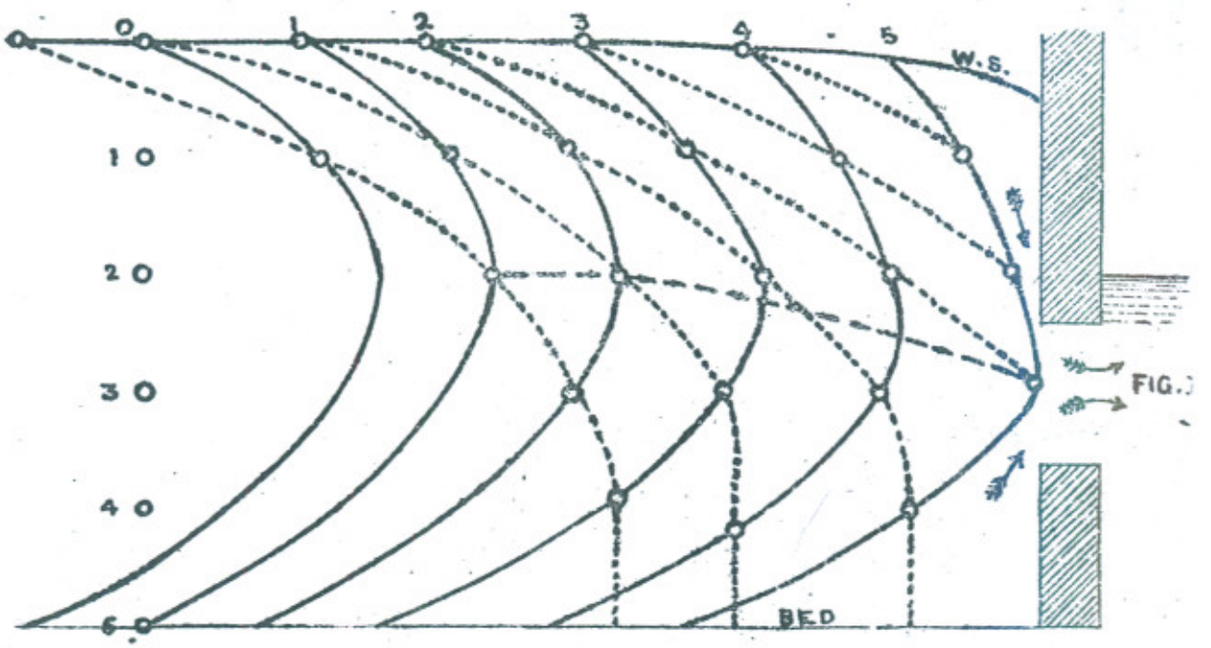
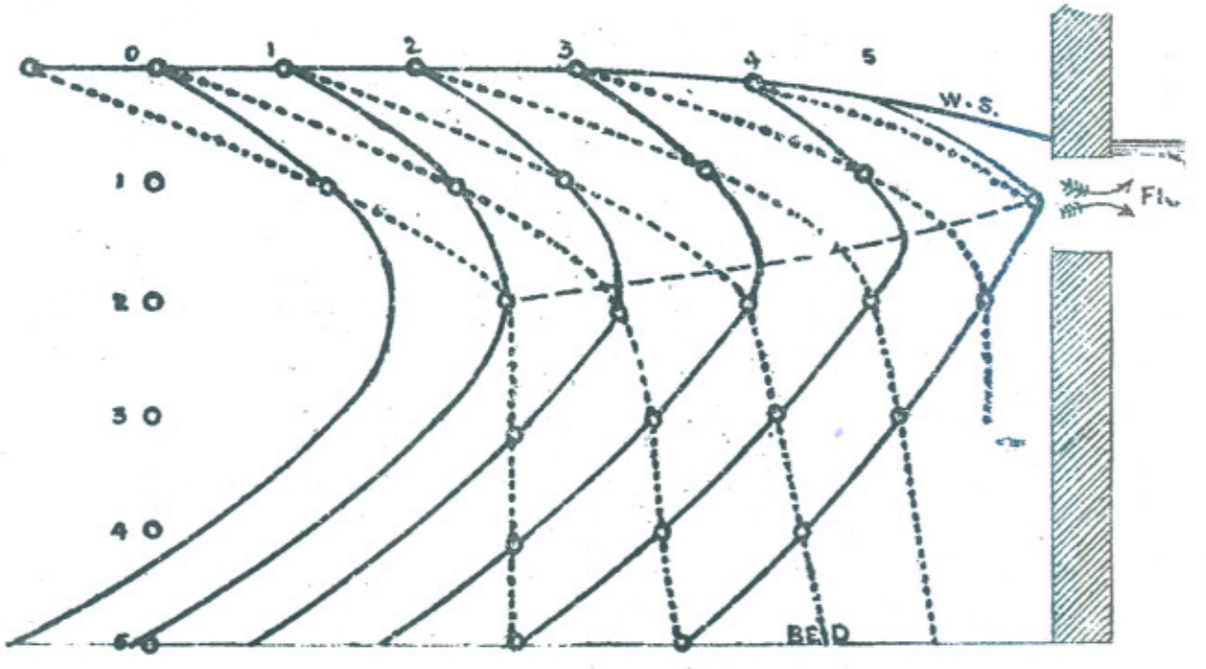


FIG.



but it obviated the complications of a more elaborate consideration of the rate of descent. The broken lines showed how the particles moved under the action of gravity and horizontal velocities. The dip which was noticeable on the surface of the stream, represented the area of contraction resulting from the acceleration of velocity due to the draw into the canal. Figure I represented a low line orifice ; Figure II, a high line orifice. In both cases as the stream approached the orifice the descending particles advanced towards the canal regulator, until some of them entered the canal. The shaded portion of each diagram, represented the mass of particles always entering the canal. It would be noticed that apart from any matter swept into the canal by vertical eddies, relatively more particles entered with a low sill level than with a high sill line. Might it not be reasonably accepted that there was some truth in the top-water theory ?

His third diagram was intended to illustrate what was likely to take place under the influence of the difference of velocity of adjacent threads of the current. This was the theory advanced by the writer of the paper under discussion. The diagram was a conventional representation of two men, and though not artistic, would, he hoped, do. The man in front was supposed to be moving forward with a certain velocity towards the door of his dwelling. The man behind was supposed to be pressing forward the head of the first man with a velocity greater than that of his feet. They then had an illustration of the difference of velocity of two adjacent threads of current. Ordinarily it would appear that the leading individual would under the circumstances exhibit a tendency to fall forward on his face at his door step, but according to the writer's new theory, this anticipation would not be fulfilled. The leading man on the contrary would give quite a startling exhibition as a transformed acrobat. He would begin to spin round on his centre of gravity, and would at the same time begin to ascend, rising upwards up and up, slowly at first, but quicker and yet quicker with an accelerated velocity, until he was shot into the house through the window of the first floor, if conveniently left open. Might it not then be said, with some reason, that the man w.- gone in the upper story ?

MR. FOY said that the paper was of particular interest to him on account of the references to the Bari Doab Canal Head Works at Madhopur. He had gone there some thirteen years ago as Sub-divisional Officer and had been connected with the place for nearly three years. It was therefore very flattering to find

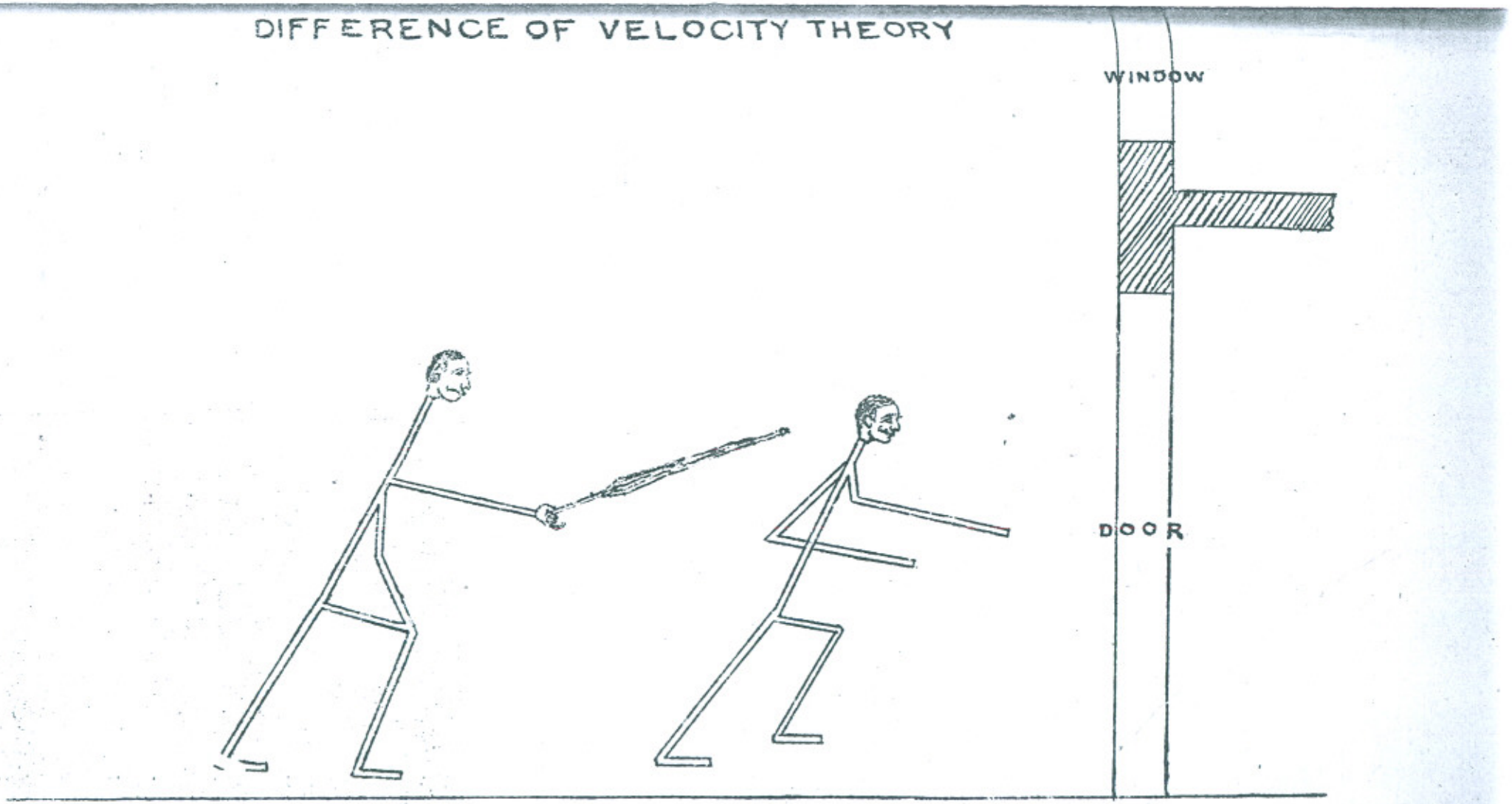
some one who had devoted special consideration to the subject confirming his own impression of the time. Although he had regretfully to admit that he had devoted no particular study to the subject yet he remembered often, when standing on the regulator, hearing boulders and shingle rumble through, and thinking of the annual shingle clearance looming ahead. He had wished he could pull down the regulator and build a wider one, and one higher above the river bed. Mr. Schönemann however went further than this, and advocated the total abandonment of the training works, and a concentration of all resources on the strengthening and, he presumed, raising of the weir.

This did not appear to him to be feasible, and while admitting that something might be done to the weir, he could not realize how that alone would control the vagaries of the main stream. In a river bed of such steep gradients, the effect of controlling the river at any point went back such a short distance that half a mile or so above it the river was again out of control. How did Mr. Schönemann propose to deal with the river, assuming the training works to have been abandoned, and the river to have gone to the right flank of the weir, while between it and the Canal Head a big shoal had formed upstream of the weir? When the river fell how would water be made to enter the canal across the shoal? Such a case practically occurred, or was in danger of occurring in 1903. The mainstream deserted the high cliff along which it had flowed for many years, cut into an old channel about three miles above the weir, and but for the upper training works would have left that side entirely. As it was, it cut a big gap of two or three hundred feet in the weir. Mr. (now Sir John) Benton, Chief Engineer, came down and raised the Dhanna and Lower Training Works, strengthened the Upper Training Works, and built an entirely new training work between the upper and lower. He admitted that the remedy was afterwards found to have been too drastic when an uncomfortable volume of water impinged on the regulator; but still something had to be done to prevent the river changing over, and nothing at the weir itself, contracting it or raising it, would have kept the river on the canal side.

In a river with such steep gradients training works successively upstream were essential, the one immediately above being built where the effect of the one below ceased to be felt.

With the other Head Works he had no personal acquaintance, but there was one point on which he would like to hear the author. Mr. Schönemann had recorded the actual afflux at

DIFFERENCE OF VELOCITY THEORY

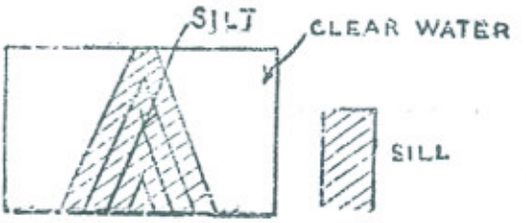


each Head Works, and had also recommended that the minimum afflux should never be less than four feet, but it would be interesting to know what was the afflux aimed at in the designs. Had that ever been attained ?

In attempting to calculate the afflux in a river many assumptions had to be made, a bed slope, a co-efficient, and a maximum flood discharge were all assumed, and consequently the result could only be an approximation, and for safety's sake was always an approximation on the side of an excessive afflux. It was quite likely therefore that the poor designers of the original works, who had been criticized, might have contemplated the bigger affluxes recommended by the author, but had never attained to them.

Mr. MIDDLETON said that it was stated in connection with silting at Rupar * that "if the sill had been increased still more in length, it alone could have accomplished the whole cure" and in the concluding summary (f) is the remark† "and the length of sill, or the width of the waterway of entry to the canal, should be so great, as to ensure such a low velocity of entry, as will not have greater silt carrying power than the canal itself," but it was difficult to believe, that under all conditions this would be sufficient in itself to prevent the canal silting.

Fig. I.



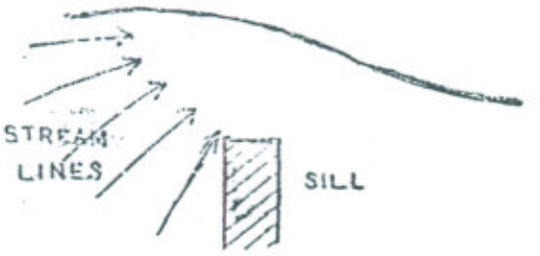
The silt taken in depended on the silt in the water at the offtake. In the diagram (Fig. I) the hatched area represented the proportion of silt, as compared with the proportion of water in the silt laden water alongside the sill. However slow the velocity over the sill, the silt in the water strata above sill level would enter, or deposit on the sill in entering, until the waterway became so small as to enable the increased velocity to transport all the silt in the water, above the silted level of the sill. It was possible for the conditions to be such that this amount of silt would be more than the canal could transport.

* Pape 78.
† Page 98.

Even with a small velocity over the sill some of the water from the lower strata passed over it, and with every increase in velocity, more and more of this water passed the sill, taking with it part of its contained silt.

This was clear from the direction of the stream lines given in the second diagram (Fig. II).

Fig II.



The author's theory on pages 72 and 73 appeared to be applicable to unobstructed flow in channels, but was it so in the case of such an obstruction as a raised crest ? The horizontal flow in the lower strata, in the case of direct attack, was either deflected upwards, or suddenly checked and the energy dissipated by the formation of eddies and the water rising up the face of the sill wall.

The speaker's own view of the effect of the velocity on the silt taken over the raised sill might be stated as follows :—

"The amount of silt taken over the sill, in excess of that in the water above the sill level, only depended on the velocity over the sill in so far as this velocity resulted in the lower strata of water, containing more and heavier silt, being drawn over the sill at a greater velocity, and increasing the velocity of approach.

The concluding remark in the first paragraph of page 79 that "*per contra* water may be taken from the bottom of a heavily silt ladened stream, and may carry no silt with it, provided it be drawn off with a velocity sufficiently low was not practicable for any length of time, if the silt dropped were not removed by flowing water in another direction. In the example given, AB and BC would silt until the velocity increased to such an extent that, aided by eddies due to abrupt change in direction, it became capable of carrying the silt on.

The eddies in the upper and lower layers of a stream, above and below the stratum of maximum velocity, rotated in opposite directions, and appeared to counteract each other to a

certain extent, since, when the maximum horizontal velocity was at a low depth, the silt carrying eddies, as far as appearances went, did not reach the surface, while when the maximum velocity was at a high level the eddies appeared freely on the surface.

Consider the flow obtained with a canal taking in water over a raised crest, and the undersluices passing water through an orifice at floor level. In such a case there was a combination of maximum horizontal flow, both at a high level, and at a low level. At Rasul the eddies, which freely appeared at the surface, were most extensive where the position of the maximum velocity began to be raised by the draw over the regulator sill, and diminished as the underdraw of the undersluices took effect. It therefore appeared as if the flow over a sill into a regulator caused the eddies and silt to rise nearly to the surface, whilst the low orifice of the undersluices kept down these eddies and silt. The low-lying strata of water in this case impinged on the sill wall at an acute angle, and were probably diverted towards the undersluices ; less of the energy of flow being dissipated into eddies, or diverted up over the sill, than in the case already considered, when the flow was directly towards the sill wall. A reference to the last paragraph of page 68 would show what happened at Madhopur, when the canal regulator side of the undersluices was closed.

The capacity of such a pocket for acting as a still pond, in which silt would be deposited, and clean water drawn off, was much too small to be really effective, without closing the canal and scouring through the undersluices with a frequency which would be prohibitive. The pocket should be a smooth channel, designed so as to cause the water to flow in uniform stream lines as free of eddies as possible, thereby keeping the silt as much as possible in the lower stratum, and to this end the raised sill should present a smooth surface with no piers projecting beyond it. At the same time if the sill were somewhat in advance of the piers the effectual length of the sill would be increased as far as carriage of silt over it was concerned. In the case of distributary heads, which was somewhat analogous, the well retired temporary crests had not been found so beneficial as permanent sills built up flush with the wing walls.

Mr. Schönemann made no reference to the effect that an unobstructed gradient, steeper towards the canal regulator and the undersluices than towards the weir, had in drawing the heavier silt in that direction. In the case of water entering the

pocket, the speaker would like to reproduce the conditions in front of the canal regulator already referred to by adding a raised crest running at a slant upstream from the end of the divide groyne. Face scour along such a crest wall would be produced by keeping down the drop shutters of the bay of the weir nearest the undersluices, or by having additional undersluice bays.

If this were done it would result in the water being freed a proportion of its silt before entry into the pocket, and would obstruct the steep grade towards the regulator, thereby excluding the heavier rolling silt. It appeared to the speaker that very similar conditions existed at Rasul at the present time, which might partially account for the canal being as free of silt as it was. The water entering the pocket, passed over a loose stone *bund* with its top slightly below the weir crest level, which projected out from the head of the divide groyne and almost met the unsubmerged *bela* on the left bank of the river.

MR. CARNE thought that to those engineers who had had acquaintance with the head works described by the author, the paper must be of much interest, but the author seemed to err on the side of excessive criticism of the opinions and actions of engineers who had spent much time in intimate connection with those works, with which he himself had very little acquaintance.

The speaker thought that it was now admitted that the silt difficulty had been overcome at Rupar as a result of the fact that there was a deep pocket, or flume, between the canal head regulator, the undersluices, and the divide wall, in which silt was deposited, and which was periodically scoured out by closing the canal head, and opening the undersluices. At Rupar opportunities for scouring the flume were frequent as compared with Khanki ; moreover a really effective clearance was possible, because there was a good fall between the river surface up stream and down stream of the undersluices, which did not exist at Khanki, when he was there.

The depth of the silt accumulating in the pocket or flume was to a great extent dependent on the height of the canal regulator sill. If at Rupar the flume were to be allowed to fill up with silt it would then get into the canal through the regulator openings, and that it also got in, if the canal head were left open during a rising flood, the speaker knew from experience. The real benefit of a high sill to a canal regulator lay in the fact that it increased the capacity of the silt trap, or flume, or pocket as it was often called, but that the benefits of a high sill were

nullified if the flume could not be effectively cleared of silt, immediately it had become filled.

The author apparently thought that because one weir at right angles to the river sufficed for a sand bed river, that therefore one would also suffice for the river at Madhopur. Anyone who had had charge of the head works at Madhopur, and also of those at Khanki between 1906 and 1910, could, he thought, fully appreciate the difficulty there was originally at Madhopur in getting the river to feed the Bari Doab Canal head on the left bank, when four miles above, it had to be kept on the right bank, for the purpose of feeding the Kashmir Canal. Had the author been at Khanki at the beginning of September 1910, when there had been some trouble in getting the river to feed the canal, he would have been able to appreciate the difficulty of getting water to the Bari Doab Canal head, if the river had taken a course in close proximity to the right bank. If it was difficult to wash out a sand shoal intervening between the river stream and the canal head, how much more difficult would it be to wash out a shoal consisting of boulders, shingle, and coarse sand. The means of securing a supply for a canal head were not necessarily the same in the cases of a sand bed river, and a shingle and boulder bed river.

With reference to the author's remark regarding the raising of the crest of the Khanki weir, it was originally proposed to raise the crest over the whole length of the weir, but as this would have increased the afflux of a maximum flood, it was deemed desirable at first to raise only a portion of the weir crest. When the maximum flood of 1903 occurred, there were at least three fairly permanent islands masking three bays of the weir, and therefore it was concluded that, as these islands had since disappeared, the raising of a portion of the weir crest would not affect a flood supply more than it had been affected in 1903 by the islands. An increase of afflux with low and moderate supply conditions was what was wanted, and this could be attained by keeping the shutters raised in the raised bays of the weir, under river conditions that would not permit of their being kept up on the low portions of the weir. Presumably it had not yet been found either necessary or desirable to raise the crest over the whole length of the weir.

CAPTAIN BATTYE said that as a Power Engineer he had often wondered what the essential difference was in the requirements of head works for irrigation as contrasted with power work. Accordingly he took up Mr. Schönemann's paper