PAPER No. 103.

WEIRS AND HEADWORKS ON THE SUTLEJ VALLEY PROJECT AND SOME CONNECTED PROBLEMS.

By Mr. E. R. FOY, C. I. E.,
Chief Engineer, Sutlej Valley Project.

General description of existing Headworks.

This paper makes no attempt to speak of weirs outside the Punjab, but an endeavour is made to show in what respects there has been a departure from existing Punjab practice in designing the weirs and headworks for the Sutlej Valley Project. The most general type is that followed at Rupar, Khanki, Rasul and Merala, which consist of a masonry bar across the river, the crest of which is considerably above the level of the ordinary bed of the river and on the crest are falling shutters of iron about 6 or 7 feet high for holding up supplies at the required level in the winter, and concentrating flow over any particular portion of the weir when necessary. At the end adjacent to the canal are a set of undersluices fitted with gates and gearing, the floor of the sluices being at a considerably lower level than the weir crest.

Tajawala, the headworks of the Western Jumna Canal, conforms to the general idea, but is so far the only weir on our Punjab Rivers with a canal taking off on either bank ; it therefore has two sets of undersluices but it differs from those first described in that the weir portion is not a continuation of the undersluices, but abuts on an intervening island and owing to the peculiar conformation of the river and to the fact, that being the first irrigation work of the Punjab, a relic of Moghal times, revived about 100 years ago, the headworks as they now stand have been built up piecemeal as required and as experience taught the engineers. To those engineers all honour is due, for they had little to guide them in their first endeavours to harness an unruly river, how unruly, the floods of September 27th to 30th 1924 have fully shown.

Madhopur again follows the ordinary type of raised weir and undersluices, but there are no shutters on the weir, winter supplies are held up by boulder and brushwood bunds. Shutters were tried on a part of the weir but the heavy movements of shingle wear them out and this militates against their usefulness.

Sidhnai Weir is a simple structure worked with needles and does not come into the present review. There remains Balloke which is totally different. These headworks consist of a barrage fitted with Stoney sluices made at Amritsar, extending across the river with the cills at a low level.

At Balloke the Upper Chenab Canal tails in on the right bank and the Lower Bari Doab Canal takes out on the left ; the barrage therefore functions as a level crossing similar to those across the torrents of the Upper Jhelum Canal. This work will be referred to again later.

In recent years Mr. F. W. Woods when Chief Engineer made some changes to the Khanki and Rasul Weir removing the shutters at Rasul and raising the crests of both weirs. These however are questions of details and do not affect the general idea of the existing headworks.

Function of Undersluices.

The first thing to establish correctly in our minds is what is the function of the undersluices? To the uninitiated the answer would appear to be, to pass surplus water. There is probably little doubt that they originated with this idea but this view has been entirely altered owing to the experience when the Sirhind Canal was opened. In the early nineties of the last century it was found that if the undersluices were kept open in a heavily silt-laden river the inflow of silt into the canal was so tremendous that the canal was choked. This trouble befell the Sirhind Canal and at one time it was seriously proposed to keep the channel closed in the Kharif season. Fortunately however, men like Sir Thomas Higham and Mr. Kennedy came to the rescue and from the methods introduced by them which have entirely eliminated any silt trouble in the Sirhind Canal the function of the undersluices would now be more correctly described as follows. To create a deep pool by scouring out in front of the canal offtake, then when the gates are closed again forming a still pool from which comparatively clear water can be drawn into the canal; this procedure converts the deep pool into a silt trap, which when fully choked is again flushed out by opening the undersluice gates, and the process repeated.

All surplus water is then passed over at the far end of the weir by dropping the shutters. This also keeps the varying conditions in the river as far from the Canal Head as possible and ensures a far steadier regime in the river near the Canal Head. Coupled with this method of regulation through the undersluices one presupposes a suitably designed Canal Head Regulator—*e. g.*, one with a sufficiently high crest to give a good depth upstream, that is in the silt pocket, in order that silt may deposit there to such a depth before it can be carried over the canal regulator crest that intervals between flushings are as long as possible.

This brings us to the draw-back to the alternate silting and flushing of the silt pocket, *viz.*, the inconvenience and loss to irrigation if the canal has to be closed when flushing has to be done. However it is the lesser of two evils to have two or three days stoppage periodically during the Kharif crop than a choked-up canal at the end of the crop with a big rabi demand.

This is one of the problems which has not yet been solved. Mr. Woods advocated the full use of the undersluices, but he relied only on a high cill, based on his silt index formula, so far not acceptable to the Department. The personal opinion of the writer is that the undersluices can be kept slightly open thus extending the periods in which the silt pocket is fully charged. But what amount of flow through undersluices is allowed must be fixed at each Headworks by trial and no general

rule can be laid down. The late Mr. Elsden had designed a new type of undersluices and Regulator by which top-water is drawn off across the river over the top while the silt is carried through culverts below. This design is claimed to be an evolution of the vanes suggested in Mr. King's paper at the Congress of 1918. The Elsden type of regulator is more expensive, while the efficacy claimed for it has not yet been proved, and the additional expenditure would not have been justified on a Project already criticised for its cost. The small one built for a distributary on the Lower Chenab Canal has not been fully tested.

Principles followed in the New Designs.

Therefore, in tackling the designs for the Weirs of the Sutlej Valley Project, we had to rely on what past experience had taught, and it was decided to adhere to the still-pond and silt-trap methods. The first problem which faced the designers was, that unlike other headworks, canals took out on each bank. Obviously, for the reasons already given, Tajawala was scarcely a satisfactory model. In a previous paragraph it has been mentioned that when the silt-pocket in front of the under sluices is used as a silt trap, surplus water is passed over the extreme end of the weir. With another silt-trap and canals on the far bank, it is obvious that the heavily laden silt stream must be kept midway between the two. When therefore the centre of the weir has to be used for regulating surplus supplies the question at once arises: Is the primitive falling shutter good enough, can we not give something better? When shutters are dropped at the far end of a weir, the solid abutment and dry land gives a certain amount of confidence and safety to the staff working the shutters but imagine the same being done in the middle of a weir on a dark and stormy night with a very full river. The answer to the question is at once, Have carefully placed gates. Quite so, but if you have undersluices at each end of the weir and also centrally placed regulating gates, why not have them right across? Exactly, and that is what has been adopted; the weirs on the Sutlej Valley Project have therefore been designed as barrages. In this respect the new works are an innovation, with the exception of the Headworks at Balloke, but in the latter, conditions are not identical, as the inflow from one bank and outflow on the other necessitates stream flow across the face of the Barrage which would otherwise be discouraged. In the Sutlej Valley Project Weirs all flow is trained directly on to the weir as will be detailed further on.

Having decided to substitute Gates for the older shutters we are no longer tied to the maximum size of 7 foot high shutters capable of holding up 6·0 feet of water. This enables us at once to reduce the length of the Weir. By reason of the greater depth of gate possible the weir crest need not be so high, and the length of waterway to pass the maximum flood anticipated is very much reduced owing to the increased depths.

For economy however it must be carefully estimated that the heavier and deeper gates should not be more expensive than the length of weir masonry which can be saved.

Description.

Having dealt so far only in generalities we now come to the specific cases of the three Weirs on the Sutlej, this paper proposes to consider the one now approaching completion at Suleimanke with brief references to those at Ferozepur and Islam.

The work at Suleimanke was entrusted to Mr. H. W. Nicholson as Executive Engineer and as that officer had been engaged in preparing the Bhakra Dam Project in the Sirhind Circle from October 1915 to May 1919 he had collected a considerable amount of data with reference to Canal Headworks in the Punjab which he utilized for designing the proposed weir at Aliwal near Phillour on the Sutlej, which has consequently largely influenced the Suleimanke design. The two other designed later differ somewhat.

As now sanctioned and under construction the work follows the general principles laid down in the opening paragraphs of this paper. Briefly put, the weir consists of two sets of undersluices at each end, with 8 gates 30 feet long capable of holding up 18 feet of water, the central portion or weir proper has a crest raised eight feet above undersluice floor and surmounted with 24 gates 60 feet long holding up 10 feet of water. The undersluice piers are 5 feet wide, and weir piers 7 feet. Total length between abutment is 2,223 feet, some space being needed for the left and right divide groynes and two fish ladders.

The first question which will probably strike most of the readers of this paper will be to enquire why, when putting gates across the whole river it has been found necessary to keep the central portion higher than the ends ; why not have one level throughout for the barrage ? In a preceding paragraph it was pointed out that economy has to be considered. When the Suleimanke designs were under consideration all the information at the disposal of the designers and approving authorities was that the economical sizes in gates were 60×10 or 30×18 and in consequence these were adopted. With these data the design had to be as described, but later information showed that gates of 60 feet and a bigger depth than 10 feet were practicable and it then became merely a question of estimating to see at what height of gate their cost ceased to be economical as compared with length of weir.

The faces of the Head Regulators taking off on each side are skewed to the centre line of the weir at a batter of 1 in 4. This gives a better offtake for the Canals. A straight piece at right angles to the centre line of the weir is left between the undersluices and the nearest canal regulator abutment, because it was possible that when the undersluices are open and the canal closed, stream lines flowing along the regulator face might strike the piers of the undersluices obliquely. With the intervention of a straight length of flank wall straight line flow direct on to the undersluices is induced.

After the order for the Suleimanke gates had been placed, thus irrevocably fixing the design as now being constructed, the data of costs for gates again came up for consideration and Messrs. Ransomes and

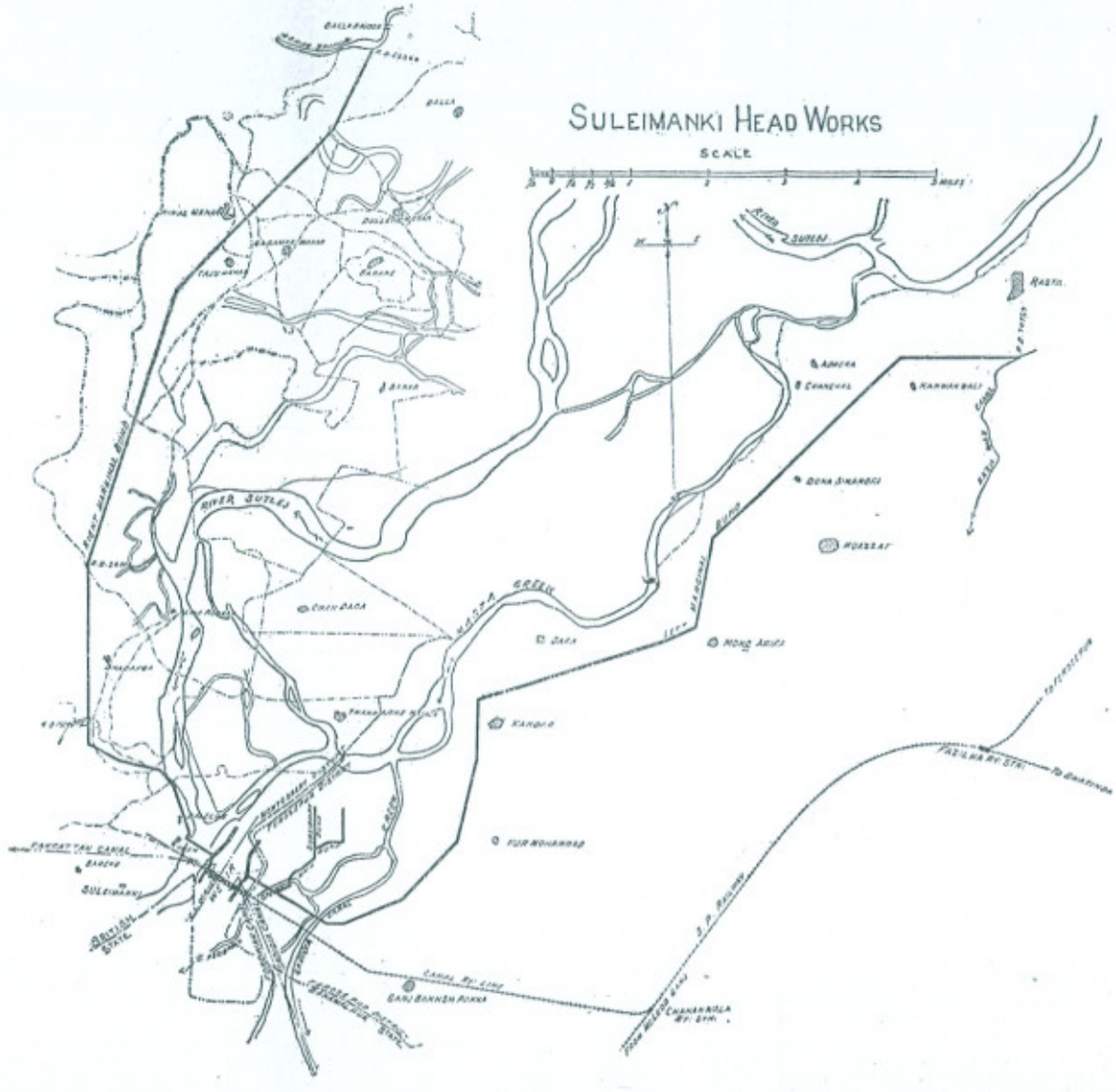

SULEIMANKI HEAD WORKS
SCALE
RIVER SUTLEJ
MADRA CREEK
SULEIMANKI
BRITISH STATE
BANJ BAKHSH WALA
FAZILKA RY STN
TO GHARIBWALA

PLATE II.

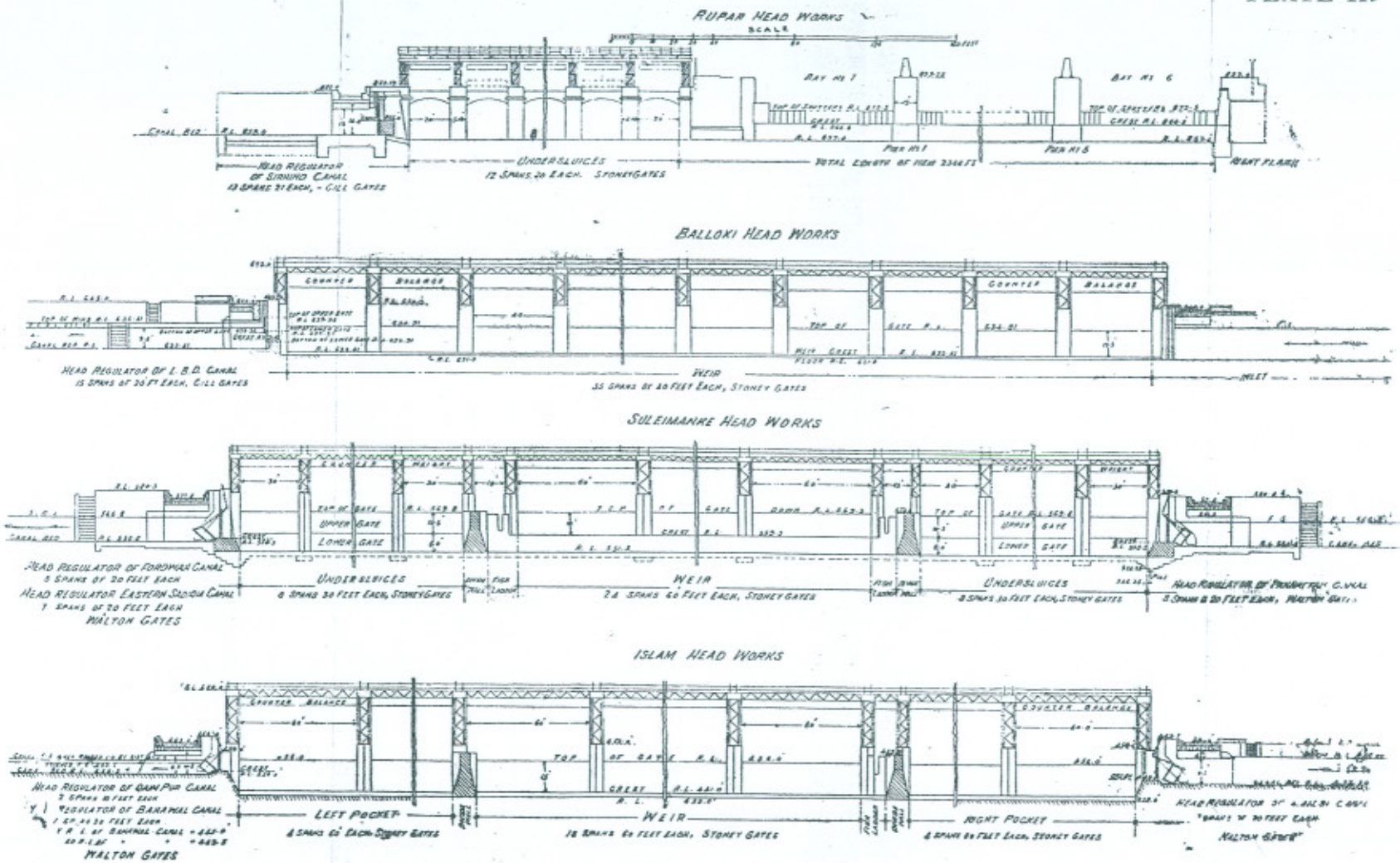

RUPAR HEAD WORKS
SCALE
BAY No 1
BAY No 6
PIER No 1
PIER No 6
HEAD REGULATOR OF SIRHIND CANAL
13 SPANS 21 EACH, = CILL GATES
UNDERSLUICES
12 SPANS 20 EACH. STONEY GATES
TOTAL LENGTH OF WEIR 2346 FT
BALLOKI HEAD WORKS
HEAD REGULATOR OF L.B.D. CANAL
15 SPANS OF 20 FT EACH, CILL GATES
WEIR
35 SPANS OF 40 FEET EACH, STONEY GATES
SULEIMANKE HEAD WORKS
HEAD REGULATOR OF FEROZPUR CANAL
5 SPANS OF 20 FEET EACH
HEAD REGULATOR EASTERN SUTLEJ CANAL
1 SPANS OF 20 FEET EACH
MALTON GATES
UNDERSLUICES
6 SPANS 30 FEET EACH, STONEY GATES
WEIR
24 SPANS 40 FEET EACH, STONEY GATES
UNDERSLUICES
8 SPANS 30 FEET EACH, STONEY GATES
ISLAM HEAD WORKS
HEAD REGULATOR OF GANDA PUR CANAL
3 SPANS 18 FEET EACH
REGULATOR OF BAHAWAL CANAL
1 SP. 20 30 FEET EACH
MALTON GATES
LEFT POCKET
4 SPANS 40 EACH, STONEY GATES
WEIR
18 SPANS 60 FEET EACH, STONEY GATES
RIGHT POCKET
4 SPANS 60 FEET EACH, STONEY GATES

PLATE III.

PART PLAN OF SULEIMANKI WEIR

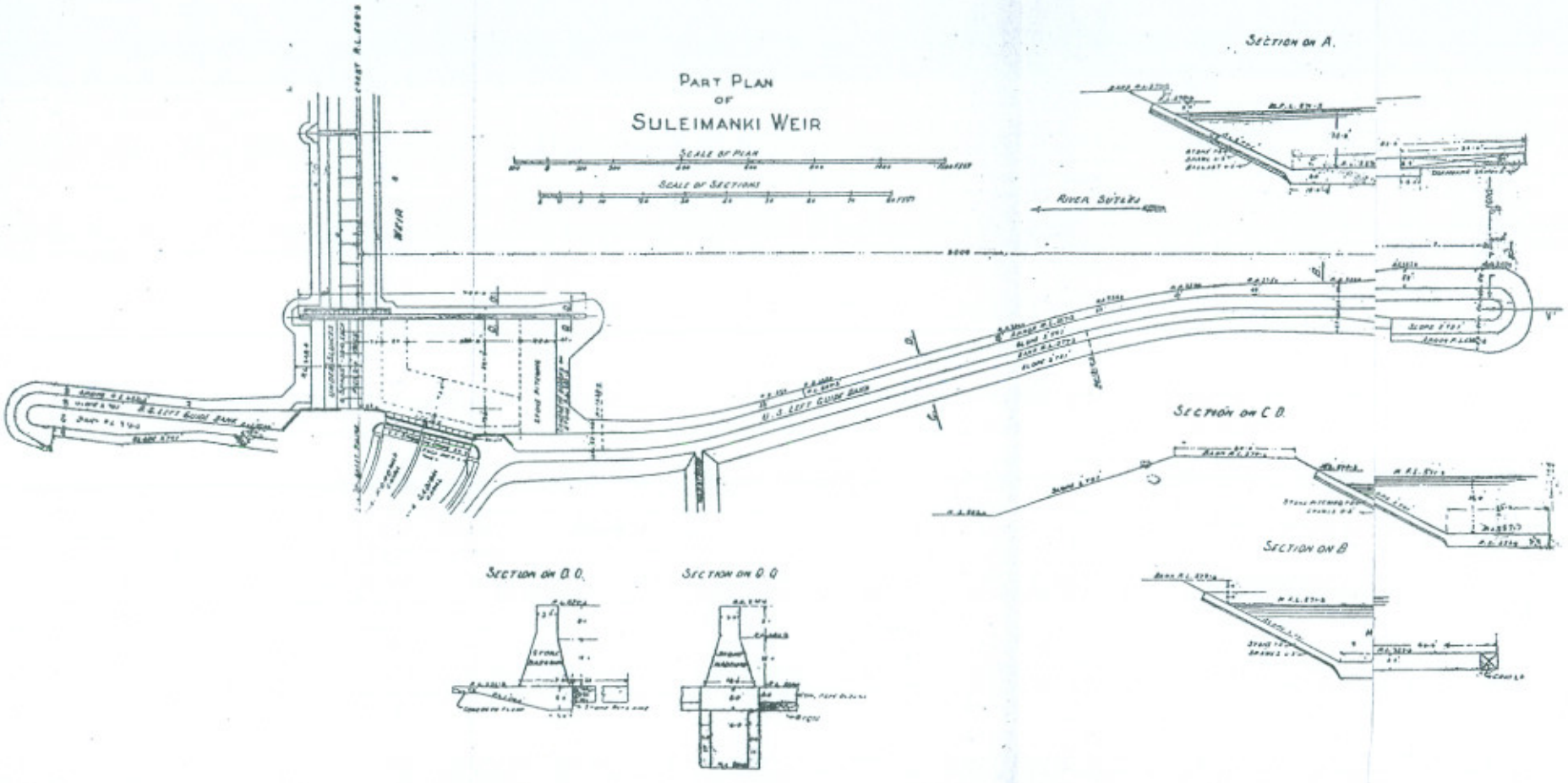


PLATE V.

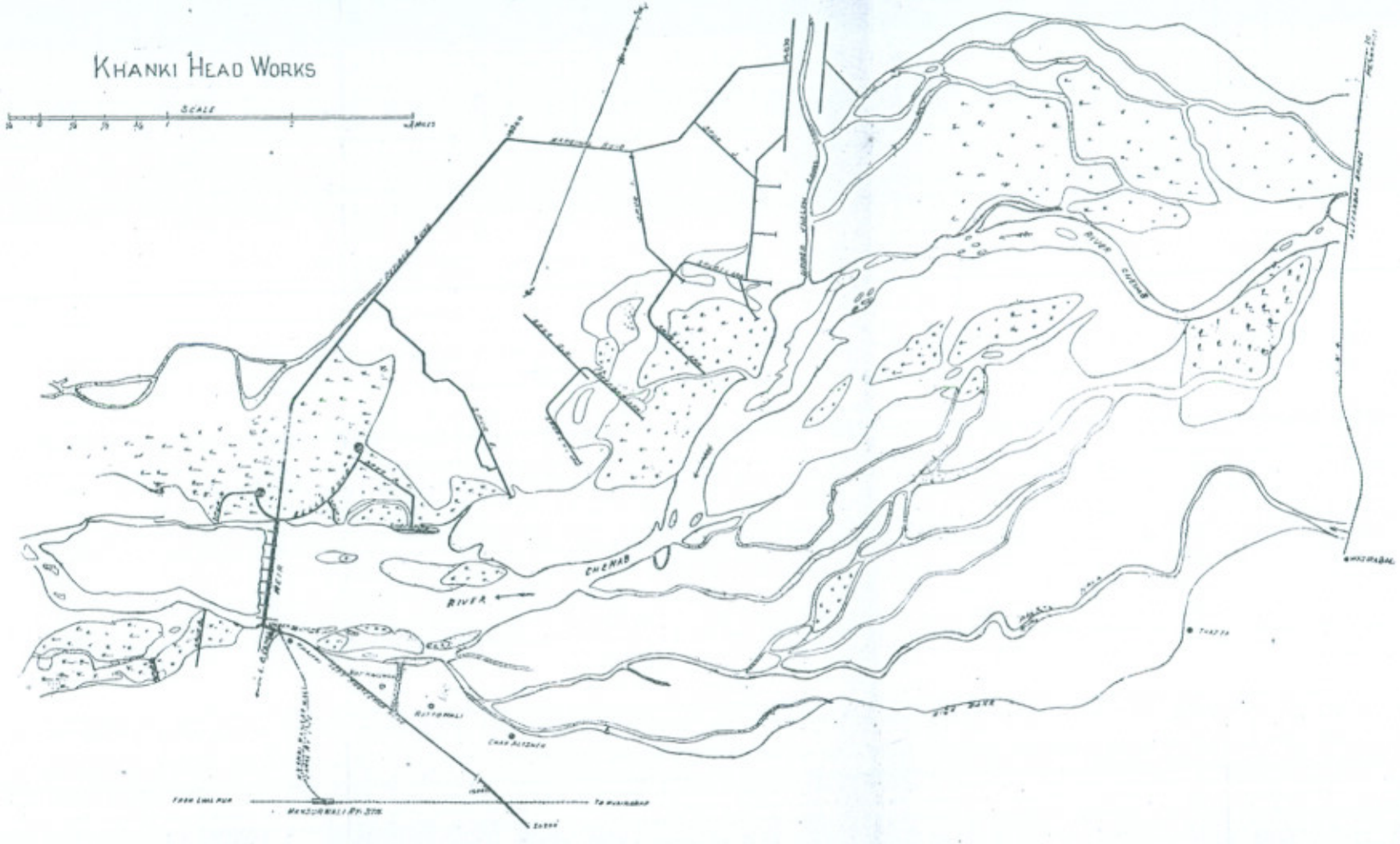
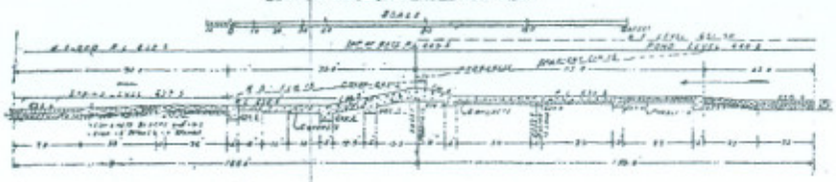
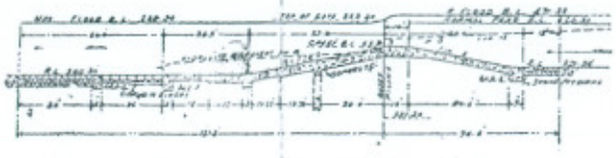


PLATE IV.

SECTION THROUGH FEROZE PUR WEIR



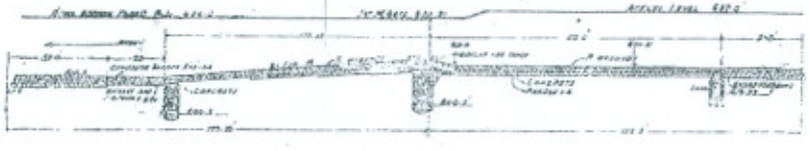
SECTION THROUGH SULEMANKE WEIR



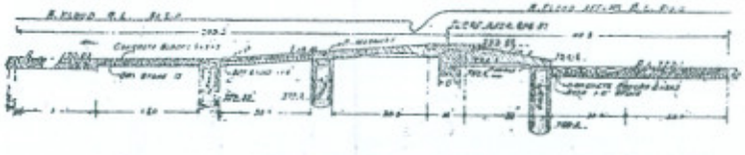
SECTION THROUGH ISLAM WEIR



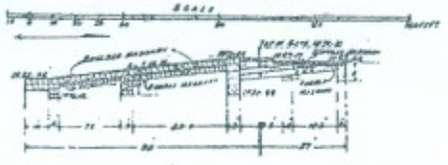
SECTION THROUGH BALLOKI WEIR



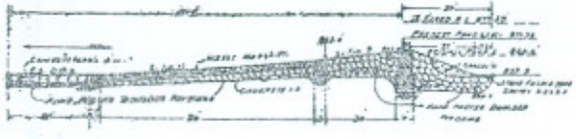
SECTION THROUGH MARALA WEIR



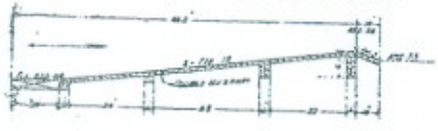
SECTION THROUGH TAJEWALA WEIR



SECTION THROUGH RUPAR WEIR



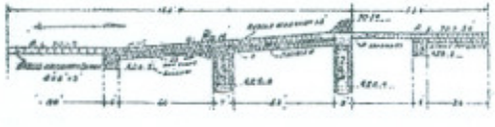
SECTION THROUGH MADHOPUR WEIR



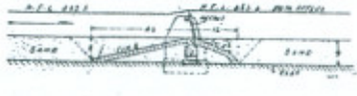
SECTION THROUGH NEW KHANKI WEIR



SECTION THROUGH RASUL WEIR



SECTION THROUGH NEEDLE DAM AT HEAD OF SIDHNAI CANAL



Rapier were asked to quote for 60 feet gates of sizes 10 feet to 18 feet. They were good enough to do so. Taking then the command level required at each site and working down from it, the necessary length of weir resulting from varying heights of cill to suit each size of gate to pass maximum flood discharge were worked out by Mr. Burkitt. At the same time the cost of masonry in weir section and piers saved in the shorter lengths, resulting from the increased depth of water which could be passed over the cill was worked out and the most economical height of gate for such conditions was sixteen feet to hold up 15 feet of water. This height of gate was therefore adopted both for Islam Weir the second to be started, and for Ferozepur Weir now also designed and under construction. This has resulted in a still further contraction of the free water way over the headworks. In the case of Islam 24 spans and at Ferozepur 29 all of 60 feet. The maximum flood discharge at Ferozepur is much larger than at Islam which is 140 miles lower down the river, the storage capacity of a river in flood having a marked effect in damping down its intensity as it passes down the river.

The very much shorter weir possible by the use of deeper gates is chiefly due to the very great rise in cost of the stone masonry and concrete used for the Weir. When the Suleimanke design was decided on, the anticipated rate for those classes of work was not nearly as high as subsequent experience has shown it to be. On the other hand iron work is cheaper than it was then ; these alterations in rates are responsible for the big difference between an 11 feet and a 16 feet gate holding up 10 and 15 feet depth of water respectively.

At Suleimanke a wide bridge has been provided below the line of gates ; it has been designed as a Railway bridge in the event of the Fazilka-Haveli Railway link ever being made. When it is the bridge will be a combined Railway and Road bridge. If the traffic requirements of the Railway eventually necessitate its being reserved entirely as a Railway bridge, a separate road bridge will be added by extending the piers. In order to cheapen any future work, the foundations for such an addition are being put in now, the Railway paying. The Communications Board of the Punjab pays for the difference in width of the bridge. Our own requirements were 10 feet the Communications Board require for a main arterial road 18 feet. If the Railway ever take over the whole bridge as it now stands they will repay the cost of the present work to the Punjab Government.

At Islam a 10 feet bridge is being provided for Headworks requirements only because at present neither the Punjab Government nor Bahawalpur Durbar anticipate a through arterial road will develop.

At Ferozepur the question of the bridge is closely connected with Railway and Road requirements. This question has been fully discussed between the Railway, Buildings and Roads and Irrigation Branches, and the final decision arrived at is that the weir must carry a Railway and Road Bridge ; the present bridge will be abandoned till such time as it is needed for a double line.

Sections of the Weirs.

A reference to the plates showing sections of the Punjab Weirs old and new will make clear the big departure that has been made from the older types as regards the sections adopted for the new weirs. Rasul, Merala and Balloki have their crests founded on wells running the whole length of the weir with subsidiary lines of wells at the ends of the floors upstream and downstream and in the middle of the glacis. Khanki has only one line of wells at the end of the upstream floor and the crest is merely a solid wall. These are all fair samples of weirs built on sandy river beds. Tajewala, Madhopur and Rupar are in a class by themselves as they are founded on shingle and the same precautions are not so necessary there as lower down where there is no shingle.

Now probably the majority of the readers of this paper know that in structures founded on sand, where a high head of pressure is induced by the use of gates, two dangers have to provided for :—

(*a*) that the water creep in the joint between the floor and the sandy bottom is so reduced that the flow is not enough to move the sand, and

(*b*) that the upward pressure developed on the underside of the floor below the gates is not so big as to blow up the floor.

In both cases the controlling factor is the head of pressure developed, the extreme condition being when the river is ponded up to its full height upstream while it is at a minimum downstream. Experience has shown that if a hydraulic gradient of 15 to 1 be adopted in the sands of the Punjab the adverse conditions noted above will be sufficiently guarded against. This gradient of 15 to 1 can be obtained in 2 ways—by a very long impervious floor upstream or by vertical watertight obstructions in the sand below the floor, or by a combination of both. In the works described, *viz.*, at Merala and Rasul, reliance was placed on the lines of wells ; at Balloki on a very long flat impervious floor upstream of the gates coupled with 3 lines of wells. In the designs of the Sutlej Valley Project sheet piles have been adopted coupled with long apron upstream. These sheet piles in the case of Suleimanke and Islam go down 30 feet. At Suleimanke we were fortunate enough to find a stratum of clay right across between 20 and 25 feet down and it was not necessary to drive the piles more than two or three feet into this clay. At Ferozepur instead of one row of 30 feet two rows of 15 feet each are being driven. It is claimed that these sheet piles form a much more water-tight barrier to water-creep than the older type of wells because gaps between the wells are impossible to staunch absolutely.

The deep curtain walls at the upstream end of the floor such as has been provided in the older types of headworks is not being built on our present designs as the contracted river and the great control given by gates right across, coupled with two divide groynes, make it extremely unlikely that there need ever be any parallel flow on the face of the Barrage.

Well Foundations.

On the weirs now under construction well foundations have been reduced to a minimum. At Suleimanke they have only been placed under the flank walls and at the ends of the divide groynes. Piers have been built on open founds because when the foundations were excavated good firm sand was discovered not intermixed with clay and this gives a very satisfactory foundation to bed on, especially when all fear of creep has been removed by the sheet piles. At Islam and Ferozepur, however, the larger gates meant much heavier pressures on the Piers and to meet this the foundations have to be much deeper. If open founds had been used here it would have landed us into pumping and other difficulties. Wells have, therefore, also been used under the Piers.

Shape of Piers.

All the latest hydraulic research shows that the shape of the downstream end of the Piers is really of more importance than the upstream end in reducing turbulence and thereby improving discharge co-efficients over the weir. It will, therefore, be noticed that all the Piers are designed with fish tail ends.

Materials used.

An innovation on the weirs on the Sutlej is the exclusive use of Portland Cement. At first it was intended that Portland Cement would only be used in foundation work and in the Glacis of the weirs and that all superstructure should be done in the ordinary Kankar Lime mortar but to have two classes of mortar on the same work was found to be troublesome and nothing but cement mortar is now being used. The paper by Mr. Robertson read at the Congress a couple of years ago gave a full account of the cement from Wah and the 1 : 4 : 8 mixture was found strong enough. On the surface of the Glacis of the weirs the abrasive power of the water was found to be considerable and a richer mixture is desirable. The top 9 inches, therefore, all over is covered with 1 : 2½ : 5 mixture which stands up well against water flowing over it.

Building stone is used exclusively in the Piers, flank walls and divide groynes. Its use on the Glacis of the weir has been abandoned, it being found that cement concrete is easier and quicker to lay and stands up better than stone masonry.

But the use of cement mortar brings new problems which had not occurred before, of which the most important is that of temperature cracks. Cement laid in the summer months or warm days of spring and autumn stands up without any signs of cracking until the freezing nights of the Punjab cold weather set in and the resulting cracks have been a source of great anxiety. However, experience appears to point to the necessity for using a fairly dry mixture with a minimum of water content and of course provision of expansion and contraction joints. A further point which still needs more investigation is the desirability, when laying the cement concrete, of completing a certain length to a considerable depth, *i. e.*, not to spread the concrete over a very large area to a depth

possibly of only 9 inches or a foot and then many days after to lay another layer on top of it. It appears to be far better to reduce the initial area and concentrate on that until it is built up to its full height.

Having provided contraction joints a suitable medium for filling those joints is desirable. Bituminous filling suggests itself but here again care must be taken that the right grade of Bitumen or its components is used. At this stage it is impossible to dogmatise or authoritatively to lay down what shall or what shall not be the mixtures or the grades of Bitumen to be used but experience is gradually being gained and it is hoped that shortly sufficient definite information will be available. Various experiments have been tried to counteract these cracks. A system of reinforcement of the weir crest especially where the Piers exist is being tried at Suleimanke. At Ferozepur where the loads on the Piers will be particularly heavy and the vibration due to the heavy impact of Main Line trains will be considerable, each Pier is isolated by joints so that the weir crest concrete will not be affected by the vibration.

Canal Regulators.

The Head Regulators of the Canals taking out above the weir as already stated, are skewed at a batter of 1 in 4. They are novel in that they are being fitted with Walton Gates. The subject of Walton Gates is a big one and no attempt is here made to describe them in detail as the subject is worthy of a paper by itself. Suffice it to say that extensive experiments have demonstrated the fact that their use gives a far better discharge co-efficient with the result that much narrower regulators can be used than with the old type of gate thereby tending to economy.

Divide Groynes.

In order to enclose the silt traps or pockets at each extremity of the weir as has already been described, Divide Groynes are provided extending for about 700 feet normally to the face of the weir. These Divide Groynes serve an additional purpose by cutting off any parallel flow along the upstream face of the weir when silt is being scoured out of the pocket. These Divide Groynes are designed against overturning because there is liable to be a considerable difference of head between the weir side and the pocket side when the undersluice gates in the pocket area are opened. At Suleimanke both the Divide Groynes are of stone masonry but at Ferozepur it is being made of reinforced concrete, and a similar design is being sanctioned for the right groyne at Islam. There is considerable action round the noses of these Divide Groynes when the pocket is being scoured and in order to safeguard against any damage likely to occur by scour, the ends of these Divide Groynes are founded on wells with very heavy protection all round. In some of our older works the Divide Groyne is an earthen embankment, but probably it will be found that either concrete or masonry Divide Groynes are more suitable and reliable.

Guide Banks.

All the older weirs are provided with one guide bank but this is of short length and apparently not expected to do much more than lead the water sweetly past the Regulator. Consequently river training is done by the retired or marginal bunds, which need to be reinforced with armoured spurs to prevent the river swinging out and outflanking the Guide Bank. This necessitates very heavy protection by means of marginal or retired embankments. In the Sutlej designs the river is concentrated into a narrow channel by a pair of guide banks which are fairly long, from 2,500 to 3,500 feet and it is claimed for this arrangement that not only does this induce a clear and direct flow on to the weir, but it must also greatly reduce the number of spurs needed along the marginal bunds. By being forced into one restricted channel the river has no room to swing about, if it does swing about it must be above the entrance to the bottle-neck which is so far from the weir itself that little or no harm can occur to the protective works behind the guide banks at the weir itself. Forcing the river through such a narrow opening has its own risks as was discovered in August 1925 at Suleimanke. Till the river has had full time to develope a clear channel between the two guide banks, and also till it accustoms itself to the new course which it has to take there is, and must always be, very heavy action at the nose of the particular guide bank round which the main stream of the river has to force its way through the bottle-neck. The ordinary rules, therefore, for calculating the amount of protection required at the nose and along the face of the guide bank, as laid down in the standard works by Spring and others, is liable to be inadequate, and a very large margin of safety must be provided for. The drawings plate No. III show the guide banks at Suleimanke and the amount of protection originally provided which is now being increased.

The layout of the guide banks in plan may be a matter for controversy, a final answer to which can not be given until the various types have been tried. At Suleimanke owing to the greater length of weir the guide banks in plan outline a regular bottle-neck, narrow at the entrance and widening towards the weir. At Islam this is not so evident, but at Ferozepur the guide banks are straight. It still has to be considered whether the guide banks should not diverge from weir to entrance possibly to reduce action at their noses. Personally the writer's feelings are in favour of straight guide banks, on the ground that sufficient protection at the noses can always be given whereas straight flow on to the weir is sacrificed.

Conclusion.

The heading of this paper refers to " connected problems." Those interested in the subject will have no difficulty in framing many problems for themselves. Many others might like to be given some idea of what these problems are. This paper is already of considerable length and the writer feels that if he were to describe fully all the problems which still present themselves to his mind, very much more would have to be written.

A few, however, are just mentioned, but he hopes these will be largely supplemented at the discussion which follows the paper.

(*a*) The most efficient method of working the Silt Pocket :—

(*b*) What is the true Hydraulic gradient through water laden sand under the work and how is it affected by varying positions of downstream water level.

(*c*) What is the safe position for the standing wave on the Glacis.

(*d*) How to deal with temperature cracks in cement concrete where it is imperative to stop percolation.

(*e*) Should the floor of the silt pocket be paved.

(*f*) What should be the outline of the guide banks in plan, bottle-necked, straight or divergent.

(*g*) What is the best form of nose for a guide bank blunt as on the Sutlej Weirs or with returned ends advocated by Spring.

More than one of these problems are important enough to warrant an individual paper at some future Congress.

DISCUSSION.

MR. FOY introduced his paper by remarking that he had avoided purely theoretical problems, and had employed description as a means of inducing discussion, which he welcomed, as it was impossible to dogmatize, because methods which suited one set of conditions, often did not suit another set.

He explained the practice in the Punjab of making the waterway between the guide banks proportional to the discharge to be passed, *i. e.*, diminishing the waterway by the draw-off of the canals.

He thought that at Sukkur the conditions were different and that as they were not able to put the regulator on the skew, the guide banks would have to be parallel, but that would not really be objectionable.

He then dicussed the hydraulic gradients, and raised the question whether it followed the line of creep, *i. e.*, the junction between the masonry and the soil, as being the line of least resistance, or followed the shortest lineal route, *viz.*, from point to point of the salients of the floor and lines of wells, &c.

He indicated that another important problem was to find what range of conditions of quantity and elevation of supply per lineal foot of weir would ensure the standing-wave remaining on the *pacca* glacis, and thus keeping within the safety line.

MR. HADOW remarked that he had hoped to find in the paper an explanation of the principle governing the design of undersluices.

He referred to Mr. Schoeneman's paper before the 1914 Congress on the "Design of Headworks" in which the writer had pointed out that waterways of the undersluices at Rupar, Madhopur, Khanki and Rasul were each 240 feet in width, and had stated that in the design of undersluices, high velocity and great erosive power were the *desiderata*, rather than great waterway and great discharging capacity ; that sluices should therefore be relatively narrow and deep, relying for their draught and velocity upon the afflux set up by the weir, and that their discharging capacity need not be very much more than the full capacity of the canal at the low stages of the weir.

From the paper quoted it appeared that Mr. Schoeneman had considered this coincidence in the width of undersluices to be due to imitation, but he had not himself enunciated any principle.

Mr. Foy's paper stated that the undersluices at Suleimanke consisted of 8 spans of 30 feet or again 240 feet total water way.

Mr. Hadow asked if this was another case of coincidence or of imitation ; and said that it would be interesting if Mr. Foy would say exactly what considerations governed the choice of this width of waterway, *i.e.*, what were the discharging capacities and velocities in various circumstances and also what dimensions had been adopted at Islam and Ferozpur.

He would also be glad if someone acquainted with the arguments would state the principles leading up to the " bottle-neck " in the guide banks at Suleimanke.

L. JAGAN NATH stated that the position of the standing wave was immaterial as long as it was on the *pacca* section ; the shape of the entrance should be bell-mouth.

MR. NICHOLSON said that when he was preparing the data for the Weir-designs, he dived into the Government archives, and found that in the old days they had imitated the old weirs : the 240 feet undersluice had originated at Rasul in 1884.

A flood of 3 lakhs cusecs had been allowed for, without any further hydraulic data.

He thought a splay at entry of 1 in 4 was suitable for securing a good V_o for scouring purposes, and that 8 feet sec. was a good figure ; one should regulate to taste, and the system should be as flexible as possible.

As would be seen from Irrigation Branch Paper No. 9, as soon as the velocity in the undersluice pocket went up, the silt deposit in the canal increased.

The question of opening or closing the undersluices was a matter of experiment and the choice between one and two gates, a matter of experience.

Deeper undersluice gates at Rupar gave a greater draw, and did more work in less time.

He said that the rise from low to maximum supply was a constant figure of 15 feet for all headworks. He considered that there was more in the selection of data than in the mathematical handling of it.

Mr. R. E. Purves had said that one gate should not be more than 10 feet high because of the velocities produced.

Expansion and contraction of the concrete due to temperature changes was great, and a weir should be reinforced against climatic variations.

Mr. Nicholson added that much could be learnt from studying inflow through models with glass sides.

He proposed 300 feet as the minimum radius for the nose of a guide bank, to ensure stream line flow.

He had experienced a scour of 80 feet at the nose of a guide bank.

MR. BURKITT compared the advantages of a solid glacis and a cellular one of reinforced concrete filled with sand, and favoured the latter, as in many cases such a glacis would cost less than a solid one and could, without appreciable increase in cost, be made indefinitely heavy to resist blowing up.

He considered that, for the same money, greater security could be obtained from a guide bank without a curved nose, and with heavy aprons, than from one with a curved nose of easy radius and lighter aprons.

At the Ferozepore Weir they had no cracks, only joints which had been specially designed. Cracks at right angles to the weir were worse than those along the weir. A concertina joint of copper laid across the joint in the concrete would stop blowing.

In choosing the site for a weir it was most important to choose a place where extensive temporary training works would not be necessary. If the site was badly chosen, temporary training works might cost nearly as much as the weir itself.

Engineers should not follow text-books in calculating afflux which depended profoundly on the shape of the weir. A glacis slope of 1 in 5 was suitable as it brought the standing-wave close up to the gates and reduced action on the loose stone protection downstream of the *pucca* floor.

Observations made during the big flood of August 1925 indicated that the distance between ou guide banks could, if desired for other reasons, have been made less, as the velocity across the stream was not uniform, but increased towards the centre. The velocity-curve across the stream during the above mentioned flood was roughly a parabola of the form

$$V_x = V\left(1 - \frac{ax^2}{l^2}\right)$$

where V_x is the velocity at distance x from one bank, V is the central velocity, l is the width of the stream, and (a) is a constant. One flood gave $a = 2{\cdot}0$, and the other, $a = 2{\cdot}5$. A small value of (a) will give a great depth of scour at the centre and a high value of (a) will give a small depth of scour for the same discharge.

He thought, from the sketch made by Mr. Musto, that most hydraulic engineers would agree that a considerable part of the money being spent on the Sukkur Barrage was being wasted and that the waterway was much greater than it need be for conditions of no afflux in maximum flood.

By a simple calculation it is possible to design head regulators to prevent excessive silt entry into the canals. This could be achieved by making the regulator of such a length that the velocity of the water, just before it entered the regulator, would be lower than the critical velocity with an accumulation of silt in the pocket up to any fixed depth.

MR. BOSTOCK discussed the best method of laying cement concrete on the floor of a weir and particularly the case of the downstream glacis. He pointed out that with quick-setting concretes (such as most cement concretes) the old method applied to lime-concrete of laying in horizontal layers might not be suitable.

He had seen at the Suleimanke Weir that, in places, the upper layers had very poor cohesion and were easily detached. This was done by cutting vertical "chaces" so as to form separate slabs about 3′ × 2′ which were then lifted quite easily with a crow-bar without applying any appreciable leverage. He believed that the bad cohesion was considered to be largely due to the employment of a brand of cement which was far too quick-setting for that class of work and that the engineers

at Suleimanke had removed all the loose layers by cutting "chaces" in the manner already described. But he was not satisfied that the bad adhesion was entirely due to the use of this particular cement because there had been similar trouble to a much less extent at the Islam Weir where no cement of that brand had been used, and he considered that most cements set too quickly for the horizontal layer system to be a success. He was therefore of opinion that the full depth should be laid straight away when constructing a weir-floor, and any joints should be vertical rather than horizontal. Suitable measures were being taken to caulk such joints against the passage of water caused by either infiltration (downwards) or "blowing" from below.

MR SMITH said that the problem at Suleimanke had been to turn the river over an unfinished weir of which it had been possible to lay only one foot of concrete in places except at the talus.

2. In one bay of the weir a longitudinal crack was noticed through which water oozed. When examined it was found that the top layer, in setting, had lifted away from the concrete below it. It had been easy to lift sections of this top layer with a crow-bar. At the crest of the weir in this bay the steel piles had been previously countersunk under a concrete wall and the top layer of concrete referred to was found to have lifted away from this wall and from elsewhere lower down the glacis. This was attributed to the use of a certain brand of cement. Tests of this brand made at Alipore, showed for certain consignments, that the initial setting had occurred in 3 or 4 minutes instead of 30 as required by the British Standard Specification. The Chemical Assistant of the Firm, through which the cement was supplied, had examined the conditions of the use of this particular brand in the bay in which this lifting had occurred. He came to the conclusion on documentary evidence that the defect noticed was due to the use of this brand. The concrete underneath the layer that had lifted had been done prior to the arrival of this particular brand on the weir and had not been similarly affected anywhere.

MR. MUSTO asked Mr. Foy to explain the following points :—

1. How had he decided the capacity of the undersluices and the width of the approach channels ; also the length of the divide-walls, and the level of the cill and length of the Head Regulator ?

2. Had he attempted to fix any ratio between the maximum or mean velocity of the discharge over the gates, and the mean velocity of the canal, and if so, what was that ratio ?

3. Had he fixed any limit to the discharge per foot run of cill ?

4. Did he consider it specially desirable to have a great width of approach channel at the upstream and of the regulator, in order to obtain greater area for the maximum discharge of the canals passing this point, and diminishing as the supply was taken off by each opening of the regulator ? If this was desirable, could the same result be obtained with a parallel channel made deeper at the entrance ?

5. Could he give any statistics to show the results of scouring out the approach channels, *i. e.*, the relation between scouring-head at under-sluice gates, and depth and distance of scour in a given time?

6. Did he consider it necessary to give a smooth paving in the approach channel, or merely sufficient protection against undue scour which might undermine continuous structures?

7. Did he consider a raised cill at the entrance to the approach channel desirable or necessary to exclude rolling silt.

Mr. MUSTO considered that divide walls need not be made *pacca*. His own design was for blocks 10 feet by 5 feet by 3 feet diminishing in width towards the top of the wall, protected with aprons of pitching stone.

He found it almost impossible to discover what the views of the Punjab Government were in these matters, as they always endorsed their Irrigation Branch Technical Papers with a statement that the Government were not responsible for the opinions expressed therein.

He then described the Sukkur Gorge as a Venturi neck, stabilized by nature, and which never changed, although the approach channel varied from year to year over a width of about 5 miles. They wished to avoid interfering with the stable regime of the gorge, and had therefore made the regulator the full width of the natural channel.

Mr. MUSTO suggested that very valuable experience could be gained if systematic experiments were made at the various Punjab Headworks, upon different methods of working the undersluices, by working one system only for a whole season, and by another system the following season, simultaneously observing the effect upon the silting of the canal, &c.

MR. NICHOLSON stated, with regard to point (5) that at Rupar 4 miles of channel had been scoured in 36 hours with a head of 8 to 10 feet.

MR. COLYER contributed the following remarks upon the most efficient method of working the Silt-Pocket.

He was pleased that Mr. Foy had stated that the ideal method of working the undersluice-pocket had not yet been fully established, as it showed that his apparent adherence to the old "still-pond" system, entailing the complete closure of the undersluices while the canal was open, was wavering.

This "closed under-sluice" version of the 'still-pond" system held the field until 1912, when, soon after the opening of the Upper Chenab Canal, it was found that the system did not suit Marala Headworks. Actually it had not suited Khanki, where 3 or 4 years previously the Lower Chenab Canal was being fed by passing the supply over the weir, and round back into the canal *via* the downstream end of the undersluice-pocket.

At Rasul, the Lower Jhelum Canal was saved by an experienced Jamadar who to save the Headworks kept the bottom tier of gates open, against orders, and to save his head, entered them in his papers as "closed."

Notwithstanding, it took months of struggling before Superior Authority would allow any change in the method of regulation.

At last, however, more freedom was given, and it was permitted to raise all the undersluice gates one foot above floor level, on the assumption that this would enable the bed-silt to roll on ; woeful hydraulics of a very eminent Chief Engineer, but a step forward.

Owing to natural stream-line flow, scouring velocities were only generated to within 3 or 4 feet upstream of the gates, the rest of the pocket remaining as before.

With this wedge, permission to experiment was obtained and a system evolved which, though it has been considerably developed, remains the same in principle 12 years later.

This system consisted in inducing the bed-silt and the heavier silt-charged water which must enter the undersluice-pocket along with the clearer supply, to separate from that clearer supply, and pass out through the undersluices.

This was effected with considerable success by grading the undersluice gate-openings from " almost closed " on the canal side, to " fully-open " on the divide-groyne side ; with the object that the bed-silt, and the silt dropped by the stilled water entering the canal, should be attracted towards the high velocity side of the pocket, and carried through the undersluices.

This " keep moving " principle is now supplemented by direct calculations of the Critical Velocity Ratio and by daily observations of silt conditions both in the river and in the canal.

Mr. Colyer also remarked upon the importance of another point raised by Mr. Foy, *viz.*, the true hydraulic gradient or piezometric-line of a work founded on sand. It was surprising, at the All-India Irrigation Conference of 1913, when this subject was discussed, to find the lack of precise knowledge upon the point, existing among Irrigation Engineers.

Even in 1926 our knowledge is very hazy and it will be regrettable if advantage is not taken of the new weirs on the Sutlej Valley Project, and elsewhere, to erect several series of stand-pipes in the structures, and to record continuously the actual height of water in them.

Engineers are apt to confuse two separate matters, *viz.*, Bligh's co-efficient (1 in 15 for Northern Punjab rivers), and the " hydraulic gradient " or piezometric line.

Bligh's co-efficient indicates only the limit of the gradient of enforced creep which, in a given soil, will ensure the absence of serious transport of sand, *i. e.*, the absence of " blowing " ; the hydraulic gradient, or piezometric-line is the line to which the substructure water would rise at each point, if a pipe were inserted connecting with foundation level ; and this is a measure of the hydrostatic uplift, or " blowing-up " pressure at any section.

Some engineers hold that this presure line is a straight line found by joining the water-level at the upstream end of the impervious floor to

the tail-water level at the downstream end of the impervious floor ; others, that it is a line of the form of a gradient with vertical steps, the rate of slope of the gradient being the rate of loss of head by interstical friction in the creep-path between the structure and the soil, with consequent vertical steps at vertical changes of section, and that the pressure or uplift may become zero before the end of the floor is reached. It seems probable that there are two conditions under which the *full* hydrostatic or uplifting pressure can develop, *viz.*, (*i*) when the actual flow along the creep-line is slow, and therefore the loss of energy is small, and (*ii*) when "piping," or "blowing," even to the extent of removing the finer grades of sand, takes place, and a continuous filament of water connects the upstream and tail supplies.

If this hypothesis is correct, then many of our masonry works are not safe, and the only thing that saves them from disaster is the fact that owing to dispersion by percolation and capillary action, the *full* hydrostatic pressure has not yet come into action ; it is probable that it will come into action at some future time.

Mr. Wilson's research work on subsoil water has an immediate bearing on this point, and it would be interesting to know his conclusions, both absolute and tentative.

As Honorary Secretary to the Congress, Mr. Colyer stated that he would be pleased to receive papers on any of the subjects mentioned by Mr. Foy at the end of his paper, for presentation before a future Congress.

Mr. Haigh writes that he wishes to correct Mr. Foy's remarks regarding Madhopur. The primitive methods of control attributed by him to Madhopur have not been in use for the last two decades. It is true that the earlier shutters used were defective, but the defects were merely those of design which were subsequently overcome. The shutters were removed in 1922, and replaced by a solid masonry crest from motives of economy and simplification of regulation.

The raising of the cill of the Madhopur Regulator has reduced the grade of silt entering the canal, from boulders to small shingle.

Mr. Montagu writes—

In Mr. Foy's paper occurs the following :—

"Undersluices can be kept slightly open thus extending the periods in which the silt-pocket is fully charged."

The so-called "still-pond" system is believed to be convenient and successful at Rupar. Apparently a succession of closures of some hours causes little or no inconvenience there. But on the bigger canals (Upper Chenab Canal 14,000 cusecs and the Lower Chenab Canal 11,000) the "still-pond" system would be very inconvenient indeed.

It is not so much the time needed for scouring out the silt in the undersluice flume that matters, so much as the absolute necessity of gradual closure and even more gradual re-opening necessitated by avoiding damage to berms and banks consequent upon large fluctuations of supply.

It becomes necessary then to devise some method of " continuous scouring " of the undersluice flume. The methods in use at Marala and Khanki—and probably elsewhere—have been the subject of much discussion and correspondence over a number of years. It is believed that the basic principles upon which this " continuous scouring " is carried on are now sufficiently evident to permit of their being laid down with some degree of confidence.

I. The C. V. R. of a canal is always varying. In summer when the water is heavily silt laden, and the C. V. R. required is high, the slope steepens, the mean velocity increases, so raising the silt-carrying power of the stream.

In winter when the water clears, the required C. V. R. is low, the water scours the bed, the slope flattens and the mean velocity falls, till balance is reached once more.

The above remarks particularly apply to the head reaches of big canals. The Upper Chenab Canal may be instanced. There the head reach attains a slope flatter than 1 : 10,000 in winter and as steep as 1 : 4,000 occasionally in summer.

II. The object of " silt regulation " is to reduce this range of variation. Obviously, the means of so reducing the variation is to exclude silt in the hot weather, and reduce excessive scour in the cold.

III. The variation of silt content in the river as a whole, is beyond our control. But we can take selected portions of the river supply and :—

(*a*) By means of high cills exclude a considerable portion of the heavy rolling silt.

(*b*) By means of actual regulation of weir shutters and undersluice gates, cause the water which we are utilising to drop a portion of its heavier silt. Put another way ; by manipulating the velocity and shape of the approach channels to the head regulator, we can create a C. V. R. therein which is less than that of the river as a whole.

The immediate and obvious result will be a dropping of a portion of the silt content.

IV. The process detailed in III (*a*) *supra* is limited by the actual constructional details of the Headworks and need not be further mentioned here. We are chiefly concerned with the operation (*b*).

In point of fact the efficiency of our efforts in the direction of III (*b*) is also limited by such details of construction as relative height of weir, afflux available, width and length of undersluice pocket, etc.

But no matter what these may be, our considerations in manipulating them are unaltered.

V. It is clear that if we take a portion of the river discharge, which is heavily laden with silt, and if we exclude a portion of that silt, we have to drop that silt somewhere or supercharge a portion of the water to remove that excluded silt. In practice our operations are definitely directed to obtain both these effects.

VI. It becomes necessary here to make a statement which is admittedly under dispute.

The silt content of the water taken into the canal is primarily dependent on the silt content of the water crossing the face of the regulator.

Subject to acceptance of this postulate the remainder of the theory is comparatively simple of exposition.

VII. The function of the undersluice gates is to remove the rolling silt excluded by the mechanical action of the high cill.

The water so issuing is supercharged with heavy silt and this promptly deposits below the undersluices introducing another problem, which need not be discussed here.

The daily soundings of the undersluice pocket should be used merely as a guide as to whether the above function is being adequately performed.

VIII. The writer prefers his daily soundings to indicate a hissa or so of silt on the paved floor. If successive days' soundings indicate an increase of silt the discharge through the undersluices must be increased to clear it (this has the important result of increasing the discharge and therefore the velocity of entry into the pocket : see XII below.)

If soundings indicate an absolutely clean floor the velocity is higher than is essential, and may be reduced *if necessary*. It will be necessary if the corresponding day's soundings indicate a rise in the silted bed of the canal. If the silted bed of the canal is also in a satisfactory condition, then the high velocity may be continued for the sake of its effects upstream of the undersluice pocket (see XII below).

IX. Reference is now invited to III (*b*).

Although heavy rolling silt may have been successfully excluded *and removed* as described in VIII, the water which enters the undersluice pocket may still carry, in suspension, silt which will drop to the bed under the hydraulic conditions of the canal. This causes the canal to silt and must be avoided.

Clearly such silt may not be dropped in the undersluice pocket.

The velocity required to cause it to settle is so low that the operation detailed in VIII could not be carried out.

The undersluice pocket would speedily silt up, and we should have " still pond " conditions.

The silt, then, must be dropped—or allowed to become rolling silt—before it reaches the undersluice pocket. This can only be done by creating conditions of flow in the channels of approach to the regulator, such that the C. V. R. is very little in excess of that obtaining in the canal, and decidedly lower than that of the main river.

X. Let it be assumed that ideal conditions obtain at the beginning of the silt season as a result of cold weather regulation.

The bulk of the River passes over the weir, heavily silt laden, at the furthest point from the regulator.

That portion of the discharge intended for the canal supply plus the discharge through the undersluices is drawn through a broad deep channel, at a velocity suited to the conditions required. (In practice the amount of such variation available is extremely limited).

XI. The water reaches the undersluices pocket and the regulator in the condition desired. The approach channel has silted up—chiefly in the first reach.

The main river is then turned over the weir, at a point nearer the regulator. The approach channel is shortened and rendered less effective, but in the meantime the river is scouring out the portion so abandoned.

This process goes on until the river is being put over the weir on the side nearest to the regulator. It is then turned over to the far side once more, leaving a scoured approach channel.

XII. It must not be thought, that the above process is continuous from April to October. It only becomes essential during those periods of the hot weather season when the water is particularly heavily silt laden.

Periods of comparatively clear water must be seized upon to clean up the approach channels.

XIII. Nor should it be thought that it is 100 per cent. effective. In X *supra* it has been pointed out that the amount of variation of velocity in such approach channel is extremly limited. The reason is this. When water is taken over the fully raised cill gates, and the upper regulator gates are clear of the water, a given discharge in the Canal requires a definite water level in the undersluice pocket.

Now the discharge through the undersluices is regulated by the considerations dealt with in VIII *supra*. The canal discharge is fixed. Therefore the discharge entering the undersluice pocket is fixed within small limits. Since the section of entry is fixed also by the required R. L. in the pocket, the velocity of entry is also fixed within narrow limits.

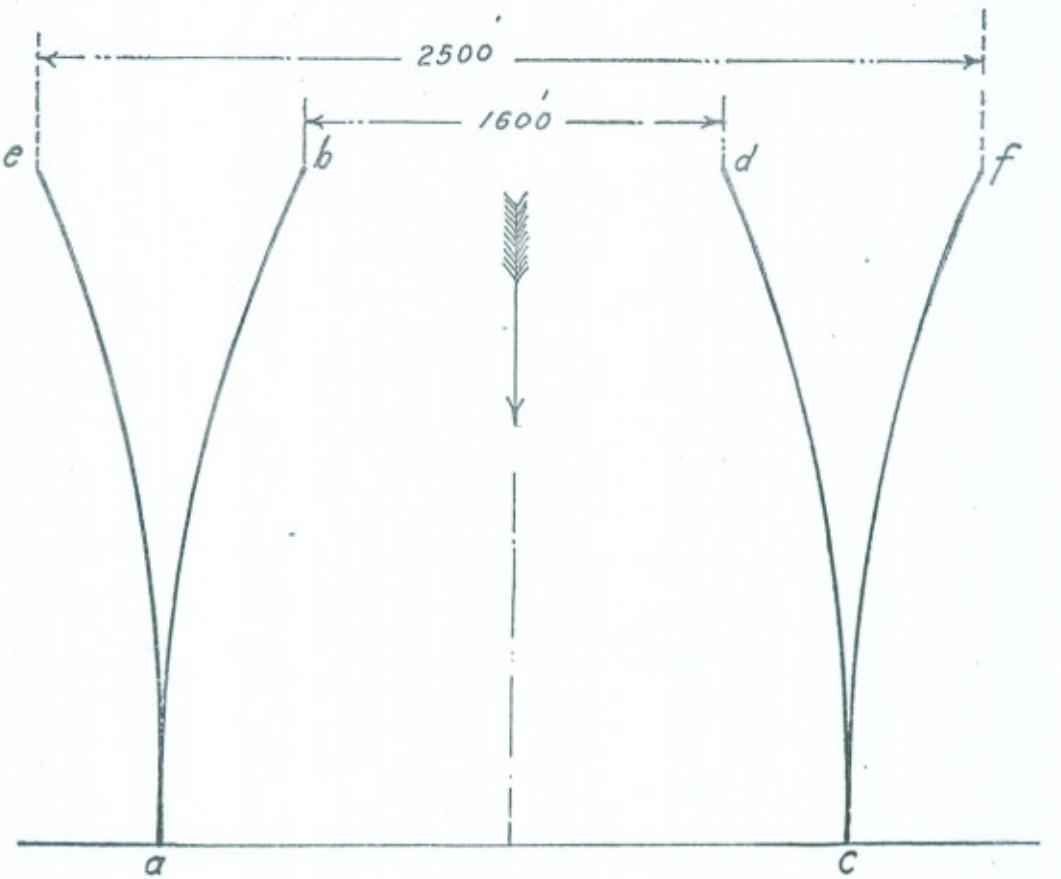
XIV. In view of the above it is clear that the approach channel should be both wide and deep to ensure a low C. V. R.

It is not possible to attain this solely by the processes outlined in X and XI. One additional factor must be used, *viz.* : Floods.

It is not proposed to discuss flood regulation beyond saying that a rising and falling flood—particularly the latter—can be made to clear the approach channels quite effectively, provided the demand is not so keen, as to require the canal to be opened before the process is complete.

XV. In conclusion, it follows from the above remarks that a high cill is most useful : for this reason overshot gates (as now installed at Khanki), radial-arm gates (as at Rasul and Madhopur), are more effective than the simple rising cill as at Marala.

MR. CLAXTON writes :—The sketch below compares the 'bottle-neck' design b d with the the case e f where the guide-banks converge : b a, d c are diverging banks giving a bottle-neck of about 1,600 feet at b d ; and e a and f c are guide banks converging in the same degree, giving a neck 2,500 feet wide.



To force the river between the guide-banks its energy is concentrated into a narrow neck and its tendency to swing from side to side is suppressed. At Suleimanke this neck is 1,600 feet wide while the normal width of the river is 4 miles.

The tendency to erode and to shoal, however, still remains, and sooner or later loops will form outside the line of the guide banks ; this will happen more frequently in the case of a narrow neck than in the case of a wider one, and consequently the occurrence of scour at the nose of the guide-bank is more frequent when the neck is narrow. The narrow neck also tends to increase the intensity with which the current of a loop, swinging round one guide-bank nose, impunges upon the opposite guide-bank.

An example of the extent of this angular deflection is the Panjnad at the Chenab Bridge, where, although the neck is wide, the river passes from the nose of one guide-bank right across the bridge till it strikes the abutment at the other side ; it has maintained practically the same position for four years.

There is one more point to consider. Diverging banks lose control once the neck is past, while converging banks retain it right down to the weir since the splay creates afflux where flow may be inclined to break away to the sides, and by reaction this afflux regulates this tendency, by centralizing the flow right down to the weir.

With the river tied up at the weir a good deal of the trouble below the neck may be eliminated by regulation whatever the alignment of guide-banks be and this is probably why there is so much difference of opinion ; the results are obscured by regulation at the weir. On Railway bridges there is no regulation but the Railway people are prepared to throw in as much stone as the river will swallow, and do not trouble about niceties of alignment for guide-banks.

Comparing alignments for converging or diverging banks the former seem better. By them we obtain wider necks and so decrease the recurrence of side-looping which is so dangerous in scour and deflections of flow. Secondly, we reduce the intensity of action. And lastly we hold the power to centralize and control in a measure right down to the weir itself. In each of these respects the 'bottle-neck' is less efficient.

As the guide-banks give protection against outflanking above the weir, the talus gives protection against collapse below it. The talus should be laid in stone as are the aprons of the guide-banks, *i.e.*, the stone should be laid so as to fall into the scour-hole till the downstream bed is paved to the lowest limit of scour. The sides of the talus will be splayed outward into the banks diverging from the point where floor and side pitching end. This will keep the scour from working round behind the pitching. The length of the talus will depend upon experience, but the more experience we have the longer we are inclined to make it.

MR. ORAM writes :—Referring to the penultimate paragraph on page 78 and to page 86 (*a*). *The most efficient method of working the silt-pocket.*

I have had experience of working the Headworks of the Lower Chenab Canal at Khanki for some 3½ years includng Flood Seasons of 1922 to 1924. There the still-pond system as described by Mr. Foy has been abandoned in favour of what may be termed the equilibrium system, *i.e.*, the silt-pocket is kept to a velocity which keeps it practically clear of silt, but does not stir up bed silt any more than is necessary to achieve this. The same method more or less is adopted at Headworks of the Northern rivers generally, *viz.*, Marala, Rasul, etc. The chief reason is that the quantity of silt moving is so great that the closures of the canal necessary to scour out heavy deposits in the silt-pockets become too frequent under the still-pond system.

I may also remark that in either method the height of the sill is important, *i.e.*, the higher the sill above river bed the better. The late Mr. Elsden has demonstrated pretty clearly that if the canal discharge

is of any magnitude a considerable proportion of water from the lower depths of the silt-pocket must enter the canal over the raised sill ; as the height of sill is increased, this proportion reduces.

If the silt deposits rapidly in the silt-pocket the depth is reduced, and the proportion of bottom-water entering the canal is increased.

The aim of the equilibrium method is to maintain the maximum depth practicable with the minimum amount of disturbance to both bed rolling and suspension silt. Regulation by this method has proved a very great improvement on the still-pond system at Khanki.

With reference to the late Mr. Elsden's new type of Headworks referred to by Mr. Foy, it fell to my lot to get out designs and estimates for a skimming platform for the Khanki Headworks. This was evolved in collaboration with Mr. H. W. King, Superintending Engineer, Lower Chenab Canal, and is very similar to the adaptation of Mr. Elsden's type which Mr. Elsden brought out some weeks or perhaps a month later. The main feature of the difference is the absence of skimming gates in the design for Khanki, as the advantage gained by the great expenditure which such gates entail is, I think, too small to justify them.

The consideration of carrying out this design has been postponed by Government for the present.

With reference to Mr. Foy's item (*e*) on page 86, should the floor of the silt-pocket be paved? I would offer the opinion that so long as the still pond system gives satisfactory results a pucca floor is not a necessity though it would in my opinion be an improvement in the still-pond system also. If the equilibrium system has to be adopted, the sooner a smooth floor is provided in the silt-pocket the more successful will the equilibrium system be.

I would also like to add as regards the design of the Sutlej Valley Project described by Mr. Foy, that these designs are as suitable for use by the equilibrium method as by the still-pond method, and should conditions necessitate the consideration of further improvements such as the addition of smooth floors to the silt pockets and skimming platforms, etc., such can suitably be made without scrapping any of the work now being put in. The reasons why such improvements are not being put in, in the first place, are those already given by Mr. Foy, also the consideration of loading a new project with large additional expenditure before the necessity and financial justification for such has been established.

The means of putting the equilibrium system into effect adopted during the years referred to was based on soundings taken in the first mile of the canal daily or twice daily when conditions were changing, and in the silt-pocket as often as possible. If the canal showed a tendency to deposit silt the pocket was sounded and almost invariably the results indicated that when silt began to deposit in the pocket the canal also tended to deposit silt and when the velocity in the pocket was increased slightly so as to remove or almost remove the deposit, a reduction be of deposit in the canal followed. The extent to which the effect can

obtained is not naturally always the same and largely depends on circumstances. Rapid fluctuations in the river supply are more difficult to deal with than slow steady rise and fall. The extent to which water can be headed up at all headworks is limited, *i. e.*, there is a maximum limit to the depth which can be run in the pocket, and before this is reached there is usually a limit to the difference between level up and down stream of the weir which may not be exceeded for reasons of safety.

The values of the Critical Velocity Ratio (Kennedy) were carefully watched. The most marked check to the tendency of silt to deposit in the canal was obtained when conditions permitted of a slight increase of both depths and Critical Velocity Ratio in the pocket. When maximum depths had been reached in the pocket and a slight increase in Critical Velocity Ratio only could be obtained the effect was less.

There were periods when the quantity of silt moving was such that it could not be prevented from depositing in the pocket at any velocity which did not maintain silt at such a height as to cause excess quantities to enter the canal.

These periods were usually of short duration and if conditions of demand in the canal system did not permit of the canal being closed completely for a few hours the excess quantity of silt which entered the canal had to be accepted. This however was seldom such as to cause a temporary deposit in the canal of over 2 feet for short periods.

MR. FOY replying said that he did not attach much importance to the 240 feet width of undersluices, and that the essential requirement was that the undersluices should be able to pass about 20,000 cusecs without undue heading up.

Referring to the question of vertical obstructions in the subsoil he remarked that Mr. Hadow had said that Colonel Clifford's experiments had established that flow took place along the line of creep, and not directly across the soil.

A hydraulic gradient of 1 in 15 had been allowed but as a gradient of 1 in 15 was not given in the case of an ordinary sand *band* there seemed no particular reason for it in a weir.

With regard to the bottle-neck design, he pointed out that the approach between the guide-banks at Ferozepore Weir was straight.

He stated that the fact that no cracks had appeared at Ferozepore was due to experience elsewhere. The lifting of the layers of concrete at Suleimanke had been due to the use of unsuitable cement. The laying of cement-concrete in too thin layers rendered it liable to separation. No interval should elapse between the placing of the layers, when possible work should be concentrated on the completion of one bay before passing on to the next.

Replying to Mr. Musto, he remarked that the length of the divide-wall was empirical. The principle was that it should mask the regulator and extend beyond that ; in one case this extension was 400 feet.

He thought "dry" blocks were suitable, as the only function of the divide-wall was to prevent cross currents.

With regard to Mr. Nicholson's remarks concerning the opening between the guide-bank and the regulator, a definite channel could be secured if the proportion of flood discharge to be passed, and the depth of scour in the pocket were known. The maximum safe non-silting velocity could then be arranged to keep above the maximum permissible silt-deposit.

Discussing the need of paving in the under-sluice pocket he said that on the important occasion of the design of the first Sutlej Valley Weir, he had called in consultation Messrs. Sangster, Murray and Gebbie, and that they had over-ruled him, with the result that paving had been used in the first weir, but had been omitted in the subsequent weirs. He considered that if the regulator and divide-wall, etc., were protected with sufficient stone to take up the scour, it was *not* necessary to pave the rest of the pocket.