The great benefit was undoubtedly the small disturbance caused at the parting of the waters. He looked on the arrangement as ideal, but possibly not quite practicable in all cases. In the case of a distributary having its bed above the bed of the canal, he presumed the author would place the bed of the intake channel on the same level as the distributary bed, in which case there would be a sill at the entrance. This would obstruct the forward motion of the bottom strata of water in the canal and would produce eddies. If the bed of the intake were to be at canal bed level, then the intake would silt up in all probability to the level of the distributary bed. The chief defect in an offtake of this design would be its liability to admit too much heavy silt, but quite possibly it would not admit more than its true share of the silt passing down the canal. The author had given reasons* why a distributary should take off the same proportion of silt of all grades as was present in the water of the parent channel, but were those reasons supported by facts ? Did not heavy silt in the process of transportation grind its own particles, with the result that silt got finer as it passed down ? If this were so then it surely was not necessary to pass into the distributaries the same proportion of silt of all grades as was present in the parent channel. It was not always easy to arrange to give a distributary grades and sections to provide silt transporting power equal to that of the parent channel, had it been so why should canal engineers have remodelled distributary heads on lines particularly intended to exclude the heavier grades of silt passing down the parent channel, presumably having to alter their distributaries so as to dispose of these heavier grades of silt ?

MR. RADHIKA NARAIN thought that Mr. Schönemann's conclusions were of great practical significance. He was fully at one with him in attaching much importance to the main feature of the suggested design for a distributary head regulator consisting of a raised crest and a rising gate sill. He had to confess, however, that he could not always follow the writer in the theoretical side of his paper. To begin with, it appeared that Mr. Kennedy's theory of silt transportation, as stated succinctly by Mr. Higham, included by inference M. Dupuit's theory of the relative velocities of contiguous currents. If T represent the silt transporting power of a channel, V_m the mean velocity, V_o and V_d the surface and bottom velocities, d the depth, and V_r the difference in the relative velocities of two

* Pages 128 and 130.

contiguous streams of water a unit distance apart, according to Mr. Kennedy.

$$1_2 \propto \frac{Q V_m}{f d}$$

when V_m is constant T would increase as d decreased, and *vice versa*, but when d decreased the difference between V_o and V_d would increase hence V_r would increase, and when d decreased the reverse would be the case. Hence it followed that V_m remaining constant, T varied as some junction of V_r, or in other words T varied directly as both V and V_m.

$$\therefore T \propto Q V_r f V_m.$$

Representing V_r by $\frac{Vo - V_d}{d}$ and V_m by $\frac{V_o + V_d}{2}$, and omitting Q and f for the sake of simplicity.

$$T \propto \frac{(V_o - V_d)(V_o + V_d)}{2d}$$

$$\text{or } T \propto \frac{(V_o - V_d^2)}{d}$$

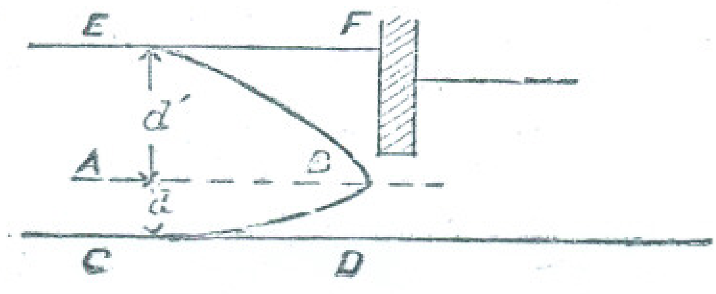
which was accepted by Mr. Higham as more rational* than Kennedy's original formula from which it has just been deduced !

Again he did not quite understand why fault was found with Mr. Kennedy's method of dealing with the question of silt transportation. The problem before him was how to prevent the deposit of silt in running channels. He started with a careful observation of the hydraulic conditions of channels, which had attained to a permanent regime, and were therefore neither silting nor scouring their beds. From a close study of the data thus collected it appeared that the mean velocity of the channels under observation had a certain constant relation to their depths and supply. This relationship was reduced to a curve from which a mathematical formula was deduced, and it was argued that since this particular relationship between the mean velocity and the depth of a channel was attended with neither a deposit of silt nor scour of the bed, any deviation therefrom in either direction would result in a deposit of silt on the one hand and a scour of bed on the other. From an examination of the mathematical formula deduced, it appeared that any further increase in the mean velocity or decrease in the

* Page 99.

depth of the channel would result in the scouring of the bed, whilst any further decrease of the mean velocity or increase in the depth would cause a deposit of silt. These facts could be briefly expressed in mathematical language by saying that the silt transporting power of a channel varied directly with its mean velocity and inversely with its depth. This was the stage up to which Mr. Kennedy carried the solution of the problem in hand. His method might be called empirical, inasmuch as he did not take up the very difficult task of explaining scientifically how and why the silt transporting power of channels varied with the velocity and depth, but that task would demand more time, attention, and resources, than a departmental engineer could possibly have at his disposal. Nothing short of a separate Engineering Research Section could tackle such a huge task satisfactorily. With due deference to the ability of the author of the paper, he ventured to differ from him in attaching any great importance to mere speculations in the regions of theory, more especially because a mere theorist of this kind was generally induced to attach too much importance to his own pet theory, and to try to make out that one theory alone was capable of explaining all the various natural phenomena of that and other cognate kinds. Even in the case in point, *viz.* the power of silt transportation of channels, the writer of the paper appeared to claim that his theory of the eddies produced by the difference in velocity of contiguous currents of water being the cause of the suspension of silt therein, was capable of satisfactorily explaining all cases of silting and scouring of channels under all imaginable conditions. It was very possible that there might be other distinct causes of the silting and scouring of channels, and there did not appear any likelihood of finality to their designs of channels and head regulators until all causes of silting and scouring had been discovered.

In this connection there was one point in the application of the theory propounded in Mr. Schönemann's paper which he did not understand. Taking the case of what was called an under-shot regulator.



Suppose A B is the line of maximum velocity, then C D and E F would be the lines of minimum velocity, and d and d^1 the depths of the portions of the streams A B C D and A B E F. The theory was that since the depth d was very small, the relative velocity between contiguous filaments of the portion of the stream A B C D must be very great. Hence the silt carrying capacity of this portion would be excessive, and in consequence must carry through the orifice a big charge of silt. As regards the portion of the stream A B E F, which was much larger in volume than A B C D, the depth was relatively great, and hence the difference of relative velocity between contiguous filaments would be small. The silt transporting power of this portion would be correspondingly less, and it would therefore drop a good deal of its silt before passing through the orifice, and would carry with it only a small charge as compared with that of the lower portion. The question, therefore, arose, what guarantee was there that the much smaller portion of the streams A B C D would carry so much more silt than the portion A B E F as to more than compensate for its deficiency in volume ; and if there were no such guarantee, what was there to substantiate the claim that an undershot regulator would take more silt than an overshot one ? There might, however, be some difference between the two when the sill was raised to a considerable height.

MR. NICHOLSON pointed out that Mr. Schönemann had said that Mr. Gibb had abandoned his position as being untenable and then continued that he would discuss the matter in popular language, this might be interpreted as being a strategical retreat ! He had always considered that, in a regular straight channel, water flowing from the sides to the centre of the surface was an accepted fact, and referred to the debris flowing through the centre space of the Siswan super-passage, after a sandstorm, as an example.

Mr. Schönemann had in a former paper laid down that the only cure for silt trouble was to draw off water with a low velocity at a high level ; and also that there was no difference in the law governing the transportation of silt whether carried in suspension, by rolling, or by saltation.

Regarding Mr. Elsden's paper, it appeared that the author in making his assumptions had simplified them too far : he had accepted the vertical velocity curve as effecting the distribution of silt on a vertical axis, but he had assumed uniform velocity on a horizontal axis with consequent uniform silt distribution. By this, he assumed that a vertical strip of water, say five feet wide, near the bank or centre of the stream had an equal silt burden, which appeared to vitiate any results he might have theoretically obtained.

MR. LINDLEY remarked that Mr. Schönemann's condemnation of a raised sill in front of a submerged orifice appeared to be too radical, though those mentioned might be too low to cure the silt evil in their distributaries. The vertical velocity curve in a case without such a sill would be similar to that given by Mr. Schönemann in his Figure 7.* However low a sill was placed in front of the gate, it would have some effect in raising the point of maximum velocity on that curve and so decreasing the silt index of the orifice.

MR. MIDDLETON asked with reference to Mr. Gibb's theory if circulating currents took the silt from the centre to the sides, how was it that the centre did not scour and the sides silt up ?

MR. SHIV SINGH BEDI said that Mr. Gibb had explained at some length the theory of cross currents, but it was not quite clear how far these currents were present in channels, and what part they played in the actual working of canals. Anyone examining the marks on the sandy bed of a canal could form a fairly accurate idea of the direction of all such currents. A careful observer would not fail to note that all the waves, big or small, travelled in a direction which was approximately parallel to the general run of the stream. The fact that there were no cross wave marks indicated the insignificant part the cross currents (if any) played in the stream hydraulics. That such cross wave marks would be found, if there were any cross currents, was seen from their presence near distributary heads, where there was a change of direction of stream lines. Again, even if the presence of these currents were assumed in a marked degree, it was not clear what force was present to drive the current upwards in the marginal strip, since in rising up, the current had to contend against gravity. Mr. Gibb had adduced* the fact of silting between spurs in support of the cross current theory, but this deposit of silt was probably due to the water losing its kinetic energy on entry, and not to the presence of cross currents. Further on in the same paragraph Mr. Gibb admitted the well established fact that rapidly flowing water carried more silt than slow flowing : how did he reconcile this with his conclusion " that the supply should be

* Page 103.

drawn towards the head at a high velocity" ? Would not the current by virtue of its higher velocity pick up silt from the surrounding mass of water, especially when it was found that there was nothing to prevent the lateral transference of silt across the stream ? In fact if there were no such transference, there would be no undue proportion of silt in any channel. It appears that in the case of a channel carrying a surcharge of silt, the parent channel was probably relieved of its charge, whilst in the opposite case the parent channel was slightly overcharged ; the change, however, was, generally speaking, an imperceptible one (since the distributary supply usually was a small proportion of the canal supply), and hence no silting or scouring was noticed. It followed that this lateral travel of silt always took place in front of all heads, because the void created by the offtake had to be made good. It must be remembered that there was no impenetrable barrier between a rapidly flowing and slowly moving current, and hence they must adjust their charges in accordance with their carrying capacities. It was not clear how a brick floor would help the situation, since, as already explained, the water picked up the silt, not from the bed of the channel, but from the surrounding mass of water. Scour only took place when the scouring power extended through the entire mass of the water, otherwise the unaffected portion tried to keep a balance by what was called the lateral transference of silt.

He considered that a skew head should be followed by a skew bridge otherwise a loss of kinetic energy would ensue. He did not see how the gradual expansion below the head was going to help matters. A gradual alteration in waterway would only introduce a gradual change in the silt carrying capacity of the water : but the change they were mainly concerned with was there, and was bound to produce attendant results. It was of course necessary to avoid having the area of flow greater than the normal waterway of the channel, since that would no doubt mean unnecessary loss of energy.

MR. ASHFORD referred to the wave motion mentioned by Mr. Gibb in the appendix to his paper, and said that experiments made by him on his patent tube well strainer appeared to throw additional light on the subject. His tube was built up of bars supported at intervals on rings and bound round with wire. When he first made up this tube he feared that the supporting rings, in their opposition to the flow of water, would cause a serious amount of friction. To test the matter he placed a length of ten feet in a truly horizontal position, and provided means for keeping the tube fully submerged while passing water at any desired velocity through it. The results obtained at first seemed strange, for it was found that for low velocities of flow the co-efficient of friction was high, and that, as the velocity of flow increased, the co-efficient decreased. This decrease was not uniform, however, but when plotted upon a curve, the line first mounted to its greatest height, and then reduced its level in a wave-form, until it closely approximated to that of a plain tube. The experiment went to indicate that the water flowed through the tube in a wave like stream, and the least friction was found when the velocity of flow produced waves which synchronised with the pitch of the supporting rings. He had also observed that the particles of water seemed to progress with a helical movement, and this was specially noticeable at a bend, where the water had been observed to issue from the pipe with sufficient twist to cause the water to be quite hollow at its interior.

MR. SCHÖNEMANN said that in his paper Mr. Gibb had formulated a novel theory of silt transportation by water, which was directly opposed to the views expressed in his own paper. However, Mr. Gibb had now abandoned his own theory of silt transportation, and accepted the speaker's view generally as to the hydraulic forces actuating silt-carriage, so that there appeared to be no material disagreement now over the essentials of the problem under discussion.

Mr. Gibb had expressed agreement with him on the following points :—

(*a*) In the description of the conditions of flow that make for lifting silt from the bed and sides of an earthen water-channel.

(*b*) In that, other things being equal, the intensity of cyclic flow, and, therefore, of silt getting ability, depended on the rate of change of velocity along lines at right angles to the boundary of the channel.

(*c*) In the relative merits of overshot and undershot regulators.

(*d*) In the importance attaching to the level at which water passed through a regulator, which went completely across a canal and dealt with the whole supply.

Admission of the above points appeared to him to concede the essentials of his principles of design for distributary head regulators. The only material points to which Mr. Gibb still demurred were his silt-index, and the supposed conflict of his views with the principle of the conversation of matter. His silt-index was merely an index of *potential* capacity for scouring or for carrying silt. In the case of a channel lined with non-friable material (say masonry or metal), and fed with clear water, there would be no silt in the current ; yet, if its silt-index were high, the potential would be there, ready to act at the first opportunity. The problem under discussion, however, concerned silt-laden water, flowing in channels of friable soil. If such a channel A, with a current carrying a certain silt charge (*i. e.*, a certain proportion of silt in suspension per unit volume of water), bifurcated into branches B and C respectively at a certain point, the proportions of silt-charge passing into each branch would be proportionate to the silt-index of the head regulator of each branch. Thus, if the silt-indices of B and C respectively were in the ratio of 2 to 3, then, out of every hundred parts of silt carried by the water in the trunk channel A, forty parts would pass into channel B, and sixty parts into channel C, and by suitably altering the silt-indices of the head regulators of B and C, it would be possible to alter the relative silt-charges of the channels fed through them.

Mr. Gibb had admitted the truth of this principle of design in the case of regulators across a canal, but thought that it did not necessarily apply to the case of a relatively small distributary offtaking from a relatively large canal. Yet, in the case of the canal-bifurcation imagined above, one had only to imagine channel B to be an extension of channel A, and nearly of the same capacity as A, and to imagine channel C to be one of relatively small capacity, offtaking at any angle to A, in order to see that there was no essential difference of principle, *qua* silt-carrying conditions, between the canal regulator and the distributary regulator. It was conceivable, however, that some function of the volume of water supply might appropriately be introduced as a factor into the formula of silt-index as had been, indeed, suggested by Sir Thomas Higham.

He did not think that anything written by him bore the interpretation that he had questioned the principle of the conservation of matter, as stated by Mr. Gibb. He had given precise diagrammatic details of a case of bed-scour, which had extended to five miles upstream of the canal regulator at

Amipur; and he was not aware of any means of precisely determining, by theoretical reasoning, the point at which such scour must cease in an artificially graded channel in friable soil.

Mr. Lindley, as well as Mr. Gibb, had taken exception to his condemnation of the "advanced sill" depicted in Fig. 9 on page 107. They thought that the sill or crest HK was well calculated to exclude silt from the channel fed over it, in spite of the fact that the current might be flowing into that channel at a high velocity through the low gateway-orifice F G. The fact remained, however, that, although many of these advanced sills existed on Punjab canals, he did not think any body could point to a single one that was successful as a silt-excluder. In the case depicted in Fig. 9 the sill was inert. There was no afflux over it; and it effected no appreciable alteration, *qua* silt-carriage conditions, between the parent channel and the offtaking one. The governing silt-factor, in this case, was the current of high velocity through the low gateway-orifice F G.

Mr. Carne had deduced from Kennedy's hydraulic diagrams a theory which Kennedy had certainly never formulated himself. Kennedy had very distinctly stated that the silt carrying power of a current depended on the ratio of its mean velocity to its depth, and that the width of the channel had no influence on that power. It was well-known that however reliable Kennedy's hydraulic diagrams might be in ordinary cases, the extreme limits of some of his critical curves were not reliable as guides to design. Mr. Carne had said that the speaker's design of distributary head required working conditions that were seldom obtainable in practice, but that was not the case. Cases would be rare in which those principles of design could not conveniently be applied in practice. Mr. Carne also wanted to know how his design acted as a silt-control? In reply it was sufficient to say that at any offtake; one had only to build a regulator across the offtake-orifice, and another across the parent channel below the offtake, and to design the two regulators with selected silt-indices, in order to apportion silt to the two channels, fed by the regulators, in any manner that might be desired. It was not even necessary to build a regulator across the parent channel below the offtake. The silt-index of the parent channel below this point could be judged from its mean velocity and water-depth; and that of the offtake regulator designed greater or less, according as the conditions of the case demanded. The data of observation at the Bhatinda Abohar bifurcation of the Sirhind Canal, presented by Mr. Colbourne, at Mr. Carne's request, appeared to be a strong confirmation of his views.

He thought Mr. Elsden's paper was too purely speculative. He had presented no data of experimental observation in support of his particular views; probably because he had not had opportunities, within recent years, of dealing with flowing water. Mr. Elsden had said that the design of distributary head regulators had not received much attention up to date. That was not quite true. When Colonel Cautley designed the Ganges Canal, sixty years ago, he elevated the sills of distributary heads above the level of the canal bed; and this tended to modify the silt charge passing through them. On the Punjab canals, some thirty years ago, it was the general practice to pass water from canals into distributaries over elevated sills, or crests of *karries* or flashboards; and this also tended to reduce the silt-charge passing into distributaries. Karries, however, needed two men to lift them, one at each end; and ideas of economy of establishment led, in course of time, to the substitution of undershot gates, workable by a single labourer turning a windlass. This was a change for the worse from the point of view of silt-regime, for it led to the passage of an excess of silt-laden water by under-scour into the distributaries.

The climax was reached when Mr. (now Sir John) Benton, about twenty years ago, devised a method of measuring the discharges passing into distributaries through undershot gateways, by means of tables of co-efficients varying according to heads of pressure and other considerations. As a means of conveniently measuring discharges Mr. Benton's method failed and was soon discarded; but while it lasted it led to the universal adoption of undershot gates for distributary heads on Punjab canals, and to the fixing of the sill of these gateways in most cases at the lowest possible level, *viz.*, the canal bed level. Hence it was that since 1830 a new factor of silt trouble had been introduced into their canal systems.

In the days when Kennedy devised his silt formula and hydraulic diagrams (1882-1885) karrie regulators were in general use, but the subsequent introduction of the undershot gateway greatly altered the silt-hydraulics of distributaries and the applicability of Kennedy's silt-formula to them. The official acceptance of these diagrams in 1897 synchronized, unfortunately, with the official acceptance of Benton's undershot gate gauge device, and the latter to some extent vitiated the action of the former. In justice to Kennedy this should be borne in mind. The speaker felt sure that if undershot gateways of the Benton type had been in use on the channels studied by Kennedy, in the early eighties, the latter would have found a solution to the silt problem appropriate to those conditions.

Mr. Elsden admitted that a raised sill tended to exclude from an offtaking channel the more heavily silt-laden waters of its parent channel, whence it logically followed that by suitably controlling the level of the sill of an offtake the proportions of the silt-charge could be controlled.

Mr. Elsden, in his constructive proposals had advocated a supply channel 198 feet long between the canal and the distributary head, and had recommended the adoption, in a sample case, of a gradient of 1 in 4,444, in preference to one of 1 in 5,000. The difference between the two gradients in a length of 198 feet was only 0·005 foot ; and if that difference seriously mattered, it was placing a higher reliance on the skill of the Indian cooly, than was usually justified, to expect him to dig or build with such nicety. Mr. Elsden had, however, been quite candid in criticism of his own design where he wrote* "An offtake constructed on these principles would silt up when the distributary was closed. It is not easy to see how this can be overcome except at prohibitive cost."

In conclusion, whatever difference of opinion there might be amongst those present on the details of the theory of design there seemed to be no reasonable doubt that, in the main, water passing with relatively low velocity over a relatively high sill or crest, carried a relatively low silt charge ; whilst water passing with a relatively high velocity, through an orifice at a relatively low level, carried a relatively high silt charge (assuming the water upstream to be silt laden). It was reasonable to urge therefore, that by suitably regulating the level and velocity of offtake, the proportion of silt, drawn by the offtaking channel from the current of its parent channel, could also be regulated and controlled. This was one obvious method of design ; and a simple and efficacious one.

MR. GIBB, in reply to those who complained that he had put forward no direct, practical evidence in support of his theory said that he had refrained from doing this intentionally, though he had collected a good deal of material of the kind called for. He considered that hydraulics was suffering, because it had

* Page 133.

become purely empirical, and that no real advance was being made on that account. They must, he thought, get back to something rational, and for this reason he had tried to deal with the subject on rational lines. Different people would have different objections to offer to any line of reasoning, and he asked those who criticised his theories to experiment for themselves and decide their own doubts. There had been a tendency throughout the discussion to confuse silt-carrying power with silt-getting power.

Mr. Schönemann had said very little about distributary heads, and he was surely inaccurate when he said that the use of an overshot regulator was similar to a uniform steepening of gradient up stream. The effect would really be similar to a gradient gradually getting steeper as the stream approached the regulator. He also wished to say that Mr. Schönemann had spent much time in dealing with the position he (Mr. Gibb) had abandoned, but he hoped he had made himself clear on that matter.

Though Stearn's paper on circulating currents was interesting it was quite unsound in the way it tried to account for the rising current at the margin of a stream. The line of least resistance past an obstruction was not upward as Stearn stated, because the energy derived from flowing upward from a position of high to one of lower pressure was exactly balanced by the work done against gravity in rising.

Referring to Mr. Carne's remarks on Kennedy's silt diagrams, no one had ever been bold enough to base a channel section on the part of the critical velocity ratio curve below the apex. The form of those curves was due to the empirical way in which they were obtained, and he believed that none of Mr. Kennedy's data referred to the part of the curve below the apex. Probably Mr. Kennedy was very annoyed when his empirical formula gave this form of curve. It was an example of the danger of purely empirical methods.

The speaker was not responsible for the advanced sill design as Mr. Carne suggested. He had introduced a modified form of it into his early designs, in order to get them sanctioned, as such sills were popular then and his design was not.

Distributary heads like that illustrated in Fig. 16 of his paper* were designed by taking the aspect of the head looking down stream towards it, and making the area between the point

* Page 84.

of the downstream jetty and the upstream wing wall such that, to pass the required discharge into the distributary, the velocity there had to be greater than that in the water passing on down the parent canal.

With regard to the question of the distribution of silt in the cross sections of a canal he saw no reason for supposing that silt was uniformly distributed ; that would be a very special case. They might for some purposes have to make that assumption, but it would only mean that they did not know how the distribution really varied ; it would not mean that they believed the distribution actually was uniform. In a similar way they were accustomed to deal with absorption as if it were constant, though they knew for certain that it was not ; only they did not know how it varied.

In reply to Mr. Middleton, channels *did* tend to scour at the middle and silt at the side. Practically all channels formed berms which went on silting up till an almost vertical bank was formed.

The absence of waves on the sand bed of the canal indicating the cross currents was accounted for by the fact that the cross current represented only a gentle twisting motion, the cross components of the whole velocity being small as compared with the forward component.

Mr. Ashford's remarks interested him greatly but he had been unable to treat the subject of submerged wave motion mathematically ; all the forms he knew were unstable under the conditions obtaining.

COLONEL CRASTER, in thanking the members for their interesting papers, and the instructive discussion to which they had listened, said he would far rather that Mr. Ward had been in the chair, as the latter had had long experience in canal matters. He confessed to considerable difficulty, on reading the papers on canal distributaries, in imagining all the conditions necessary ; whereas to a canal engineer it was a matter of experience, and hence the imagination of such conditions was a simple matter. One thing which had impressed him during the progress of the discussion was the great variety of opinions held by canal engineers on the subject of distributaries and their design, and he thought that whilst the Irrigation Department was served by a body of officers possessing such vigour and independence of thought, His Honour the Lieutenant-Governor might rest assured that the interests of canals, on which the country depended, would be well looked after.

CORRESPONDENCE.

MR. RADHIKA NARAIN wrote with reference to Mr. Gibb's paper that the author had based all his suggestions for the improvement in the design of distributary and other heads on the following three propositions :—

(*a*) In an ordinary straight canal the bottom water flowed from the middle towards the margin, the surface water flowed back towards the middle, and there was an upward current in the marginal region.

(*b*) Surface water, which contained a relatively low silt charge, tended towards the region of highest forward velocity, and bottom water densely charged and containing the heaviest silt tended to pass towards regions of low forward velocity.

(*c*) The kinetic energy of flowing water should as far as possible be concentrated and conserved, and should not be allowed to go to waste in any way, because this kinetic energy meant so much command.

A good deal had been said in the paper in support of these propositions, but so far as he could judge there was nothing which could be considered a sufficient justification for any one of them.

The first proposition, it was said, laid down a well-known fact, but it appeared incredible that the bottom water should be constantly flowing from the centre towards the sides and the surface water should be continually passing in the opposite direction. Were such the case, the taking of reliable discharges would be well nigh impossible, as no float would travel at all straight, but as a matter of fact no such difficulty was ever experienced in actual practice, whenever, of course, there was no wind and the discharge run was in good order. Moreover when channels dried up no indication of any bottom cross current had, so far as he was aware, ever been noticed on the bed. Sandy beds clearly showed any wave action whenever a channel dried up soon after the passing of a wind-storm, and the branches of a bush on the bed had often been noticed, when the bed was dry, to lie parallel to the flow of the stream, but none of these marks seemed to lend any support to the theory of cross currents.

The writer of the paper, however, had shown an actual representation* of these cross currents in the case of a certain marginal strip of the Upper Gugera Branch, and had plotted

*Figure 6 facing page 74.

the lines of flow of both the surface and the bottom currents. The former had been arrived at directly by noting down the paths actually travelled by floats, whilst the latter had been deduced indirectly by plotting the directions of travel of both rods and floats, and by working out therefrom the component direction of the bottom currents. No details of the experiments had, however, been given anywhere ; and there was nothing to show that the observed deflection from the straight course, in the case of the surface floats or rods, was not due to some local cause, such as wind, or to some undersurface obstructions. It was obviously of great importance to scrutinize thoroughly the details of such experiments if they were to form part of real scientific research, with a view to ensuring that all sources of error had been scrupulously provided against. In the absence of conclusive scientific proof, the correctness of the first proposition (*a*) could not be admitted.

Having advanced the existence of these surface and bottom cross currents, the writer of the paper proceeded to trace their origin, and in doing so started by quoting Appendix B, which was not only too theoretical to be of much practical importance, but was also at its best only a partial proof. If the supposed rotating eddies, caused by the relative differences in velocity of adjoining streams, were really capable of acting as more or less rigid bodies, the existence of some sort of irregular currents from the centre to the sides and from the top to bottom might be possible, but there seemed to be nothing to show why the side currents should first rise up from the bottom to the top along the sides of a channel, and then flow in from the sides towards the centre. It was asserted that the deposits of silt induced by spurs placed at an angle to the sides of a channel, indicated the existence of the cross currents in question, on the assumption that this silt must have drifted to the sides from the centre of the bottom of the channel, but the more commonly accepted explanation that the silt was deposited by the streams of water flowing slowly along the sides of the channel, on account of the further retardation in their velocity caused by the projecting spurs, seemed more probable.

Proceeding to his second proposition (*b*), Mr. Gibb drew a further inference by generalization, to the effect that in order to exclude silt from a distributary the supply should be drawn towards its head at a high velocity. This inference, however, seemed inconsistent with the statement that water flowing with a high velocity lifted and carried more silt than water flowing more slowly,* and it was difficult to see how the author reconciled these two statements. Regarding the case of a double regulator where both a high and a low level distributary were taken off together, put forward in further support of this second proposition, the author maintained that the low water distributary towards which water flowed with a high velocity would take less silt than the high level distributary towards which the draw was much less; but there was nothing to substantiate the correctness of this view. A more rational explanation appeared to be, that the low level channel, which in all probability possessed a fairly steep gradient, being capable of carrying away a heavy charge of silt, would not deposit any of it, in spite of its drawing towards it more silt laden water than that which flowed toward the high level distributary, which, on account of its flatter gradient, was not capable of carrying away even its comparatively light charge of silt without depositing part of it above and below its head regulator.

As regards the third proposition a good deal of stress had been laid on the conservation of energy, but it was not clear to what use it was proposed to put this conserved energy. It was said that all this energy meant so much command, but the question was how was this energy going to be converted into command, and how and where was this command going to be utilized? Very little of this concentrated energy was in evidence in the case of distributaries which suffered from bad command. The gates at their heads had to be kept fully open to admit their full supply discharge, and if the gate openings were sufficiently wide, there was no appreciable loss of energy by sudden expansion when the supply emerged into the open channel. Distributaries possessing good command had necessarily to get their supply at a lower level than that of the parent channel, and while the loss of so much head was essential for cutting down the cost of making unnecessarily high banks, this loss was converted into so much energy in the form of increased velocity of entry into the head of the distributary, especially when (as the writer of the paper advocated) the gate openings were kept as narrow as possible. There was no object in conserving this energy, even if it could be converted into command, because no more command was wanted in this case, and it naturally followed that this energy should be dissipated by means of cisterns, &c., instead of allowing it to play havoc with the distributary bed and banks below the head regulator. It was, therefore, not clear what object would be served

*Page 73.

more slowly,* and it was difficult to see how the author reconciled these two statements. Regarding the case of a double regulator where both a high and a low level distributary were taken off together, put forward in further support of this second proposition, the author maintained that the low water distributary towards which water flowed with a high velocity would take less silt than the high level distributary towards which the draw was much less; but there was nothing to substantiate the correctness of this view. A more rational explanation appeared to be, that the low level channel, which in all probability possessed a fairly steep gradient, being capable of carrying away a heavy charge of silt, would not deposit any of it, in spite of its drawing towards it more silt laden water than that which flowed toward the high level distributary, which, on account of its flatter gradient, was not capable of carrying away even its comparatively light charge of silt without depositing part of it above and below its head regulator.

As regards the third proposition a good deal of stress had been laid on the conservation of energy, but it was not clear to what use it was proposed to put this conserved energy. It was said that all this energy meant so much command, but the question was how was this energy going to be converted into command, and how and where was this command going to be utilized? Very little of this concentrated energy was in evidence in the case of distributaries which suffered from bad command. The gates at their heads had to be kept fully open to admit their full supply discharge, and if the gate openings were sufficiently wide, there was no appreciable loss of energy by sudden expansion when the supply emerged into the open channel. Distributaries possessing good command had necessarily to get their supply at a lower level than that of the parent channel, and while the loss of so much head was essential for cutting down the cost of making unnecessarily high banks, this loss was converted into so much energy in the form of increased velocity of entry into the head of the distributary, especially when (as the writer of the paper advocated) the gate openings were kept as narrow as possible. There was no object in conserving this energy, even if it could be converted into command, because no more command was wanted in this case, and it naturally followed that this energy should be dissipated by means of cisterns, &c., instead of allowing it to play havoc with the distributary bed and banks below the head regulator. It was, therefore, not clear what object would be served

*Page 73.

by converting the tail or the delivery end of the regulator into a masonry flume "diverging at a small angle until the width of the distributary was reached." The concentrated energy would be dissipated by the time the masonry flume ended. Only its dissipation would be gradual in this case, not sudden as in the other case. What then was the object of wasting a large amount of money on the construction of the masonry flume ? It appeared that even the soundness of the third proposition had not been established.

As regards the improvement actually effected in the case of the Gajiana distributary of the Upper Gugera Branch by an alteration in the design of its head regulator, even this did not appear to have anything to do with the action of the cross currents. It was to be noted that alterations were made, not only in the intake portion, but also in the crest-wall and bed, and hence probably also in the bed slope of the distributary. A comparison of figures Nos. 15 and 16* shows that the floor of the head regulator had been raised by about two feet, and the full supply depth of the distributary correspondingly reduced. These alterations were calculated to bring about a radical change in the regime of the distributary quite irrespective of the new theories propounded by Mr. Gibb. For instance, the alteration made in the intake tended to smooth off the flow of the supply into the distributary, and removed the disturbance which used to be caused by the old head projecting too much into the parent channel, at right angles to its current. The raising of the crest reduced the quantity of silt that used to pass into the distributary, and the regrading of the bed slope increased the silt carrying capacity. The improvement effected in the silt conditions of the distributary in this case was, therefore, easily explainable, without the assistance of any of the three propositions set forth in the paper. It was due to the reduction in the silt charge of the supply entering smoothly, and without any disturbance, into the raised head regulator, as well as to the increase of the silt carrying capacity of the distributary, resulting from the regrading of its bed slope and improvement of its cross section.

Turning to Mr. Elsdon's paper Mr. Radhika Narain noted that the writer started with the assumption that the silt distribution in a water channel was of a uniform kind. This assumption might appear to be quite feasible from a purely theoretical point of view, but in actual practice a uniform

*Page 84.

and regular flow was rarely to be met with. All sorts of obstructions, both big and small, were to be met with in every running channel, and these set up disturbances of various kinds in its silt distribution. Hence it was quite out of the question to count upon a regular symmetry of silt distribution in actual practice, and any design of a distributary head regulator based on this assumption, even apart from the almost insuperable difficulties of construction, would not serve the purpose.

Even if the assumption made by the author be taken to be well founded, it did not appear to be sound engineering practice to slavishly follow the particular distribution of silt in a channel, in designing an offtake. The function of engineering was to control and utilize the available forces of nature on as remunerative a basis as was consistent with permanent efficiency, and for that purpose it was no doubt necessary to work out the forces in the line of least resistance, consistently with reasonable cost, and suitability to the essential conditions of each case, but this did not mean adopting the line of no resistance at all, regardless of cost, and unmindful of the limiting conditions. The suggestions made by the author appeared to be somewhat of the latter kind. He seemed reluctant to upset the supposed symmetry of silt distribution, for fear of complicating the silt conditions of the parent channel, and of thereby rendering it impracticable to pass down a proportionate share of silt to the offtaking distributary, but this was surely not the right spirit in which to meet engineering problems.

In taking off a distributary from the parent channel some deviation from the existing silt conditions was essential, but that such deviations were not essentially bad was proved from the fact that all distributaries did not suffer from silt trouble. In fact in seventy-five per cent. of them no such difficulty was to be met with, in spite of the fact that their head regulators were built at right angles to the parent channel. The problem, therefore, was to provide against the causes, which actually produced silt difficulties, in the case of the remaining twenty-five per cent. of the distributaries which suffered from such troubles.

The author admitted* that where it was in any way possible to design an offtake to carry off a known excess or defect of silt, this might be the most satisfactory procedure, but declared it was impossible to design offtakes in this way.

* Pages 136 and 137.

It was no doubt impracticable to determine exactly the proportion of silt carried away by an offtake from the parent channel, but it was quite practicable to increase or decrease the quantity passing into the various distributaries in accordance with their silt carrying capacities. Mr. Kennedy's researches have given a measure in the form of his critical velocity ratios for comparing the silt carrying capacities of the parent and distributary channels, and Mr. Schönemann's discussion of the whole question in his papers of this year and of 1914 enable them to design a head regulator which would regulate the passage of silt into a distributary according to its silt carrying capacity. If, in addition to this, and in accordance with the general suggestions made by Messrs. Gibb and Elsden, they tried to make their head regulators in such a way as to interrupt the free flow of water in the parent channel as little as possible, consistently with considerations of cost and local conditions, they could effectually cure the silt troubles of almost all their distributaries without giving rise to any similar troubles in the parent channel, or in any of the distributaries taking out lower down.

If head regulators were provided with raised sills, or advanced crest walls supplemented with variable rising gate sills, or temporary arrangements for raising the height of the crest walls by means of karries, it would be possible to regulate the passage of silt in distributaries to a very large extent. In case of distributaries with a large silt carrying capacity, the sill could be kept low and the opening of the head regulator comparatively small ; while in the case of high-level distributaries, the silt carrying capacity of which was small, the sill could be raised and the opening made much wider. Similarly, when the supply and the quantity of silt in the parent channel was high, the variable gate sill could be raised to the required extent, and when the supply and quantity of silt was low, the sill in question could be correspondingly lowered. A raised sill did not necessarily exclude all the more heavily silt laden bottom water which lay below the top of the sill. The draw of water into the head regulator generally stirred up the whole supply in front of the sill from top to bottom, and all the layers of water contributed more or less to make up the supply passing into the distributary. As regards the quantity of silt carried with this supply, it would depend on the velocity of draw into the regulator, as well as on the relative difference of velocity on the contiguous filaments of water.

The suggestions for the design of distributary head regulators made by Mr. Elsden seemed to be all more or less impracticable, and he had not been able to solve satisfactorily even those difficulties which were raised by himself. There were however several other difficulties. For instance in the case of inundation canals the supply was by no means constant even in the kharif, while, on the perennial canals, the kharif supply fluctuated from a variety of local or other causes, such as rainfall and the varying states of demand in the different stages of a crop, etc. Again, in actual practice, the head regulators of the distributaries could never be set back sufficiently to ensure exactly the same condition of silt distribution in the distributary as in the parent channel.

MR. M. S. DHODY thought that it was well known that, in spite of the old type of head regulators, comparatively few distributaries gave silt trouble, and this itself was enough to prove that it was not the design of the head regulator alone which was at fault. Engineers seemed to be getting scared of silt particles much as their sanitary and medical advisers were of all sorts of microbes.

It seemed over elaboration to theorize on the movement of water and its cross currents operating in straight reaches of channels, where there was no appreciable outside force worth consideration except gravity carrying the water onwards in its motion, as there was on a curve. If Mr. Gibb's theory was made applicable to offtakes on curves, and if his design of a head regulator reduced silting tendencies in such a channel, it would certainly be a gain, but it hardly seemed to apply to straight offtakes. If the bed of any channel large or small was examined in closure time, the lightest obstructions and sand drifts lying on it would indicate a tendency towards motion in the direction of flow and not crosswise.

The theory of silt being sucked in could be summed up as follows :—

(*i*) Projecting wings caused a spur action, with silt depositing on the lee side, which would stop there, were it not for the high suction through the diaphragm arch. The tighter the water-way, the greater the velocity and suction, and therefore the greater the quantity of silt taken in, and the more heavily graded it would be.

(*ii*) Such a suction might well cause scour holes in the bed opposite the offtake, and such pits would encourage rolling silt which also got caught in the suction stream.

(*iii*) The command on the minor channel was poor, and the bed had a tendency to silt, owing to the reduced velocity, and if haphazard silt clearances were done, they would only tend to get more silt in.

(*iv*) The head from the parent channel was not sufficient and consequently the minor channel could not be pitched up high enough to command land, or given a better grade.

(*v*) The offtake was in a bad curve.

(*vi*) If a tight head with an under-shot gate came in conjunction with the above, the chances for a silting channel were well established, and the remedy would lie in removing these faults in so far as they could be established as having an effect on the working of the minor channel.

Wings should be made so as not to cause eddies or swirls in the parent channel, but should be such that a floating particle placed alongside the berm above a head regulator would travel quietly down into the head. The downstream wing should be such as to prevent any dead areas in front of the offtake, so as not to create any back currents, and the best form for this would be a straight wing finishing off with the berm slope of the channel.

The head opening should be such as to give a gradual fall in velocity, without such abrupt changes as now obtained from about three feet per second in a parent channel, to ten or twelve feet below the diaphragm arch, and 1·0 to 1·8 in the minor channel.

The gate might be one of four types—a falling gate, a rising gate, an opening out gate, or an open weir. The first had been tried and had certainly aggravated matters, but the second and third had still to be tried. The former would still keep off the due share of silt from a distributary, and so send more to the lower reaches, but would be preferable under certain circumstances ; the latter, with a workable mechanism, could be made to admit water through the whole depth over a raised crest. These gates would open or close like those for a lock channel on side hinges, with karrie grooves above. The open weir type would not suit regulation methods.

The next point for consideration was the head from the parent channel, in which most of the difficulties lay. This pressure head was small, and the working difficulties great. Even in some of the latest designs, the channels were designed with as low a head as ·31 ft. It was perhaps premised that such channels would be worked only in special cases of supply, but with the complicated system of allotments and working of channels, all these small points were lost sight of, and engineers who followed had to do their best to meet demands, and force supplies down ; and thus difficulties occurred which were directly due to these forced remedies.

Enough pressure head therefore must be allowed—a foot would be the minimum—and the more the large branches and main canal could be made to give, the less would be the silt troubles, even though only minor points in head regulator design were kept in view.

The difficulties of the set back head of Mr. Elsden's design had been seen by himself, as shown by the device of putting in a karrie groove at the nose. The leading channel would be difficult to work and keep clear, and was sure to cause complications in design.

MR. F. V. ELSDEN wrote that Mr. Gibb's method of designing distributary heads aimed at the regulation of the amount of heavy silt admitted to a distributary, by selecting for admission water carrying more or less silt as the particular case might require, and was based on a theory of silt distribution evolved by the author, to the effect that heavy silt tended to flow away from water having a higher velocity towards that with a lower velocity. Reliance was placed on two phenomena for proof of this statement.

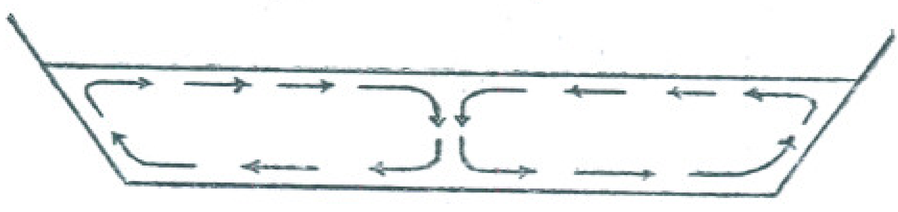
(i). The transverse currents said to exist in any open channel, which flowed from bank to centre along the surface, and from centre to bank along the bed.

(ii) The well known fact that silt accumulated on the inner circumference of a curve where there was slack water, while scour took place on the outer circumference towards which the higher velocities occurred.

Dealing first with the question of transverse currents, Mr. Gibb had, he thought, extended this principle far beyond the limits within which it applied. The starting point of this phenomenon was the admitted existence of an upward current close to the bank which was dependent on the rugosity of the bank. This action was general throughout the width of the channel, due to the rugosity of the bed, but owing to the depth being less near the banks the upward currents were stronger there, and in consequence of this there was a greater or less tendency for a current to establish itself outward from the bank along the surface, and it had been deduced, but not experimentally shown, that there must somewhere be a downward current which fed a current flowing along the bed towards the bank, thus establishing a complete system of transverse circulation, That such a circulation existed to a greater or less extent was, he thought, generally admitted, but the extent of this action was a very important point on which information was scarce.

Mr. Gibb appeared to consider that this action extended well out into the stream, the downward current being near the centre, and the current along the bed traversing nearly the whole half width of the channel as sketched in Fig 1.

Fig. 1



If this was indeed the case there was much to be said for Mr. Gibb's theories, but he knew of no evidence that this did actually occur. On the other hand, the known absence of marked silting along the sides, or scour in the centre, was evidence against it. The experiments quoted by Mr. Gibb, and illustrated in his Fig. 6,* also failed to convey conviction, since they did not give a most important dimension, namely, the total width of channel experimented on and the width throughout which float observations were made.

*Page 74.

His own view, unsupported, it was true, by any experiments, was that these transverse currents existed only in a small portion of the cross section close to the bank as shown in Fig. 2.

Fig. 2.

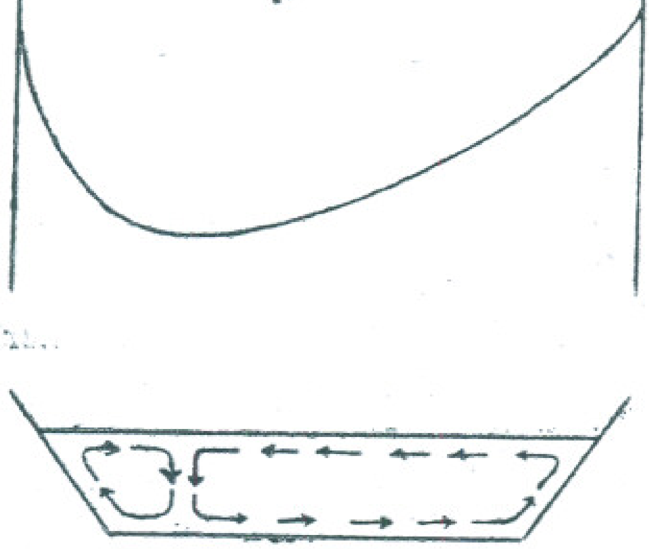
the intensity of the downward current being probably greatest at a short distance away from the toe of the side slope, and reducing gradually to nothing at a relatively small distance from the bank, and if this view was correct, transverse currents might for practical purposes be considered as non-existant, since their effect on silt distribution would be negligible. It should be borne in mind that these currents would be due entirely to the effect of rugosity combined with the shallow water near the bank.

Coming now to the second example quoted by Mr. Gibb, that of silting on the inner circumference of a curve, this was a very well known action, which had been shown by Professor Thomson to arise from the piling up of the water on the outer circumference of the curve producing a static head, which resulted in a flow in the slower moving water near the bed transversely across the stream, which carried heavy silt with it, this silt being deposited in the slack water on the inner circumference of the curve.

Neither of these two phenomena appeared in any way to justify the sweeping conclusion that heavy silt tended always to move away from the higher velocity. Each had a definite and well established cause, which was different in each of the cases considered, and might with some horizontal distributions of velocity be entirely absent.

Mr. Gibb appeared to consider that by increasing the velocity of that portion of the stream which was to enter the distributary head, silt would be driven away from it ; his idea being apparently that the position of the point of maximum velocity was shifted towards the distributary side of the channel, and that the point at which downward flow occurred would be correspondingly shifted, as shown in Fig. 3.

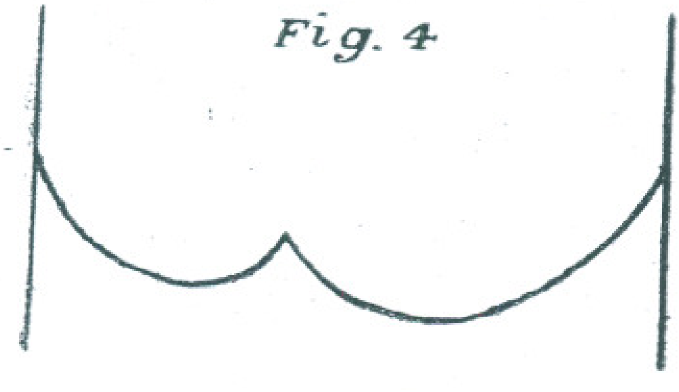
Fig. 3.



This view he contested as a consequence of his opinion that the transverse circulating currents were purely local and did not extend far from the banks.

If, on the other hand, Mr. Gibb considered that a secondary point of maximum velocity had been established, giving a horizontal velocity curve across the stream somewhat as shown in Fig 4,

Fig. 4



then it was not easy to see how any transverse current could be set up, which would carry heavy silt across the bed away from the portion of the stream which would enter the distributary, since there was between the two maxima no bank which could cause an upward current. On the other hand it seemed probable that the reverse might occur—a downward current occurring at the point of minimum velocity between the two streams, and feeding a bed current which would tend to carry silt into the distributary.

Mr. Gibb had further pointed to the rapid silting, which occurred between spurs in a silting reach, as evidence supporting his theory, but this was quite explicable without requiring any such theory. Silt was deposited in the slack water between the spurs because the velocity there was not sufficient to carry it on, but this fact was not inconsistent with the presence of a far greater quantity of silt in the fast current outside the spurs than was present in the slack water between them, and was not therefore at all convincing evidence of the presence of the transverse currents to the extent supposed by Mr. Gibb.

To sum up, there was not sufficient evidence that the transverse circulating currents in question were anything but purely local currents near the bank, while, even supposing them to be more extensive, the evidence of these currents and of those which occurred at bends did not form a basis from which it was possible logically to deduce that heavy silt tends always to flow away from that portion of the stream in which the velocity was highest, which was a condition essential to the correctness of Mr. Gibb's method of designing distributary heads.

In view of the foregoing remarks, he would ask Mr. Gibb if he could give further information concerning the experiments illustrated in Fig. 6 of his paper, or quote any other experimental proof of his theories, which so far appeared to be at variance with well known facts, and not deducible by any arguments so far put forward, while they were so directly opposed to generally accepted theories as to require the very fullest experimental proof.

MR. GIBB, in reply to Mr. Elsden's written communication, pointed out that he had explained, when introducing his paper at the Congress, that the basis of discussion having widened to include all the silt problem, he had included as evidence in favour of his theory the rational proof outlined in Appendix B, that cross currents of the nature described must exist in canals. Hence his theory was not entirely based on the two sets of observed phenomena quoted by Mr. Elsden, but was also deduced rationally.

Mr. Elsden considered the upward current close to the bank was dependent on the "rugosity" of the bank, and that the "rugosity" of the bed had the same tendency. Further on he says again that it must be borne in mind that these currents are actually due to the effect of "rugosity" combined with shallow water. And again in another part he objects that it is not very easy to see how any transverse current can be set up in the absence of a bank to cause an upward current by means, presumably, of "rugosity" again.

Roughness of a boundary, as such, on whatever scale, could not directly cause cross currents of any direction or kind; and during the discussion at the Congress the fallacy underlying the statement of an American writer, that the line of least resistance past an obstruction was upwards, had been pointed out.

Mr. Elsden's explanation of the cause of cross currents was thus incorrect. He admitted however the existence of the currents in question, and for their true cause he could only refer him again to Appendix B of his paper. He agreed with Mr. Elsden that the cross circulation in straight channels might be, and often was, normally confined to relatively narrow marginal strips on either side. This would occur when the horizontal velocity diagram was flat in the middle as in Fig. (*a*), while a velocity

Fig. (a)

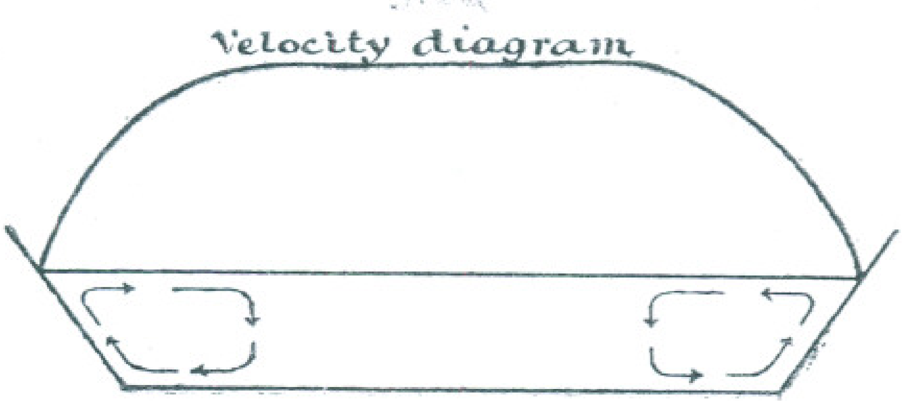
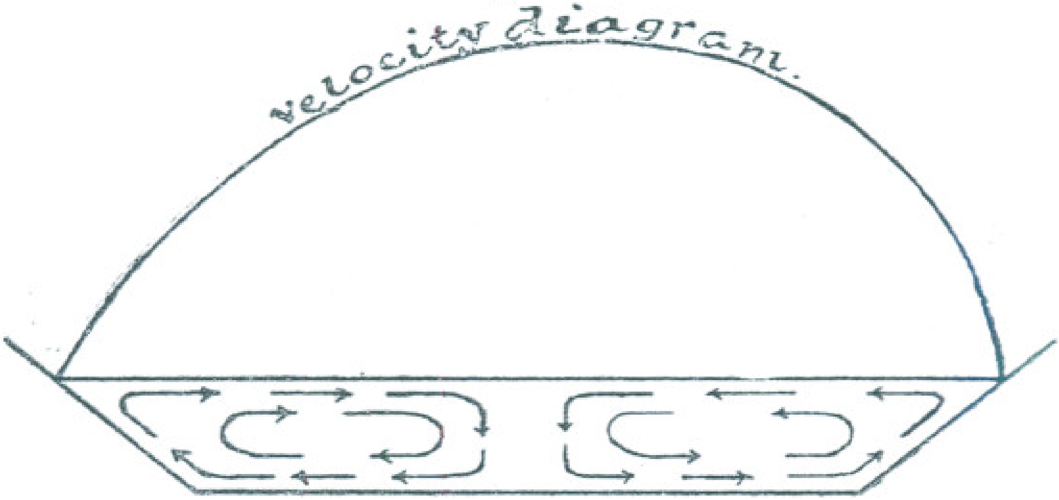


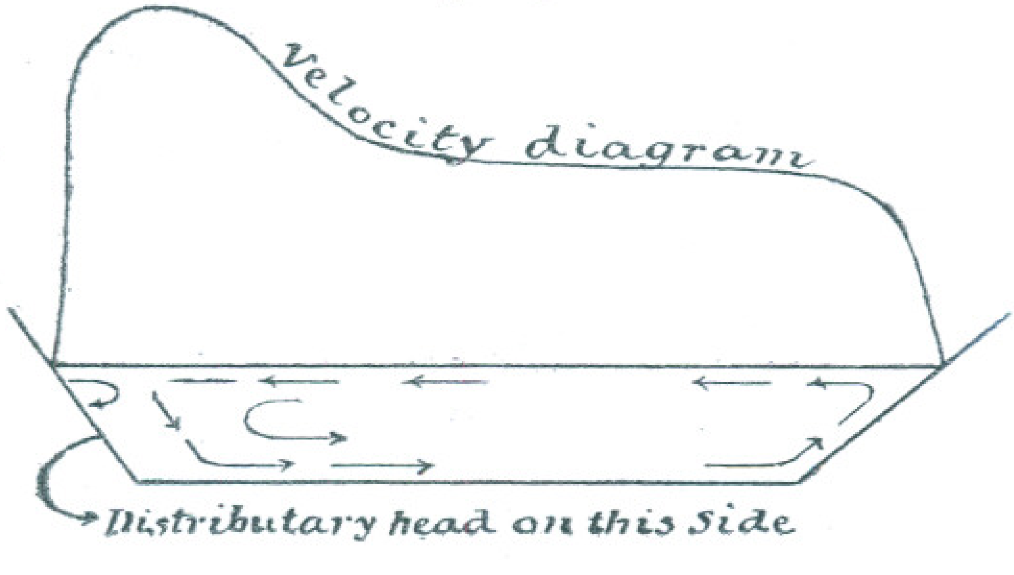
diagram like that in Fig. (*b*) would cause the circulation to extend

Fig. (b.)



towards the middle of the stream. This followed from the explanation given in Appendix B. It did not, however, make any difference in the case of the distributary head, because, according to the principle he had suggested, the head would be designed so as to impose on the approaching stream whatever direction and strength of circulating cross currents was desired. For instance the section of stream and velocity diagram just upstream of a distributary head for taking a small silt charge would be like Fig. (*c*).

Fig. (C.)



Professor James Thompson supplied an explanation for cross currents at a bend, which was quite sound in itself, except that he assumed free vortex flow, which condition was rarely, if ever, attained at canal and river bends. However, this theory was sound for any vortex, whether free or forced, and would be sufficient if circulating currents existed only at bends and did not exist in a straight channel. The causes active in producing circulation in a straight reach would also be present at a bend, and the difference in centrifugal force of the surface and bottom water pointed out by Thompson would be a contributing cause of circulation at a bend, but that it would not be the only cause was evident from the fact that cross circulating currents obtained in a straight channel, where there was no centrifugal force.

MR. WARD wrote that Mr. Schönemann had given an invaluable note of the observations, *i.e.*, measurements he had made, extending over a long series of years, and had produced an empirical formula on the lines of Kennedy's V_o to help in the designing of distributary heads. Mr. Gibb had not given his data, but only the resultant theories he had arrived at and the curve to be given to the upstream wing wall of the distributary head, with hints for the rest of the design. Using the hints given in these two papers constructively, and bearing in mind the axiom that a channel should be run full or closed, the thought arose why should not a distributary head be designed like that of a water-course ? If so, the designers of the Venturi meter* had given the form of pipe by which water could be diverted from the parent channel to a distributary, without loss of momentum in shock. Observations on a water-course at Khanewal (Fig. II) showed that a weir or bar was nature's way of adjusting matters between the high velocity stream in the pipe and the low velocity one in the earthen channel. This bar was similar to that at Mangla and Kalabagh, and was due to the change of section in the stream as it emerged from the hills to flow through the plains ; the narrow and deep channel was divided from the broad and shallow one by a bar or weir.

It was at once evident that such a pipe design was likely to be only suitable to an old canal where the irrigation system was fully developed, such as the Lower Chenab Canal. How was the head to be designed at construction ? Observations at a head (Fig. I) noticed some years ago on the Western Jumna Canal,

*See para. 32 of Unwin's article on hydraulics in the Encyclopædia Brittanica. Also articles on the Venturi meter in Mansfield Merriman's Hydraulics, and in Herschell's Paper before the American Society of Civil Engineers.

showed that use should be made of the silt reach to get a natural channel for the distributary, and utilize the bridge under the patrol bank (over which the boundary road would be diverted) for the regulating apparatus, until such time as working levels admitted of the pipe, head being built.

To fix ideas, a sketch had been prepared of such a piped head (Fig. III); it was drawn for a distributary from a canal, but by suitably modifying the dimensions it would suffice for a water-course leaving a distributary.

As already said, however, such a design would not be flexible enough for the stage when irrigation was being developed; he had, therefore, shown an arrangement (Fig. IV) for taking out from a silt reach, so that the regulating apparatus might be placed at some distance down the distributary, leaving the mouth to shape itself in silt under natural conditions. The case for a ditch channel (Fig. V) was also illustrated. The plan (Fig. I) of the silt berm on the Western Jumna Canal, which first started this line of thought, was also attached, whilst a separate plate (Fig. II) gave the dimensions of the water-course at Khanewal, which turned the train of his thoughts, started by Messrs. Schönemann's and Gibb's papers, towards what might be called the Venturi pipe form of head. If this design proved practical, uniformity throughout the distributary from head to tail, with the possibility would be secured of its also being found suitable, when practical experience had been acquired, for branch heads. American makers of Herschell's Venturi meter illustrate* a pattern in reinforced concrete (see Fig. VI) for irrigation ditches, and drew attention in a photograph of such a headwork to the quiet way the water entered and left the meter.

Working constructively from Messrs. Schönemann's and Gibb's papers this form of head appeared to be that required to pass water into a distributary or water course so that silt would not be trapped, whilst Herschell, working from the point of view of a meter had found that this form gave a very nice way of taking water out of a channel. It was, therefore, to be hoped that further work on these lines would furnish the type of head that those already mentioned were in search of.

MR. ELSDEN replying both to the discussion and subsequent communications pointed out that Mr. Gibb had said nothing on the main principle for which he was contending, but ex-

**Vide* Catalogue published by George Kent, Ltd., 199—201, High Holborn London, W. C.

pressed surprise that the existence of cross-circulating currents should be denied. He would like to explain his position more clearly in this respect. He did not deny the existence of such currents *in toto*, but he did not admit that they were anything more than purely local currents, affecting only a very narrow strip of water near the canal bank, and if this were the case, their influence on distribution of silt would be absolutely negligible. He had recently seen a very interesting piece of evidence in favour of this view, which he would describe. The Upper Jhelum Canal, which was opened, for the first time in October last, had lately been closed for a few days, after running for six months, during the last three of which the supply had been nearly constant. The bed of the canal in places was in good loamy soil, clean, and quite free from sand silt. The closing of the canal had in many places revealed striations in the natural soil of the bed which had without doubt been caused by the action of water, assisted by the heavy silt dragged along the bed. These striations were in effect a drawing made by the water itself, giving an exact record of the direction of flow of the filaments of water nearest the bed, and it was noteworthy that, without exception, they were parallel to the axis of the canal, and did not show the least tendency to outward (from the centre) obliquity as they should have done were Mr. Gibb correct.

Close to the bank no marks at all were visible, as there was a certain amount of detritus lying along the toe. This detritus was *not* silt carried in from the centre by Mr. Gibb's cross currents. It was there before the canal was opened, and resulted from the action of several monsoons on the raw earth side slopes.

These striations in pacca earth were particularly valuable evidence of the direction of flow of bottom water, since marks made in such a material were not likely to have been made or modified by the special conditions, which prevail temporarily while the canal was emptying itself, as might easily have been the case were the bed sandy. He had seen these striations continuous over lengths of several hundred feet, where the bed was free from grass, and as near as ten feet to the toe of the side slope in a bed of 210 feet width.

Mr. Schönemann argued that as it was admitted that heavy silt could be excluded by a raised sill it followed that silt could be suitably controlled by such a device. So far as any individual head was concerned this was no doubt roughly speaking correct, but Mr. Schönemann did not follow up the question by any suggestion of what happened to the silt so excluded. Obviously it was not destroyed, and it was, therefore, not unreasonable to suppose that it would make its presence felt elsewhere, so that finality or even an approximation to it was likely to be difficult of attainment if reliance were placed on raised sills.

Mr. Schönemann also took exception to the small change of slope dealt with in the sample case. This was in any case a very minor point, which had no bearing on the main argument, while his reference to the limitations of the Indian cooly suggested that he was confusing surface slope with bed slope. He made no pretence that these calculations were mathematically exact, but they formed a rational method of arriving at dimensions which were likely to be sufficiently accurate for all practical purposes, which after all was the most that could be done in the majority of civil engineering problems.

Mr. Carne surmised that in cases where the distributary bed was higher than the bed of the parent channel, the intake channel would have its bed at distributary bed level. This was not the case. At the upstream end of the intake channel the bed level would be that of the parent channel while at the downstream end it would be that of the distributary, the intervening distance showing a gradual change from the one cross section to the other. With proper care in design such a channel would not tend to silt, as feared by Mr. Carne, nor could such an offtake possibly take off more than its proper share of silt.

To Mr. Carne's suggestion that silt was gradually ground down to finer grades in the lower reaches of the canal he would say that, while some such action was probable, he did not think the extent of it likely to be important, and he would attribute the greater fineness of silt in the lower reaches of canals mainly to the existing prevalence of under-shot head gates, which drew off a large excess of heavy silt. Moreover, any such grinding action would tend to correct one of the defects of his proposals, in that the heaviest grades of silt were probably in the centre of the stream, and so would not in his design get into the distributary in quite their proper proportion, and the process of attrition would therefore tend to equalize matters, and give a nearer approach to uniformity of silt content in all distributaries.

Mr. Carne also considered that the occasional use of raised sills to exclude silt shewed that the difficulty of grading distributaries to carry their full share of silt was immense, but was it not possible that this difficulty resulted in reality from such channels having drawn in, not a normal, but an excessive charge of silt ?

Although several speakers had pointed out that the distribution of silt was not likely to be uniform in a transverse direction, as he had himself also admitted, no argument had been put forward which could be considered to show that it was not sufficiently nearly so to make his proposals worthy of trial.

One objection to them to which he had himself drawn attention, and on which Mr. Schönemann had commented, was the liability to silt deposit at the head of the intake channel when the distributary was closed, but while this was certainly a theoretical objection, working conditions seemed likely to modify it, and only the test of actual practice could show how far it was serious.

The difficulty of grading distributaries to carry the same proportion of silt as the parent channel had been referred to and considerable stress laid on it, but he did not think it was likely to prove so serious as supposed. Regrading did not necessarily mean a steeper surface slope. Much could be done by changing the ratio of bed width to depth of flow, for, down to a certain limit, the silt carrying capacity of a channel increased as the depth of flow decreased, the surface slope remaining unchanged This was shown very distinctly by Kennedy's critical velocity curves in his hydraulic diagrams.

The general trend of all the remarks made appeared to be to confine efforts at silt adjustment to individual heads, and he would, therefore, reiterate the importance of widening the basis, so as to deal with every canal system as a whole. It was sufficiently apparent that the whole of the silt admitted to a canal must go somewhere, and obviously if it was kept out of one distributary it must either go into another, or stay in the main canal. If then heads could be designed so that each would take its due share of silt, then head regulators could be left unaltered, and it could be guaranteed absolutely that measures taken to cure silt trouble in one channel would not upset the regime of others, an end which did not appear to be attainable in any other way. With this object in view he had put forward a design which seemed likely to effect the proposal. If this object was a mistaken one the design was, *ipso facto*, wrong, but if the object was correct, as he believed it to be, the design was he believed correct in general lines even though crude in detail.

L. Radhika Narain had whole-heartedly condemned his proposals as presenting insuperable difficulties of construction and taking the line of no resistance, but it was not easy to see how they could possess both these features, for the line of no resistance was not that on which insuperable difficulties were likely to occur.

He had also accused him of paying no regard to cost, and being unmindful of the limiting conditions. With regard to the former he had not shown or even suggested in what respect the question of cost had been neglected. The initial cost of an off-take to his design would not be by any means overwhelming, and should it be successful it would eliminate entirely heavy maintenance charges for silt clearance, and have the added and not inconsiderable advantage of steady supply and smooth working, which in themselves were worth a very large sum. The value of an engineering work was not to be measured only by its first cost, but also very largely by its results ; and instances were common of a more costly work proving ultimately to be the cheaper. Mr. Radhika Narain's remark regarding limiting conditions was not clear. He had endeavoured in his paper to take into account all the conditions of the problem, and L. Radhika Narain had not adduced any which had not been considered, but had ignored some with which he had endeavoured to deal. Thus he refused to pay any regard to the fate of excess silt left in the parent channel.

L. Radhika Narain's own proposals appeared to be essentially wrong. Not only would he attempt to differentiate in the quantity of silt admitted to each distributary, but he would vary this at each head from time to time by altering the height of his sill. The result would seem likely to be chaotic, for it would never be possible to foresee what would next happen to any part of the system. Finally he had condemned the writer's design as impracticable, but had omitted to point out in what respects it was so, relying apparently on the writer's own statement of the difficulties which might arise. Admittedly there were difficulties but equally, until the scheme had been tried, it was not possible to say that they were insuperable or even serious difficulties. The case of inundation canals certainly presented increased difficulties, but this did not seem a sufficient reason to condemn the system for all canals.

FIG. III.

DISTRIBUTARY HEAD DESIGN

CASE WHERE

CHANNEL CAN TAKE OUT FROM SILT TRAP AT RIGHT ANGLES

SCALE: 1/1500

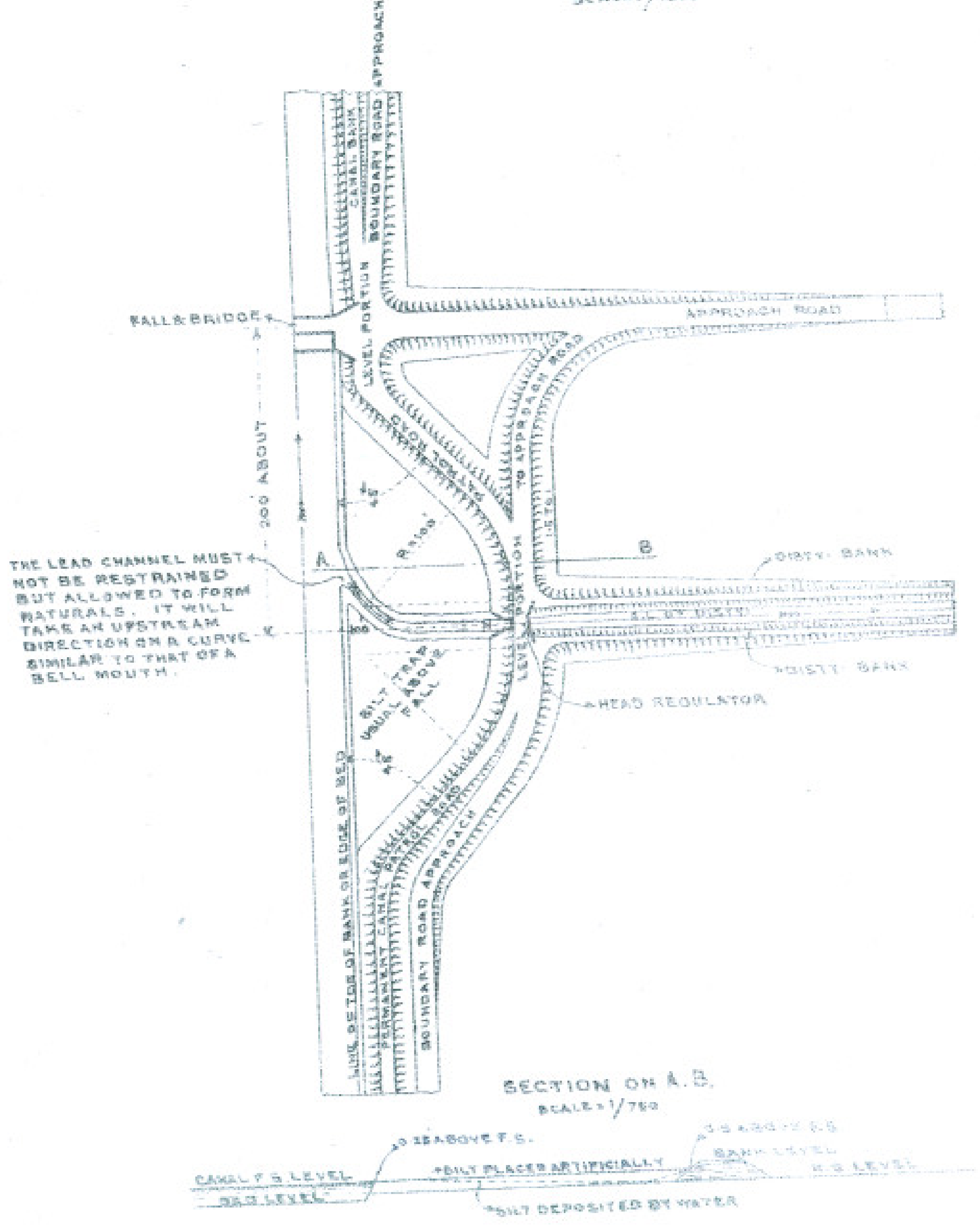


FIG. V.

Head for Distributary

Pipe Proportioned Like a Venturimeter

Scale = 1/800

DISTY: BED WIDTH ——————— b = 25·0

FULL SUPPLY DEPTH d = 2·6

N ——————— ·0225

MEAN VELOCITY ——— V = 1·65 PER SEC.

DISCHARGE ——————— Q = 70 CUSECS

CRITICAL VELOCITY RATIO — — = 1·03V

WEIR: CREST 0·5 ABOVE DISTRIBUTARY BED.

LENGTH = $\frac{D}{d \cdot 0{\cdot}5 V}$ OR 20 IN THIS CASE.

THIS IS IN ORDER TO KEEP THE MEAN VELOCITY SAME AS THAT OF THE DISTRIBUTARY.

IF THE VENTURI METER IS RESTRICTED TO A MINIMUM VELOCITY OF 7 FT. PER SEC. IN THE THROAT (PARKER, CONTROL OF WATER P. 80) WHILST THE RATIO OF AREAS IS 3 TO 1. THE EXIT INTO DISTRIBUTARY SHOULD HAVE Q = A x V THE SAME AS IN THE DISTRIBUTARY THEREFORE THE VELOCITY IN THE THROAT WILL BE 3 TIMES THAT AT ENTRANCE AND EXIT.

THIS INVOLVES A LARGE WORKING HEAD, IN THIS CASE 3·2.