with considerable zest, and was extremely interested to find that the requirements of both were almost exactly similar, except that he Power Engineer had, if anything, to go very much further, for it was necessary for him to keep silt out of his canal at all costs, or else shut up shop altogether. It might therefore interest the members of the Congress to hear what a Power Engineer had done to prevent silt from getting into his canal. The speaker had not been able to make full investigations of what had been done in other schemes, since receiving Mr. Schönemann's paper, and on the only other large scheme with which he had come in contact, which was in Scotland, there were no silt problems to be solved. In Simla, however, the exclusion of silt had been an extremely important problem. The head works in the Simla scheme had been designed more or less by the light of nature, and none of those engaged had had any previous experience of irrigation head works design. It was, therefore, extremely interesting for the speaker to find that all the main features now adopted in the design of irrigation head works were embodied in the Simla head works. The latter were of course, practically speaking, only a model, but this being the case it had been possible for them to crowd into their few months' operations much of the experience which it had taken the Irrigation Department several years to obtain. For instance, they had already had their head works entirely blocked by shoaling, and the river running on the far side of the bed after a flood.

The attached sketch showed the general design of the head works, and from that it would be seen that they had all the features of a modern irrigation head works, including the still pond groin, deep undersluices, and raised sill for excluding the detritus on the top water theory.

It seemed to the speaker that there were three problems to be solved in the design of a head works:—

(*a*) To ensure the river running past the head works entrance after a flood had subsided, instead of down the opposite bank of the river.

(*b*) To keep silt and detritus from entering the main gate.

(*c*) To remove any silt and detritus which found its way in.

For (*a*) there was no doubt that very deep undersluices immediately adjacent to the intake, and a weir as high as possible, would generally ensure the river's cold weather stream

being retained on the canal side of the stream after the floods had passed. If this were not sufficient some training works would appear to be essential. It would be interesting to consider what were the essential principles underlying the design of training works, to ensure the wet weather channel being on one side of the river after the floods had passed, as required by the irrigation people, and the maintenance of an even scour throughout the whole river bed during flood season, as required by the railway people.

For (*b*) it was essential to have as slow a velocity of approach and entry as possible, which, of course, involved very large entrance gates, which in turn had to take their supply out of as deep and large a still pond as possible, and be provided with a raised sill in the gateway to ensure only the top water being taken. This sill needed, however, to be combined with deep undersluices immediately downstream of the gate, in order to clear away all accumulated detritus, which, since it could not pass over the sill and enter the gate, must of necessity collect against the front side of the sill in a sloping bank. This could only be cleared by keeping the undersluices permanently open a few inches at the bottom, to produce sufficient under-draw to keep the still pond effectually scoured out, and prevent it from being silted up. This system had been found essential in working the Simla head works during the monsoon season, when the river came down extremely dirty.

To prevent the first portion of the canal (or flume) silting up (which in the Simla scheme was in tunnel) the top section of the flume had been made at a much steeper slope than the normal. At the end of the top section the flume opened out into a large settling tank, where all suspended matter was compelled to settle. This was fitted with three parabolic scouring baffles, and with gates, which were opened daily and which cleaned out the whole of the accumulated material in a few minutes.

The whole principle was, that having once got water into an artificial channel, it must be completely under control, and its speed and velocity and corresponding settling capabilities alterable at will. There were three such settling basins in the Simla flume ; and a large storage reservoir at the end. It was originally feared that the storage reservoir might silt up entirely during the rains, and the settling basins, or silt traps as they are locally called had been found invaluable in removing all but the very fine suspended clay from the water, and as this took several da to settle, all fear of any serious accumulation of silt in

reservoir were removed, and throughout the whole of the monsoon season last year, no serious trouble whatever was experienced.

The general priniciple for excluding and removing silt, appeared to be the adoption of a very large long weir and as large and deep a still pond as possible, which should be looked upon as a settling tank, with deep undersluices which would be capable of continuous or intermittent efficient scouring. The still pond and channel behind the groin might be simply looked upon as a portion of the main canal itself, so that the principle resolved itself eventually into the taking off of one flume from another, and from that into another, and so on, repeating the operation as often as required.

In the Simla scheme, the intake channel or still pond might also be looked on as the first flume from which the main flume took off, and the outlet of the first settling tank as the third flume, taking off the main one, and the outlet of the second settling tank as the fourth flume taking off the third, and so on. This system had been found absolutely invaluable in excluding silt in the Simla scheme and should be possible, if necessary, on a much larger scale.

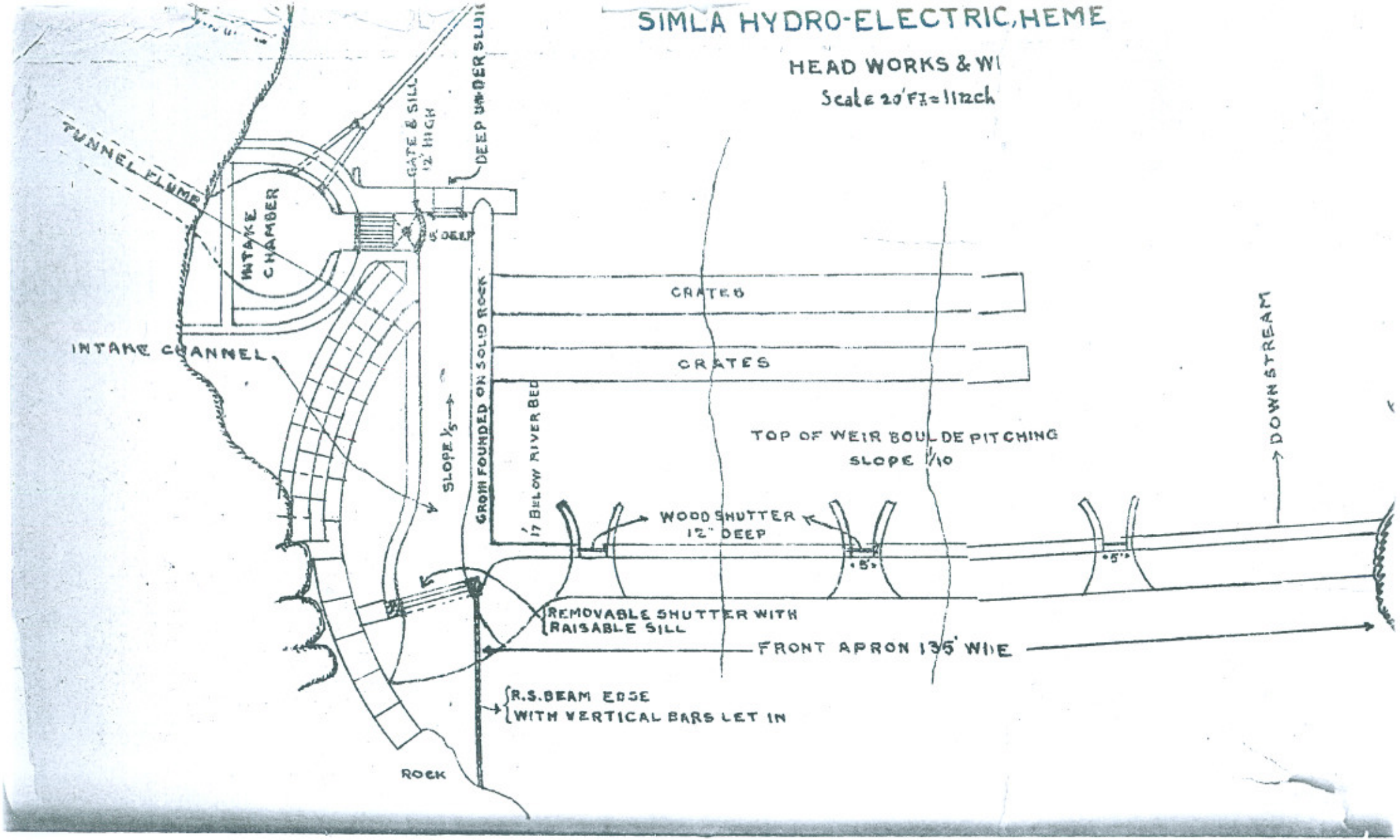
RAI BAHADUR BAIJ NATH, referred to the third paragraph on page 78, where the author stated that "the still pond device doubtless contributed to the cure, but, if the sill had been increased still more in length, it alone would have been all that was necessary. To those who attributed the silt excluding effect of a high sill to its skimming off "topwater," comparatively free of silt, he would point out that this was only a half truth; and that topwater. actuated by a high velocity, might carry just as heavy silt as bottom water of a lower velocity." He would like to ask the author how the bottom water could have a lower velocity than the topwater—velocity was entirely dependent upon the *pressure head*, so that the lower layers of water would certainly have a higher velocity than the upper layers, and the effect of putting in a raised sill would be to automatically reduce the head, and consequently the velocities of entry.

MR. DHODY thought that Mr. Schönemann's paper was really a step forward, and an attempt to bring the design of canal head works out of the old ruts. Hitherto the primitive water mill seems to have provided the guiding principle, *viz.* to pond up the river by means of a temporary bund, or latterly by a pacca weir, and then to lead off the needful supply to the water wheel, or to the canal head.

SIMLA HYDRO-ELECTRIC SCHEME

HEAD WORKS & WI

Scale 20' FT = 1 inch



Obviously a small stream with a high velocity would have a larger transporting power than a larger one with low velocity. It must also be recognised that nature abhorred any sudden change. These premises granted, the canal engineer's practice next called for examination. This was to pond up the river in a still channel ; and then start a forcible suction into the head, and upon the velocity of this stream depended the size of the boulders, shingle, or sand, that got into the head. The greater the swirls and eddies, the greater would be the amount of material carried in suspension. The author seemed to carry things too far in the matter of the height of sill which he advocated. He had tried in Figs. V and VI * to illustrate his meaning as to the effects of a high and low sill respectively. Material once disturbed, however, must be considered as being in a state of floatation ; and whether it went into the canal head or not, would to some extent depend on its being caught in a swirl which went past the canal head or into it. This would show that having once guarded against much disturbance, the length of waterway and the height of sill would not need to be carried to such extremes, but the retardation from the river velocity to the canal velocity should be affected gradually, and before the water got past into the canal regulator. Unless that was done, silting or scouring must result in the canal, when passing from high to low, or low to high velocities, as shown by the author.

Mr. Schönemann would be interested to learn that some years ago he had occasion to speak to Sir John Benton on the subject, and on his advocating larger waterways to heads Sir John replied " but what about the cost ?" Of course Mr. Schõnemann would reply—and rightly—that it was not the first cost alone that had to be considered, but the later charges also. A head with a larger waterway would be found more satisfactory and cheaper in the end.

In the speaker's opinion Mr. Schönemann did not go far enough in the matter of training works. This was a matter of great importance, as year after year large sums of money were being lost in attempts to perpetuate what in most cases had been wrongly done by past engineers. If an engineering work was rightly designed it was worth maintaining, but if it was not sound engineering in its inception, then the sooner it went the better. Railway engineers had tackled the problem of a restricted waterway for railway bridges very satisfactorily, by means of Bell's Bunds. True, they had not to dam up a river, but they

* Page 73.

had to recognise the highest flood level, and beyond that the irrigation engineer had no need to go. What the railway engineer had in his approach banks, the canal engineer should provide in his flood embankments, but they should be coupled with a system of Bell's Bunds above and below the weir.

From all this it would follow that the proper design for a canal head would be a barrage, where all velocities would be under control, and the channel would be sufficiently restricted to guard against fear of shoals. This system had been adopted at the head works of the Lower Bari Doab Canal at Balloki, but there again the system of training works spurs had been carried too far, and thus more responsibility had been laid on those in charge, for it was obvious that to control an Indian river five miles and more above a work was nothing but needless anxiety. The working of this would be watched with interest.

Mr. Dhody advocated a barrage with sufficiently low sluices,—and with a sill rising from the canal end to the other abutment, which would meet all considerations of afflux. This should give effective control over the river, without any need for fortifying shoals, or for advancing spurs which would subsequently have to be cut off, as had happened at some head works a few years ago. Such a barrage should be placed at some little distance from the canal head, so that the current passing in front of the canal head was not abruptly checked in its onward course to the sluices.

It might also interest Mr. Schönemann to know that the same method of providing a waterway sufficient to give uniform velocities at the indraw, had been very successfully adopted in removing the notoriously bad silting tendencies of some of the distributaries on the Jhang Branch.

CAPT. ANDERSON said that from the point of view of the railway engineer the question of silting and scour in a channel appeared really to turn on one point—the velocity of the stream at which any particular size of material was held in suspension. Sir Francis Spring had given certain figures for this, but it would be interesting if any irrigation engineer could give any further particulars about it.

SIRDAR LEHNA SINGH advocated making the under-sluices long enough to carry the whole of the ordinary flow, and the rest of the weir so high as only to be topped by the highest floods.

MR. BLAKER, having described certain observations which he had made connected with the transportation of silt in open channels, said that he was generally in accord with the principles of head works design enunciated by Mr. Schönemann, so far as they concerned silt carrying rivers. There was no doubt that the quantity and size of silt entering canals was best controlled by suitably low velocities through the regulator, over a suitably elevated sill ; but it must be remembered that, if large quantities of silt were excluded in this manner (which would certainly occur at all their head works on account of the smaller silt transporting power of the canals as compared with the rivers), the shoals, etc., formed in front of the head works would have to be scoured through the undersluices before they topped the elevated sill. How to effect this was the crux of the whole problem, because the quantity of silt deposited between the fall of the last flood of one monsoon and the coming of the next monsoon was enormous, and the scouring power of the surplus supplies, themselves already highly silt charged, was generally inadequate, with the affluxes available, to keep down the shoaling between monsoons. Then the height of the regulator sill must be kept within limits, for the higher this sill was above the undersluice sill, *i.e.*, above virtual river bed, the greater the deposit, which increased in proportion to the depth. Theoretically, the solution lay in creating the deposits sufficiently near the undersluices for the scour caused by their afflux to draw upon them. In practice this was generally difficult of achievement, on account of the small surpluses available, and the limits within which it was possible to raise the regulator sills. That a good deal more could be done in the way of reduced velocities of entry, elevated sills, and increased afflux, was probable ; but how far they would be effective in a given case, as a complete solution, was difficult to determine, and the question of cost involved by the larger works required was a deterrent, if there was any doubt that such works after all might be only a partial remedy. It was this consideration that had doubtless caused engineers hitherto to fight shy of incurring the heavy additional expenditure involved, in favour of the trial of other and cheaper remedies to meet the occasion.

Regarding Mr. Schönemann's advocacy of the application of these principles to the design of head works in shingle rivers, he thought that the author was unduly optimistic, and pointed out that where large boulders up to two feet or so were present, as at Madhopur, the draw of the undersluices within practical imits, and a lateral main weir alone, would be quite ineffective

in controlling the direction of the deep channel for more than a few hundred feet upstream of the undersluices. Large boulders had the property of accumulating a few feet upstream of the undersluices, at the point where the scour was insufficient to draw them through, and they packed themselves so as to form steep rapids which held up the bed upstream. In such circumstances, it was necessary to keep open the deep channel by pushing the detritus towards the undersluices, and the only way to do so was to scour a steep slope by means of training works adjacent to the required deep channel. It was futile to attempt to draw, by means of the undersluices, the afflux of which was limited by the velocity which the masonry would stand, which in boulder rivers where quartzite masonry was available was found to be a maximum of twenty feet per second, and which had practically no effective draw on boulders for more than a few feet upstream of the undersluices.

In the case of Madhopur, where the river had a natural tendency to keep to the right, whereas the canal offtake was on the left bank, it was necessary to develop and maintain a deep channel to the head works for some distance upstream. If entire reliance were placed on a lateral main weir, the river would certainly take to the right, and hug the upstream toe of at least the left half of the weir, striking the regulator in flood time at right angles. This would lead to the necessity for an enormously strong main weir and head work. A further objection to the proposal, so far as Madhopur was concerned, was that since the deep channel would, in the absence of training works, be ill defined upstream of the weir, the river would tend to spill and spread in the cold weather, leading to increased absorbtion, which would be disastrous, as the cold weather supply was much below requirements.

The speaker said that he had had three or four years' experience in charge of these head works, and was convinced that, were a fresh start to be made there, training works would again have to be resorted to, but that they would probably take the definite form of a main weir inclined upstream from the undersluices to the right bank, forming a submerged guide bund in flood, along much the same alignment as that now taken by the escape weir, the upper training works and their extension, and the Jacob's bund.

Such a weir would have to withstand the full force of the highest floods, and it would probably be better to put in a second line of defence such as that now fulfilled by the lower

training works, for were the main weir to breach (the scour on its down-stream toe, in the absence of a second work, would be enormous), the river would certainly create a deep channel through it, and leave the head works. It could only be got back with great difficulty and the expenditure of much time, which would mean disaster to irrigation.

For these reasons the present training works, although undoubtedly patchy, were in the main, justified.

The primary function of the Dhanna weir and crate bar was that of a main weir for the Kashmir Canal. It had also been considered by some engineers of some importance for training the river to the left, but the speaker was not in agreement with this. The training of the river to the head works should be begun opposite to Tidori, and the existing frontal works referred to should be gradually linked up and strengthened, as occasion demanded.

MR COLYER remarked that although correct theories as to the flow of silt were of undoubted advantage in the design of works, and in an intelligent conception of working conditions, yet he had found that in the actual working of a canal regulator, fine calculations were of little use, as the conditions under which they were applicable were greatly and often entirely vitiated by daily changes in the section and direction of the channel above the undersluices.

As an instance of this, he had, after a great deal of (authorised) experimenting at a large head works, conceived the notion of regulating the undersluices in the following manner :—

1. Taking daily cross sections of the approach channel of the undersluices.

2. Calculating the critical velocity—Vo (Kennedy)—due to this section.

3. Calculating the amount that it was necessary to open the undersluices so as to give, for the combined discharge of canal and undersluice flume, a velocity at entrance to the undersluice pocket $= \frac{2}{3}$ Vo.

The object of this was to induce the heavier (*i.e.* the more injurious) grades of silt to fall before reaching the regulator sill, and then to be rolled forward through the vents in the undersluices, where there would be a fairly high velocity at bed level. These calculations were, however, vitiated by the growth of a silt *bela*, just above the undersluice pocket, which caused

a sinuous form of approach, resulting in a heavy swirl at the divide-groyne nose, and the formation of a pot-hole twenty feet deep.

The effect was, first, that this swirl disturbed the whole of the conditions, and carried large quantities of silt into the canal, and, secondly, that, had this mode of regulation been adhered to, the growing *bela* would have squeezed them out of the under-sluices altogether—an eventuality which he believed had actually occurred at another head works on the same river. These facts were all in favour of abandoning the system of cast-iron rules for head works regulation, and of allowing greater latitude in this respect to the Sub-divisional Officer in charge, upon whom in any case, most of the responsibility eventually devolved, despite the existence of the said rules. It was his personal experience that by the exercise of an intelligent interest unfettered by inflexible rules, the Sub-divisional Officer, generally a highly paid man, could save Government vast sums of money, by the careful regulation of his river and canal head.

There was a tendency at present to leave the old groove, and orders had been issued for experiments to be carried out at Marala head works to ascertain the best method of regulation to ensure a silt-free canal and a clean undersluice pocket. This was progress, and sounded the knell of the old-fashioned method of making binding rules to apply to several canals, of which the local conditions varied, not only relatively, but even altered from day to day at the same head works.

The results of his experiments indicated that the weir shutters, undersluices, and regulator gates should be regulated with the following objects in view, *viz* :—

1. To keep a regular and straight approach channel.
2. To pr event the formation of a *bela* masking the undersluices.
3. To prevent swirl and scour at the divide-groyne nose.
4. To sl ghtly retard the velocity in the neighbourhood of the regulator silt-gates, so as to convert as much susp ended silt as possible into rolling silt, to be carri ed along the floor and through the undersluices.
5. To prevent a cross-current running with a high velocity straight from the divide-groyne nose to the regulator.
6. To induce a gentle side-spill of the top-water over the raised sill-gates.

MR. NICHOLSON referred to the author's remarks, attributing the cure to the wrong box of pills in the medicine chest. It appeared that the analogy might be carried further, and the cure attributed to the active constituent in the pill only. In all prescriptions, however, in addition, there is a corrective, and it would appear that Mr. Schönemann assumed silt trouble would be cured by the low velocity theory alone, without the corrective in the form of a silt pocket. The water was assumed to have silt in it, and if the water was taken into the canal and not the silt, what was going to happen to the latter ? Before the silt trouble on the Sirhind Canal had been solved all the silt was deposited in the main line. Last year the silt deposit, which originally, after remodelling Rupar Headworks in 1893, used to run up to $1\frac{1}{2}$ crores of cubic feet in the first sixteen miles, had been turned into as many cubic feet of scour. This had been done by studying the whole of the correspondence and information collected for the last twenty years in the records. The abstraction from the canal water of the silt, and leaving the silt to be carried on down the river, appeared however to upset the hydraulic conditions of the river down-stream of the weir. An investigation of the gauges below the Rupar Weir for the last thirty years confirmed the idea that the river bed below the weir had been rising. The cause was usually put down to the fact that there had not been any sufficiently large floods to wash the silt away from below the weir. This year, at Rupar, there had been the third highest flood on record, yet that had not cleared the collection of silt. When the minimum gauges down-stream of the weir for each winter were abstracted the gradual rise in level was most clearly exhibited. When, at the commencement of the working of the canal, there was the acute silt trouble, the bed of the river below the weir did not rise ; as the silt trouble got less in the canal, the river bed rose more below the weir. Taking the period in seven-year averages the gauges below the weir where there was no water passing and all was caulked, were as follows :—

1887 to 1892 — 1·7 ft.
1893 to 1899 + ·6 ft.
1900 to 1906 + 1·9 ft.
1907 to 1913 + 2·1 ft.

The actual minimum — 2·0 was in 1888, and the actual maximum + 3·4 was in 1913.

This figure for 1907-1913 would be 2·7 if the years 1909-1911 were neglected, when the silt trouble reasserted itself

owing to regulation on wrong lines. The rise in the level from the average of the 1887-1892 period to the average of the 1907-13 period was therefore 1·7 + 2·1=3·8 ft. and if the rise from 1888-1913 were taken, the rise would be 2·0 + 3·4= 5·4 ft. In further proof of his statement, he would invite a comparison of the floods recorded at the Patial gauge in the fourth mile upstream, and the down-stream weir gauge. In 1913 the third highest flood at Patial was 1·8 ft. lower than the highest in 1891, but below the weir instead of being lower it was 3 ft. higher.

As a result of the continual rise of the river bed below the weir, about 1900 the river avulsed for a considerable distance about two miles to the right. This effect on the river below the weir did not appear to have been considered before, and it pointed to the fact that in course of time all the Punjab weirs would become inoperative, owing to the rise of the river beds.

In view of these facts it would appear that, so far as the spurs below Khanki were concerned in lowering the bed level below the weir, they were useless.

If, instead of putting in the spurs and widening the regulator, the whole weir had been raised as well as the undersluices so as to give a command over the river, and give a deeper supply over the crest of the regulator, a far more lasting and beneficial result would have been secured.

To any one who had not been to Rupar it would appear strange to hear that the difference in the water surface up-stream and down-stream of the weir in winter was twelve feet, and in the hot weather from six to ten feet. The weir was rarely more than half opened. The undersluices could carry 50,000 cusecs out of a 2,50,000 cusec flood, as had been determined from the flood of 1913. This shewed what control there was over the river, which enabled the silt question to be dealt with in such a satisfactory manner by a clear deep silt pond, scoured out rapidly at intervals, as necessary.

On page 91 Mr. Schönemann gave the slope of the River Sutlej as 1 in 2,500, this should have been 1 in 3,750 ; and on page 92 the height of the sill should read from nine to twelve feet high instead of seven to ten, this would bring the line for the Sirhind Canal 1900 (Fig. X) well above that of the Lower Jhelum Canal.

MR. SCHÖNEMANN in reply said that Mr. Purves was unkind in representing his paper as suggesting that his predecessors in the Punjab Irrigation Service had been awful duffers, incompetent, and so forth. That was a travesty of what he had written. One engineer might dispute another's views on a professional problem without implying that the latter was a fool. Controversy was the breath of scientific progress, and it was not in the interests of the Congress that personal considerations should suppress free comments on the works of past generations of engineers. The speaker might as well be barred from a criticism of Julius Caesar's bridge over the Rhine! He understood that Sir John Benton had been invited to attend the Congress; and no one regretted more than he did that, although in Lahore, Sir John had not been able to appear amongst them, as his views on the subjects under discussion would undoubtedly have been of great interest.

Mr. Purves was mistaken in supposing that the speaker denounced what he calls the "top-water theory." All that he had said was that this theory was incomplete, and based on only a half truth; since, in order to exclude silt, water must be taken off, not only at a high level, but under a low "head," that is, with a low velocity, and he had endeavoured to make this point quite clear.* Mr. Purves claimed too much for their predecessors when he asserted that they had succeeded in overcoming silt troubles.

The opinions of the eminent engineers, which he had quoted, showed that as lately as the year 1910, or even 1912, they were still perplexed over the silt troubles at Madhopur, Khanki, and Resul. Doubtless Mr. Purves was thinking of the Rupar expedients of 1893-1900, and of the cure, which he attributed to "top-water," though Mr. Carne gave the credit to the "still pond" idea. Whilst not disputing the partially satisfactory results at Rupar, he would point to the fact that the Rupar expedients failed when applied at Madhopur and at Khanki, mainly because the active element in the Rupar cure had not yet been clearly recognized.

In Mr. Purves' diagrams, representing water passing through orifices at a high, and at a low level, respectively, the curve of water surface upstream of each orifice, depicted therein, could not be accepted as representing actual conditions. These diagrams showed vertical velocity curves depicted in full lines. Mr. Purves started with a consideration of the path of

* *Vide* pages 78, 79, etc.

particles of silt descending from the surface of the water, on the hypothesis that they were actuated only by gravity, and by horizontal eddies. He left vertical eddies out of consideration ; but if there were no vertical eddies there would be no accounting for the presence of silt in the upper layers of a current ; nor would the velocities in the vertical plane be represented by curves.

The speaker was glad to find that Mr. Foy, from his personal experience as Assistant Engineer in charge of the Madhopur works, agreed with him as to the correct design for a Canal Head Regulator in such a place, though he did not endorse his condemnation of the training works, as he considered that in a river with so steep a declivity as that of the Ravi at Madhopur, training works were necessary in order to force the current to flow past the Canal Head. He asked how the speaker proposed to deal with the river, assuming that the training works had been abandoned, and that the main stream had gone over to the wrong flank ? His reply was that if they made the weir high enough, and strong enough, the main stream *must* seek the undersluices and the canal head, for it would have no option to do otherwise. The declivity of the river affected the problem only as a question of *degree* in the main principles of design to be adopted.

Mr. Foy enquired about the afflux calculation. The formula used by the speaker $(\frac{V^2}{58{\cdot}6} + 0{\cdot}05) \left\{ (\frac{A}{a})^2 - 1 \right\}$ would be found in Molesworth's Engineering Pocket Book. It was not quite correct in form, but it gave results which were fairly consistent, *inter se*, and with the data of actual experience recorded at the various Canal Head Works.

Mr. Middleton said that " the silt taken in through a Canal Head Regulator depended on the silt in the water at the offtake." This was not the case. The number of flies inside a wire gauze meat-safe depended on the condition of the wire gauze ; not on the number of flies in the pantry : and in his paper he had likened the functions of a properly designed canal head to those of a wire gauze meat-safe. This speaker also said that it was difficult to believe that a sill as long as possible, and as high as possible, would be sufficient in itself to prevent the canal from silting, thereby leading them to infer that he was at variance with the upholders of the top water theory !

Referring to Fig. VIII* of the paper, Mr. Middleton said that the pipe A, B, C., would silt up "until the velocity increased to such an extent that, aided by eddies due to abrupt change in direction, it would become capable of carrying the silt on." He did not however indicate how this velocity was to increase. The fundamental hypothesis of the illustration in the author's Fig. VIII, was a head of pressure *very small*, and a velocity *very low*. For the rest, Mr. Middleton did not appear to have followed his argument as to the forces actuating silt carriage by a current—forces depending entirely on frictional resistance between soil and water. He had offered theories of his own on the subject which the Congress would duly take into consideration.

Mr. Carne attributed the cure of the silt difficulty at Rupar to the creation of a still pond in the pocket upstream of the sluices, and the periodical scouring out of the silt by closing the canal head and opening the sluices. He said that the opportunities for scouring out the pocket at Rupar were more frequent than they were at Khanki; but he did not explain why this was so. He mentioned that a really effective scour was possible at Rupar, but not at Khanki, because at the former place there was a better fall, or afflux, at the weir and sluice; but he did not seem to realize that this was an argument in support of the author's advocacy of a higher weir at Khanki, giving a higher afflux! He said further that if the flume, or pocket, or still pond at Rupar, were allowed to silt up, silt would then flow into the canal over the canal head sill; but he did not realize that this argument was in itself condemnatory of the Rupar system of working! During the silting season the river had more water than the canal needed, and if the system advocated in the paper were adopted, there would be no need to close the sluices in order to create a still pond in front of the canal head. If the canal head sill were longer, there would be no need to close the sluices and the canal head periodically in rotation. The partial success of the fluky empirical silt cure at Rupar had ruined the kharif irrigation of the Sirhind Canal. No other perennial canal in the Punjab had so short a flow period as the Sirhind Canal; a defect which was bound up with the Rupar system of canal control.

* Page 79.

Every time the Sirhind Canal was closed, in order to scour out silt from the Rupar river-front, there was an economic loss of water supply ; and the entire Rupar system had resulted in a discouragement to kharif irrigation from the Sirhind Canal. Mr. Carne said that he knew from experience that, if the canal head at Rupar was left open during a rising flood, silt got into the canal. That evidence, in itself, was condemnatory of the Rupar canal head design, for it showed that the empirical remedy in force there was defective.

Mr. Carne also drew a distinction between a river with a sandy bed, and one with a shingle and boulder bed, *vis-a-vis* of the silt problem. But sand, shingle, and boulders, respectively, were merely different varieties of silt ; differing only as to coarseness and magnitude of dimensions of the individual particles ; and it was obvious that the same hydraulic theory must be applicable to each and all, *qua* transport by currents of water. The coarser, heavier, particles would need a swifter current, in a given depth of water, to levitate them, than the finer, lighter, particles ; but the force actuating transport in each case *must*, from a scientific point of view, be precisely identical in nature.

He was glad to find the views of the Madhopur school of river training works so fully represented in Mr. Carne's arguments, with all that could be said in their favour. He said that "it was originally proposed to raise the crest of the Khanki Weir throughout its length, but as this would have increased the afflux of a maximum flood, it was deemed desirable to raise only a portion of the weir crest." But surely, if raising the weir by, say, x feet, throughout its length, would have increased the afflux by a certain amount, the raising of it by x feet over three-eighths of its length only, was also bound to *proportionately* increase the afflux. Mr. Carne said further that during the maximum flood of 1903 there were three islands masking three bays of the Khanki Weir, and that therefore the raising of the crest of the weir throughout those three bays (1,500 feet in length) by two feet, could not affect the afflux of a high flood at the weir. Under these circumstances the author failed to see what object there was in raising the crest by two feet in these three bays after the islands had disappeared. Would not the effect, *qua* afflux, have been the same if any other three bays of the weir had been raised similarly ? Would it not have been the same if the crest of the whole weir, throughout its eight bays, had been raised by nine inches, instead of by two feet in three bays only ?

What object was there in humping one particular portion of the weir crest, after the disappearance of the temporary mud flats of 1903 ? Sir John Benton was of opinion as mentioned in the Paper, that the raising of the weir crest at Khanki by two feet in three bays had increased its potential afflux. Was Mr. Carne at issue with Sir John Benton over this point ? Mr. Carne's explanations of the Rupar and Khanki expedients were very welcome to the speaker as lending point to his arguments.

Capt. Battye mentioned that the exclusion of silt from the supply flumes of hydro-electric Power Projects was one of the greatest importance, and thought that there were three problems to be solved in the design of a head works, *viz* :—

(*a*) To ensure the river running past the head works entrance, after a flood had subsided, instead of along the further bank of the river.

(*b*) To keep silt and detritus from entering the main gate.

(*c*) To remove any silt and detritus if it ever did get into the canal.

He agreed with him as to (*a*) and (*b*) ; but as to (*c*) it seemed to him that if problem (*b*) be solved, problem (*c*) would not come into play !

He found problem (*b*) worrying the engineers of the Avignouet Dam in France a year ago. The sill of the intake had not been made long enough ; so that for a given discharge it had to be relatively low. In order to prevent boulders from rolling into the flume supplying the turbines with water power, the intake had to be protected with a wooden grating. The boulders piled up against this grating and obstructed its waterway, reducing the discharge of the flume, and the French engineers admitted that they ought to have made their intake-sill longer and higher.

Capt. Battye's problem (*c*) had been tackled on several French, Italian, and Spanish canals, by means of numerous escape sluices in the first few miles of each canal. The remedy had been tried on the Sirhind Canal by an escape at mile 12, but it was only partially successful being uncertain, and had proved costly. It involved a waste of water in sluicing operations ; and it also required a greater head of pressure through the escape sluices than was usually available in the first few miles of a Punjab canal.

Rai Bahadur Baij Nath said he could not understand how bottom water could have a lower velocity than top-water. The speaker did not understand his difficulty, and feared he had not followed his argument. Considering the case of a free fall over a silt, and using the forumla :

$$\tfrac{2}{3}\ c\ \sqrt{2gh} \times lh\ ;\ \text{or}\ 3{\cdot}3\ lh.^{\frac{3}{2}}$$

If l=100, and h=9, they had a discharge of 8,910 cusecs. The same discharge could be given with a water depth of 1·94 feet, over a sill 1,000 feet in length. In both cases the flow over the sill would be that of " top-water, " but the mean velocity in the former case would be 9·9 feet, and in the latter case only 4·6 feet per second ; and the silt carrying power of the current would be far greater in the former, than in the latter case. Just as top-water could be taken off with a high or with a low velocity, according to the head of pressure under which it was taken off, so also could bottom-water.

He understood that Mr. M. S. Dhody agreed generally with the views expressed in his Paper ; and he was glad to learn, from one who has held charge of a portion of the Lower Chenab Canal, which the speaker formerly held charge of, that some of the principles of design advocated by him had been successfully employed to reduce silt deposits there.

There was a good deal to be said in favour of the Nile Barrage type of river control, in comparison with the Punjab weir type ; but it would take up too much of their time to enter into a discussion on this point. Sardar Lahna Singh had also raised this question, which he hoped they might discuss more fully at a later date.

Capt. Anderson said that the question of silting and scour in a channel appeared really to depend on the velocity of the stream at which any particular size of material was held in suspension. That was not correct. The power of a stream to carry silt of any given coarseness depended, not on its absolute mean velocity, but on the height above channel bed of the filament of maximum velocity. If it were possible to keep the velocity of a stream, with a given mean velocity, constant, whilst increasing or decreasing the depth of water, the silt carrying power of the current would vary inversely with the depth of the water ; as pointed out by Mr. R. G. Kennedy.

Capt Anderson quoted Sir Francis Spring as an authority who had specified certain absolute velocities as capable of moving certain grades of silt. He might also have quoted many text books and engineering manuals, which stated the same thing, but which were all nevertheless in error on this point. Mr. Blaker, who, like Mr. Foy, had been for some years in charge of the Madhopur Works, as Assistant Engineer, said that he was generally in accord with the principles of Head Works design enunciated in the Paper, so far as they concerned silt-carrying rivers (silt being, to his mind, sand and clay as distinguished from shingle or boulders), but apparently thought that, as sand increases in bulk and weight, and so merges into the classification of shingle, and thence to that of boulders, it would begin to follow different hydraulic laws in the embrace of a current ! The speaker had already endeavoured to show that this was a misconception. Where there were boulders and shingle on the bed of a stream, there the declivity of the stream and also its velocities were greater. The boulders had been brought to where they were by the current, and could be levitated again by a similar current. It was just as easy for a current of high velocity to move boulders, as for one of low velocity to move sand, *ceteris paribus*.

Mr. Blaker said further that it was futile to attempt to draw through the undersluices a current of greater velocity than the masonry floor of the sluices could stand, *viz.*, twenty feet per second. Did he mean to suggest that the floor of the sluices, composed of boulders set in lime or cement, could not stand as high a velocity as the natural river bed, composed of boulders and shingle deposited alluvially by the current ? Did he dispute the fact that the current of any flood, concentrated through the sluices, was under existing circumstances, greater than that of the natural river in its vicinity ? He had also stated that the river had a natural tendency at Madhopur to seek its right bank. That was not the case. Had it been so they would not have found the river, before their works were built, hugging the left bank, and leaving a low lying alluvial riverain, silted up, on the opposite, right bank. It was recorded in the history of the works that in their early days it was customary to build spurs along the left bank, upstream of the canal head, in order to prevent the main stream from seeking the left bank too persistently. It ought to be perfectly obvious to everybody that if the Madhopur Weir had been made high enough and strong enough

the whole of the river floods could, if necessary, have been forced through the sluices ! and it was only a question as to *how* high to raise the weir. At present the heaviest floods that passed over this weir experienced an afflux of less than one foot. Why should not this be increased to say four feet, seeing that elsewhere, in, and out of India, far greater affluxes are successfully sustained as pointed out in the Paper ? It would be time enough for the advocates of the existing regime at Madhopur to talk of the idiosyncrasies of the river, when it had been subjected to a more rational control without effect. Mr. Blaker also said that the primary function of the Dhanna Weir and Crate Bar was that of a weir for the Kashmir Canal. But what business of theirs was it to build a weir for that canal ? The Dhanna Bund was built at first in order to protect the Upper Training Works from outflankment ; and it was only when the Kashmir Durbar objected that it would shoal up the mouth of their canal, that they undertook the responsibility of maintaining the supply of the Kashmir Canal by means of a crate bar and weir. Mr. Blaker thought that a high sill with a low velocity of entry to the canal head was a *doubtful* remedy for the silt difficulty, and that this consideration had probably caused engineers hitherto to fight shy of incurring the heavy additional expenditure involved in the remedy. That was not the case. If cost had been considered, the Madhopur River Training Works, which have cost twice or three times as much as the weir sluices and canal head, would never have been built. Nor would the enormous expenditure in annually clearing the shingle from the canal, have been incurred, without some attempt at a more rational remedy. As a matter of fact, the idea of raising and lengthening the canal head sill at Madhopur was never seriously mooted prior to the year 1910.

Mr. Nicholson had made an intelligent study of the river-gauge records at Rupar, which tended to show that this river-bed immediately downstream of the weir was gradually but steadily, rising, by reason of silt deposits. The matter was of scientific interest, but it did not justify his sweeping inference that in consequence of this all the Punjab weirs would become inoperative in course of time, though it might be worth while to keep a watch on the regime of the river by means of periodic hydraulic surveys, executed *ad hoc*. In the first place, for all that Mr. Nicholson's data revealed to the contrary, the rise of the river bed might be merely local, within a short distance of the weir

and its downstream gauge. In the next place, it was absolutely necessary for them to exclude silt from the canal at Rupar, otherwise the canal would cease to flow, as it very nearly did in 1893. If the silt *must* be deposited, there could be no question, but that it was preferable to deposit it in the river below the weir rather than in the canal. In the third place, the average discharge of the Sirhind Canal during the silting season was less than 6,000 cusecs, whilst that of the river was probably at least 30,000 cusecs. The assertion that the river was unable, by natural adjustment of its hydraulic data, to carry on occasions sixteen per cent. more silt, downstream of the weir, than it did upstream of the weir, was one that needed more precise proof than Mr. Nicholson's data at present conveyed. Finally, in a river with a shifty sandy bed it was risky drawing inferences of a precise description from gauge-statistics.

Any given water level, at any given point in such a river, did not always represent even approximately the same discharge at all times ; and a really able writer might prove almost anything by the expert use of such hydraulic statistics from the point of view of a single theory. Mr. Nicholson's observations might, however, well be carried further, and the results stated in a separate paper presented to a future meeting of this Congress.

It was quite possible that the rise of the river-bed downstream of the Rupar weir sluices might be mainly due to the particular expedients employed at Rupar for excluding silt from the canal ; *viz.*, by alternately creating and scouring out silt deposits in the pocket of still pond upstreams of the sluices. This might have the effect of concentrating shoals in the vicinity of the downstream gauge, which was Mr. Nicholson's datum.

Mr. Nicholson's own suggestion of a remedy did not promise well. He proposed to raise the weir and sluices at Rupar, which already possess a scouring head of from six to twelve feet, but if the river bed was rising at the rate of one foot every three years, it would nullify, in eighteen years, a raising of their works by six feet ; and there was obviously a limit to the extent to which the works could reasonably be raised.

The speaker's figure for the declivity of the river Sutlej at Rupar was taken from the early Project Reports of the canal. Mr. R. G. Kennedy was, he believed, the surveyor who determined this figure of 1 in 2,500. Mr. Nicholson's other correction of the speaker's figures, *viz.*, as to the height of the sill of the Rupar Canal

head, only strengthened the argument conveyed by Fig. X *: and its context ; for it would have the effect of lessening the inclination, from the vertical, of the velocity curve of entry into the canal head, during the period subsequent to 1900, when as they knew, the silt carrying power of the current of entry had been so greatly reduced.

Mr. Colyer thought that the Sub-Divisional Officer in charge of a Canal Head Works ought to be given a greater latitude and license to play with the river currents. That would never do. The S. D. O., a young engineer, acquiring experience, might, very possibly, make the State pay heavily for his experiments. It was this empirical regime of hit-or-miss, fluky, expedients, that the speaker would like to see abolished in favour of a more centralized, systematic, rational principle of design. He had put forward one such principle, or set of principles, and he suggested that it be exhaustively tested, and definitely put to the proof.

* Page 92.