PAPER NO. 234.

NOTE ON DESIGN AND CONSTRUCTION OF THE SHUJABAD BRANCH AND ITS DISTRIBUTARIES.

By

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Introduction.

The Shujabad Branch is the main non-perennial channel of the Second Haveli Circle and it takes up the fertile areas of Kabirwala, Multan and Shujabad Tehsils of the Multan District, which was being previously irrigated from the inundation canals taking off from the left bank of the Chenab. It forms a link connecting the old inundation canals with the Sidhnai Canal and provides weir-controlled irrigation for the area under these canals, which had previously only a precarious supply dependent upon the river floods.

The present note contains a description of the design, construction and working of the Shujabad Branch and its net-work of distributaries, and is intended to give a chance to the Congress to discuss the standardized designs for the branch canals and distributaries followed on the Haveli Project.

Chenab Inundation Canals.

It will not be out of place to give a short description of the old and historic inundation canals replaced by the Shujabad Branch. Of these canals, Matithal and Wali Mohd. took off from the Ravi just upstream of its confluence with the Chenab, and thus had the advantage of early rise of the Chenab and late fall of the Ravi. The Wali Mohd. Canal was the oldest and most important as it served the area round Multan town. It was constructed before 1753 A. D. It had also an important offtake in Durana Langana Canal, which served a considerable new area. The remaining two canals, *viz.* Sikandrabad and Balochwah took off from the left bank of the Chenab River below its confluence with the Ravi. The Balochwah Canal had originally been excluded from the Project, and

was taken in subsequently, as the area on this system was very fertile, and was eminently fitted for secured non-perennial irrigation.

The importance of these inundation canals will be realized from the fact that they served a total gross area of 396,832 acres and culturable commanded areas of 356,666 acres, out of which in the year 1936/37 there was an irrigation of 113,692 acres in *kharif* and 117,894 acres in *rabi*. The necessity for the Haveli Project will be amply evident, when it is considered that such a vast tract of fertile area was dependent upon precarious supplies from the river floods. Further, the inefficient and expensive working of these canals will be brought home from the fact that during 1936/37 the expenditure on running these canals was Rs. 2,75,000/- and in spite of incurring such heavy expenditure, adequate supplies during sowing and maturing periods were never available. Another great drawback in the inundation canals was excessive application of water to land during flood months, which resulted in raising the water-table. This is prominently noticeable on the Taliri system, where depth of water-table below Natural Surface has been found to be directly dependent on the delta, and is only 3·0 in some reaches during August. Evidently therefore the provision of secured and regular supplies besides ensuring the safety of crops, is beneficial for improving the conditions of the land in respect of waterlogging. The Haveli Project along with the Shujabad Branch is an accomplished fact now and brings with it the advantages enumerated above which are being fully appreciated by the people.

Shujabad Branch.

Both in the 1932 and 1935 Projects, provision had been made for a new Head Works in Ravi at Abdul Hakim four miles upstream of Sidhnai and it was proposed to take off the Multan non-perennial branch, now called Shujabad Branch directly from the river and run it parallel to the Sidhani river for the first four miles, till it reached the existing Sidhani Canal. From here it was to be linked to the inundation canals for which it serves as a feeder. Further investigations, however, showed that it was quite practicable and more economical to remodel

the existing Sidhnai Dam, which has therefore been retained after necessary remodelling. In order to avoid running of widely divergent discharges in the Sidhnai Canal in the two crops, discharge in *rabi* being half that in *kharif*, it was suggested by K. B. Mian Iqbal Hussain, Superintending Engineer, Second Haveli Circle, that for the Shujabad Branch an independent channel should be constructed from the Sidhnai Head, instead of taking it off from the Canal. The extra cost would have been only about Rs. 20,000/- a negligible sum as compared to the total cost of the Branch. The suggestion was however not accepted by the Chief Engineer, who on the analogy of some other non-perennial branches in the Province taking off from perennial canals decided it to take off from the Sidhnai Canal.

Alignment.

Plate I shows the alignment of the Shujabad Branch and its net-work of distributaries and also the portions of inundation channels abandoned. The Branch takes off from the first control-point in the Sidhnai Canal at R. D. 44,077 and has been aligned so as to form a short and straight link with the old Matithal Canal at a safe distance from the river. Further, the branch was aligned so as to cause least disturbance in the perennial area in the first 12 miles, and to make maximum use of canalized portions of old canals. In all, it consists of 18 miles new and 42 miles old channels.

Design of Channel.

The design of a channel depends mainly on the quantity and grade of silt in the water, which determine the silt factor of Lacey or C. V. R. of Kennedy. The available fall between Trimmu and Sidhnai was limited to 22′ only in a distance of 230,000, thus giving a slope of 1 in 10,500, which for a discharge of 5000 cusecs in the main line gave value of '*f*' as ·82 and value of C. V. R. as ·905. The maximum size of silt, therefore that may be permitted to enter the canal as worked out from Lacey's equation $d=\frac{f^2}{64}$ comes to ·105 inch or ·27 mm. The Head regulator of the main line has therefore been fitted

with a suitable silt excluder so as to keep out all silt coarser than ·27 mm. and to ensure maximum value of $f = ·82$, which corresponds to the available slope. Having fixed the value of 'f' for the main line, it naturally followed that all its offtakes must be designed with the same value. It was, therefore, laid down by the Chief Engineer that the whole canal system should be designed with $f = ·8$.

The value of Kutter's co-efficient of rugosity which is related to 'f' by Lacey's equation $N = 0·225 f^{\frac{1}{4}}$, for $f = ·8$, comes to ·0213 and Kennedy's diagrams which are based on $N = ·0225$, therefore, for the same discharge and slope gave bigger sections. Moreover, there is only one best section with Lacey. It was, therefore, laid down by the Chief Engineer that only Lacey's diagrams should be used for design of channel sections. Slopes flatter than those for $f = ·8$ were not to be adopted. The 'f' could, however, be increased to ·9 with corresponding $N = ·0219$, in case steeper slopes of channels were needed to suit the prevailing slope of the country.

Having decided upon the silt factor, the next step for the design of the channel was to fix the discharges in various reaches and F. S. L.'s upstream of each control point. For this purpose tentative Longitudinal Sections of all the distributaries were designed and required data for design of the parent channel fixed from these. In order to safeguard against any waterlogging trouble in the riverain area served by this Branch, attempt was made to keep the full supply levels as low as possible. The working heads into the offtakes were reduced to 0·4′ only in cases of high level channels, like the Multan Distributary. Having fixed the discharges and levels at control points, the slopes of the channel in various reaches were worked out from Lacey's diagrams and in the reaches of old channels, which were too big for the new discharges, values of 'f' were kept below ·8.

In the reach above R D. 54,100, in which there are no offtakes, the bed levels were fixed on the principle of balancing depths, which gives the most economical channel. The details of design are shown in the Long Section Plate II.

Earthwork.

Detailed instructions were issued by the Central Design Office for designing channel sections and preparation of the earthwork estimates. The data for the branch were fixed according to these instructions. The patrol bank was kept 25·0′, and the other bank 12·0′ which was increased to 20′ or less in case of spoil. Freeboard was 2·5′. Hydraulic gradients were fixed for different heights of filling above N. S. Radii for curves were also fixed according to discharges. Further, the earthwork was carried out most systematically by constructing masonry pillars along the centre line by triple levelling. For a thorough control the estimates were sanctioned in 3 miles reaches.

Masonry Works.

The main idea in designing works on the Project was to produce hydraulically sound and most economical designs, and for this purpose the principles enumerated in the latest publications of the Central Board of Irrigation were adhered to. These principles are based on the experience of all provinces in the behaviour of flumes, falls and regulators constructed in the latest big Irrigation Projects like Sutlej Valley Project in the Punjab, Sarda in United Provinces and Sukkar-Barrage in Sind, which go a long way to solve the problem of designing safe, cheap and efficient works. Exhaustive and detailed instructions based on these principles were issued by the Central Design Office for designing flumes and regulators, which are briefly enumerated below:—

Falls.

(*i*) *Water way.* For metering condition drowning ratios should not exceed ·75 or submergence not to exceed 3 times the drop. In cases where submergence is of no consequence, the water way required is to be determined by calculating the discharge per foot run required for proper fluming with the available values of loss of head H_L and energy of flow downstream Ef_2 according to Plate No. VII of the C. B. I. Publication No. 7 on "The Standing Wave or Hydraulic Jump." Having worked out the discharge per foot run, the clear water

way is got by dividing the total discharge by this figure.

The value of H over crest including head due to velocity of approach is calculated from the usual free fall formula

$$q = CH^{3/2} = 3{\cdot}09\ H^{3/2}.$$

The length of crest to be from $2H$ to $2{\cdot}5H$.

(*ii*) *Glacis.* The glacis profile is to be determined from Mr. Montagu's equation for the path designed to give the maximum horizontal acceleration. This equation gives the most efficient profile for the glacis and is as below :—

$X = U\sqrt{\frac{4}{g}}\sqrt{Y} + Y$, where X and Y are the horizontal and vertical co-ordinates of any point on the glacis with downstream end of crest as origin and U is the initial horizontal velocity of the jet at that point. This equation has been arrived at by considerations of horizontal acceleration, which lay down that each point on the most efficient profile shall lie between the horizontal at crest level and gravity parabola for the horizontal velocity at the downstream end of the crest.

For big falls, crest wall should have a top width of 3 bricks and the downstream face should slope at 1 to 3 from the crest level to the bed of the cistern.

(*iii*) *Cistern.* The function of the cistern is to destroy the surplus energy in the jet with hypocritical velocity below the crest and to still the turmoil and residual eddies, before it subsides to the normal flow in the channel downstream. Mainly two types of cisterns are met with in irrigation channels, *viz.*, with vertical stream and with stream flowing down an inclined glacis. The dimensions of these two kinds of cisterns have to be determined from the data of the fall.

Taking the cisterns of the vertical which is really parabolic-jet, the actual dimensions are theoretically indeterminate and reliance has to be placed on empirical formulæ based on past experience. For the inclined glacis class of flumes, the dimensions are determined by considerations of total energy line. The width

is fixed by the degree of expansion or splay of down-stream wings. Usual practice is to allow a splay of 1 : 1 to 1 : 2 in upstream and 1:5 to 1:10 in downstream wings of flumes. The width must not exceed that fixed by these considerations, as a wider cistern causes reverse currents on sides and is inefficient. The bad level of cistern at calculated position of standing wave must be fixed from considerations of fall H_L and discharge per foot run, *i.e.*, if water way is designed from H_L and Ef_2 the cistern bed is determined from Ef_2. Summarising, the cistern should be depressed sufficiently to accommodate the standing wave, which will ordinarily be attained by fixing the level of the cistern floor at 25% of the height of standing wave below the point at which it is expected to form or at downstream bed level, whichever is lower.

For fixing the capacity of the cistern, Mr. Haigh divides it into two portions, *viz.*, dispersion chamber, where jet is broken up into turbulent or eddy flow and stilling chamber where turbulance is settled down to normal flow. The dispersion chamber should have a width equal to full downstream bed-width, depth $D/3$ below downstream bed level and capacity should be calculated from the formula :—

$C_D = K_D \; Q_F^{0.33}$ where C_D is capacity below *F.S.L.* in cubic feet, Q discharge in cusecs, F fall in feet and K_D a constant.

The stilling chamber should be of the normal water-way section, and slightly greater depth to provide for retrogression. Its capacity should be calculated from the formula :—

$C_S = K_D \; QF^{0.33}$ where C_S is a constant depending on type of soil or silt, its value for average Punjab soil being 10·0. The principle laid down by Mr. Haigh have been derived from the working experience of most of the important Punjab falls.

Etcheverry quotes the following equations for the dimensions of cisterns :—

Length of cistern $= \sqrt[3]{Ha \; H_L}$ where Ha is head over crest and H_L is the fall.

Depth of cistern = one-sixth of its length.

The Central Design Office issued the following empirical instruction for the design of cisterns, which are based on energy considerations :— Depth should be $\frac{1}{4}$th the upstream total energy line above the downstream bed level to nearest half foot. The length should be equal to the upstream total energy line above the downstream bed level to the nearest foot at bed level of the cistern. The cistern should end in a vertical wall upto downstream bed level of channel. Standard instructions for downstream wings, impervious floor, upstream and downstream protections, glacis, etc., were also issued and the design of works thus was an easy affair.

(*iv*) *Roughening*—Of the type of falls, the least efficient is the one with an inclined hypocritical jet impinging on a sub-critical stream and this is the type mostly in use. Considerable turbulence persists below the standing wave in such falls, and artificial roughening is a necessity for destroying energy, which is effected by increasing wetted area, and by deflecting high stream filaments and making them interact on each other. The design of this artificial roughness is not amenable to theoretical treatment and is therefore carried out on empirical rules based on practical experience. The roughening generally consists of friction blocks, projecting into the bed of the channel. Detailed instructions for the dimensions, spacing and arrangement of the friction blocks were issued by the Central Design Office. These instructions were based on observations on models as the blocks cannot be mathematically designed. As explained above, their function is to split up the high speed streams and deflect the filaments.

The application of the above principles is illustrated by the details of the design of some of the masonry works on the branch given below :—

Head Regulator.

The Shujabad Branch takes off the Sidhnai Canal at R. D. 43,280 R at an angle of 47°. This offtake was proposed after considering the existing religious and other buildings lying upstream of the regulating fall in Sidhnai at R. D. 44,077. The

Head Regulator is thus 797′ upstream of the fall in the parent canal and the water-way of the parent channel is proportionately ruduced downstream of the offtake. The Head Regulator is combined with an Arterial road bridge on the Multan-Jhang road, and it consists of 6 spans of 10·0′ each with a suitably raised crest, regulating gates and downstream protection. Photo No. 1 shows the completed Head in working condition.

At R.D. 19,000 there is a meter fall of 2·78′ with suitably designed glacis, and at 41,000 and 541,000 are 3·85′ and 3·42′ falls respectively with crest-walls.

The next important work is the regulator at R. D. 62,000 where the first two distributaries take off. The hydraulic calculations for this work are as below :—

Data for the Branch :— $\frac{\text{Upstream}}{\text{Downstream}}$ $Q = \frac{1834}{1655}$ *cs.*

$B = \frac{98}{93}$, $D = \frac{6{\cdot}6}{6{\cdot}4}$, $F.S.L. = \frac{438{\cdot}5}{434{\cdot}27}$ $f = \frac{{\cdot}86}{{\cdot}9}$

$Ef2$ = Downstream Total Energy $= D + \frac{V^2}{2g} = 6{\cdot}40 + {\cdot}1$

$= 6{\cdot}5$

H_L = Fall in feet = 4·23. Therefore from Plate No. VII of C.B.I. Publication No. 7, q for fluming = 27 *cs.*

Clear water-way $= \frac{1655}{27} = 61{\cdot}3'$ say 60′ or 4 spans of 15·0′ each.

$H = \left[\frac{1655}{3{\cdot}09 \times 60}\right]^{2/3} = 4{\cdot}3'$. Head due to velocity of approach upstream of fall = ·11′

∴ crest level = 438·5—(4·30—·11) = 434·31.

Length of crest = 2 × 4·30 = 8·6′

Length of Cistern.

U/S T.E.L.—D/S bed R.L. = 10·74′ say 11·0′

Retrogression D/S.

The next control point being at R. D. 125,000 and as the channel is an old inundation canal

of a much bigger section from R.D. 125 to 100, it can be safely assumed that it will work with $f=\cdot6$ from R. D. 125 to 100 and $f=\cdot8$ from R. D. 100 to 62. With $f=\cdot6$ and $Q=1655$, slope per 1000 is ·069. *F. S. L.* at R. D. 100 shall be $=425\cdot7+\cdot069\times25=427\cdot42$. Similarly slope in reach R. D. 62 to 100, with $f=\cdot8$ shall be ·113 per thousand. *F.S.L.* at 62,000 downstream shall be $=427\cdot42+\cdot112\times38=421\cdot68$. ∴ Assumed retrograted bed level $=431\cdot68-6\cdot60=425\cdot08$ against 427·87 proposed. Retrogression $427\cdot87-425\cdot08=2\cdot79$ ft. against which 2·5′ is kept and assumed retrograted bed R. L. is 425·37.

Depth of Cistern.

Standing wave formation. Allowing for 2·5′ retrogression, the *F.S.L.* downstream is 431·77, Q is 1655, velocity 2·6′ per second and velocity head is ·11′. Energy level downstream is therefore $431\cdot77+\cdot11=431\cdot88$ and energy level upstream is 438·61. The H_L or fall therefore is 6·73 and q is 27·6 cusecs.

With these values of H_L and q, $Ef_2=6\cdot97$ and level of standing wave formation is $431\cdot88-6\cdot97=424\cdot91$. The cistern bed to be kept at 424·87 or 6″ below the rest of the floor.

The above calculations are typical for such works and have been done by the Central Design Office. Though the depth of the cistern in this work has been designed with H_L including the retrogression, the water-way has been designed with the final value of H_L. It would have been safer, if the water-way too had been designed with the retrograted value of H_L but the error is not of much practical magnitude.

The most important work in the Branch is the regulating fall at R. D. 123,500. Three distributaries, *viz.*, Inaytpur, Khadil and Bagar, take off from upstream of this fall. The fall has been designed on usual lines and water-way has been calculated from the final values of $H_L=2\cdot7$ and $Ef_2=6\cdot4$. The work lies in the old Wali Mohd. inundation supply channel and the existing bed R.L. is 6·23′ below the upstream designed bed level and 3·63′ below the downstream designed bed level. The retrograted bed was assumed 2·5′ below the designed

and the cistern was kept 1·5′ below this for formation of standing wave in low supplies. The details of the design for this work are shown in Plate No. III.

A perusal of this will show that the crest R. L. is 8·5′ above the existing bed and the crest has been constructed on about 7·0′ of sand filling. This sand filling is covered over with 1·0′ thick concrete and ·65′ cement masonry, the usual thin coverings for the crests of falls. Three upstream curtain wells with adequate pitching and *pacca* floor have been added to make the sand filling safe.

Another interesting feature of this work was that at the time of construction sub-soil water level was practically at the existing bed level. The Central Design office had, however, designed open concrete foundations for the piers, abutments and wings, which could not be carried out without adequate pumping arrangements. No pumps were available for this work and there was no time to get these from anywhere, all those available having been requisitioned by Trimmu and Sidhnai. Further, cost of pumping would have been prohibitive. Well foundations were, therefore, substituted for the open ones. In the drawing the open founds as originally designed are shown. The well curbs for the wells consisted of *Shisham* wood planks and the staining consisted of one brick masonry. The wells were rectangular in plan and of maximum lengths which could practically be sunk safely. The wells were sunk to foundation depths, and cement concrete of 1 : 4 : 8 proportions was scooped in them. The interspaces between the adjacent wells were narrowest possible and were filled in with cement concrete.

Photos Nos. 2 and 3 show the completed work, without village-road slabs, in action. This work, of which the crest was 8·0′ above the existing bed both upstream and downstream and was constructed on sand filling, was the only one of its kind in the whole Project and required extreme care in execution. The success of the whole branch lower down depended on its safe running. It was carried out during the crop-cutting season with due care for all details of construction and it has worked most successfully for the first season. The actual fall on this work is 5·0 ft. due to the low bed level and it

may take years to raise the downstream levels to the designed figure. The water way therefore which is based on the final HL is rather tight for the existing fall, and there is excessive action on the sides downstream, where erosion extends upto about 200′. Staking and bushing have been added for protection.

All the falls on the Branches lower down, *viz.*, at R.D. 165,500, 199,000, 281,000 and tail have been remodelled by raising the existing narrow crests to suit the new levels and need no special mention.

Bridges.

A detailed article on the standard designs of bridges on channels of the Haveli Project appeared in the Inauguration Souvenir. The following general principles have been followed :—

(*i*) Water-way allowed was kept practically equal to the designed bed width.

(*ii*) Piers were 1·9 ft. thick.

(*iii*) Standard designs for abutments and wings have been worked out. A tension stress of 25 lbs. per square inch has been allowed on the outer side of wings because of the use of the cement mortar which can be safely and economically depended upon to take that. The rule for the resultant to pass through the middle third has been overlooked and instead outer 1/6th or 1/10th adopted.

(*iv*) Open foundations of suitable depth so as to allow maximum pressure of 1 ton per sq. ft. on the soil have been provided. The piers have been taken down to a depth of $D/3$ below the designed bed R. L. to allow for possible scour.

(*v*) The road-way is generally carried by reinforced concrete parapet girders. Standard designs for these for spans from 20′ upwards were worked out. The loading allowed is 10 B. S. units for A. R. and D. R. and 5 for V. R. Bridges, scientifically splayed.

(*vi*) As further means of economy brick ballast has been used in all the slabs, except Arterial Road ones. Compression tests with blocks made from *pacca* brick ballast gave results in the order of 3100 lbs. per sq. inch and these led to this decision. Detailed specifications for brick ballast selected for use in the reinforced concrete work were laid down. The ballast was to be broken from specially selected, slightly over-burnt bats, free from vitrified glazed and spongy material. It was to be of 1″ gauge and free from *surkhi*, brick dust and excess of small stuff. Further, the SO_3 contents were not to exceed 2% and for this purpose 5 lb. samples were sent up for test to the Research Institute. For the samples sent by Shujabad Division, not more than ·3% Sulphur Trioxide contents were found in any of them. The ballast was to be washed sufficiently before hand, to be dry before it was used in the slab work.

With the brick ballast of the above specifications the stresses allowed were the same as for the stone ballast. Ten per cent. extra cement was used, raising proportion to 1·1 : 2 : 4.

(*vii*) Wearing coat on V. R. Bridges consists of ·4′ thick cement masonry herring bone bond and on D. R. and A. R. bridges of 1 : 2 : 4 cement concrete with stone ballast.

Photograph No. 4 shows a typical parapet girder bridge on the branch.

Concreting and Mortars.

In all works cement concrete was used. The proportions were 1 : 4 : 8 for foundations, 1 : 3 : 6 for blocks and precast work and 1·1 : 2 : 4 for reinforced concrete. The concrete was very carefully manufactured in measured batches of 25 to 30 c. ft. at a time. Well washed and clean brick ballast was used. Sand available from channel beds was generally used, except in places where well sand was available. The sand was dry and screened.

Cement used was obtained fresh from Rohri and Wah and was measured by weight. Every care was taken to manufacture concrete of desired strength and upto specifications.

Cement mortar of 1 : 6 proportions was used in wing-walls and outlets and of 1 : 5 proportions in abutments and other important structures. Further, for walls upto $2\frac{1}{2}$ bricks thick 1 : 5 and for walls 3 bricks and over, 1 : 6 mortar was used. In mortar for masonry 10 per cent. lime cream was used.

Distributaries.

For designing the distributary system G. T. S. sheets 4″ to 1 miles scale showing one foot contours, and all important features of the country were available. On these the main drains, which were to form the irrigation boundaries between the various channels were laid out. The distributary system was then designed, making use of the maximum length of the existing channels. As the area was fully developed, use of the old channels was desirable in order to cause least disturbance in the existing system. Old channels were abandoned only where they were scientifically defective and ran in depressions and high fillings. Plate I shows the whole of the distributary system of the Shujabad Branch.

Having fixed the irrigation boundaries along drainages and alignments of channels along ridges, the area was divided into tentative chaks and the long sections and capacity and command statements of distributaries were designed. These were got sanctioned by the Chief Engineer individually and the work on the channels was started. Final designs of channels were, however, worked out after following the detailed procedure, as below :—

1. Chakbandi. A detailed article on the procedure followed in framing chakbandis in the Second Haveli Circle by K. B. Mian Iqbal Hussain, Superintending Engineer, appears in the Inauguration Souvenir. It has been explained therein, that the main object underlying this procedure was to remove all defects in the existing chakbandis and to frame chaks acceptable to the cultivators. For this purpose notices along with plans of pro-

posed chaks were served on all shareholders and they were given a month to put in their objections. As the sub-divisional officers were too busy in construction works this task of hearing the zemindars' objections and proposing chakbandis on the lines desired by them was entrusted to the Deputy Collector. Those whose wishes could not be complied with due to some other parties not being agreeable, were given further hearings by the Executive Engineer and the final proposals were thus based on a thorough investigation by the Deputy Collector and the Executive Engineer. These were sent to the Deputy Commissioner for concurrence and were then finally incorporated in the design of the channel. The idea that the suggestions for chakbandis should emanate from the zemindars and thus have chaks acceptable to them, was greatly appreciated by them.

2. *Design of channel.* Having decided upon the chakbandis the design forms were prepared on the following lines :--

(*i*) Hydraulic surveys of all existing channels were prepared and the proposed full supply levels were mainly determined from these. Raising of F. S. levels was avoided as far as possible.

(*ii*) Channels were designed from Lacey's diagrams; and as explained in the case of the Branch the values of '*f*' were ·8 and under.

(*iii*) Reaches were changed at some control points, *viz.*, falls, bridges, etc.

(*iv*) As far as possible a minimum working head of 0·7 ft. was allowed on all falls and minor heads. This limit had, however, to be relaxed to 0·5 ft. where larger heads were not available.

(*v*) Water allowance was 4·8 cs. per thousand acres of the gross area.

(*vi*) Absorption in the distributaries was allowed at 10 per cent. of outlet discharges, minors being treated as outlets for this purpose.

Design form for Matotali Minor of the Panjani Distributary is shown in Appendix I. This illustrates the

method of design of channels followed in the Project.

3. Masonry works. As for the Branch, the designs of falls on the distributaries were standardized and detailed instructions were issued on the subject by the Central Design Office. The following are the salient features of Distributary falls designed on the Project :—

(*i*) Fluming to be 60 per cent. of downstream bed-width or $Bt = \cdot 6B$.

(*ii*) H over crest to be worked out from the formula $Q = C\ Bt.\ H^{1.5}$ where values of C were laid down for different discharges.

(*iii*) Length of Throat to be $2H$.

(*iv*) Glacis to have a slope of 2·5 to 1 upto 3·0 ft. fall. Above 3·0 ft. fall, a drop wall 1·15 ft. at top and $\frac{1}{2}\ h$ at bottom to be provided.

(*v*) *Cistern.* For fall upto 3·0 ft. length to be $Dn + Hw$ and floor to be 3 in. below downstream bed, which covers the required values of Ef_2 for such falls. For falls over 3·0 ft. the length to be $Dn + Hw$ and depth 1·0 ft. below downstream bed, as this covers required values of Ef_2 for such falls.

Principles for other dimensions for falls were similarly laid down and are shown in Plate IV, Fig. 1.

For distributors also, standard designs were prepared. It is an established fact that an acute-angled offtake is to be preferred to a right-angled one, as it draws off its proper share of silt by using component of the velocity of approach and as far as possible such offtakes were designed. It was laid down by the Central Design Office that offtakes must be at standard angles of 45°, 60° or 90°. Co-efficients for these offtakes were given and the widths of throats were designed from these. All offtakes were designed as proportional distributors. In case of minor and sub-minor offtakes the crest level was to be kept 0·5 ft. above the downstream bed level of the highest of offtakes. For distributors, standard dimensions to be adopted are shown in Fig. 2, Plate IV.

The type design for distributors, issued by the Central Design Office was amended by Khan Bahadur Mian Iqbal Hussain for better silt distribution arrangements. The centre line of the downstream channel of the parent was shifted slightly towards the side away from the minor offtake, so as to give a larger area of influence to the offtake. The outer edges of the bed lines both upstream and downstream coincided. This is illustrated by the plan of the distributor at the Head of Kotli Adil sub-minor of Alipur Minor of Panjani Distributary, Fig. 3, Plate IV. Such distributors have been constructed at many sites on this system and are working most satisfactorily.

Bridges.

The bridges on the distributaries were designed on the same lines as on the Branch. The waterways allowed were equal to the full bed-widths. Upto 18·0 ft. slabs were designed and above that T-beams or parapet girders were adopted. Brick ballast was used for all slabs except Arterial Road ones.

For practically all slabs on distributaries earth centerings were used and after removal the same earth was used in ramps. This saved the depreciation in value of wood work and was thus much cheaper than wooden centering.

Outlets. On practically all channels both new and old, modular outlets were constructed and deficiencies in discharges and levels were made up by suitable means explained hereafter. For equitable distribution the outlets should be as rigid as possible and for stability in regime of the channels the outlets should draw their proper share of silt. With these as main considerations the outlets were designed on the following lines :—

(*i*) Working Heads permitting all outlets to be A. P. M.s except tail clusters. On very deep channels, however, which required lot of silting and tightening to attain designed sections, available masonry barrels or pipes were used.

(*ii*) The crests all A. P. M. or open flume outlets to be kept at 0·9 D for rigidity. Attempts to be made not to decrease H below ·8 D.

(*iii*) Tail clusters to be open flumes with $H=1{\cdot}0$.

(*iv*) M. M. H. for open flumes to be $0{\cdot}2\ H$ and for A. P. M.s $\cdot 75\ h$.

(*v*) C. for open flumes to be 3·0 and for A. P. M.s 7·3.

(*vi*) B for open flumes not to be below 0·2′ and only improved type of C. I. A. P. M.s to be used.

(*vii*) For A. P. M.s Y to lie between $1{\cdot}5\ B$ and $2{\cdot}0\ B$ and not to exceed $0{\cdot}5\ H$.

Graphs were supplied by the Central Design office for designs of A. P. M.s and open flumes and Type designs for all types of outlets and tail clusters were also prepared. Types of an A. P. M. and open flume are shown in Plate IV, Figs. 4 and 5.

Progress and Economy.

Much has been said in the press and on the platform regarding progress and economy with which the works on the Haveli Project have been executed. The work of the Second Circle, however, was not so spectacular as to attract much attention. It will not, therefore, be out of place, to give a few remarks regarding the feat carried out on the Shujabad Branch. The work here was of the most tedious type, consisting of patching; linking and improving of old channels. Small quantities scattered over long lengths in out-of-the-way places, was the main feature of the type of work done on this system of channels. The main factors leading to economy on the works were the standardization of designs, purchase of material on mass basis and maximum use of old channels and materials obtainable therefrom.

The actual cost of the Shujabad Branch on final completion will be about Rs. 6,25,000/- against Rs. 20,41,647/- provided in the 1935 Project Estimate, there being thus a saving of Rs. 14,16,647/- the actual cost being about 1/3rd of the estimated cost. The saving will be slightly less after allowing for proportional cost of widening the Sidhnai Canal in the first 8 miles. On the distributaries, the total area is 294,296 acres out of

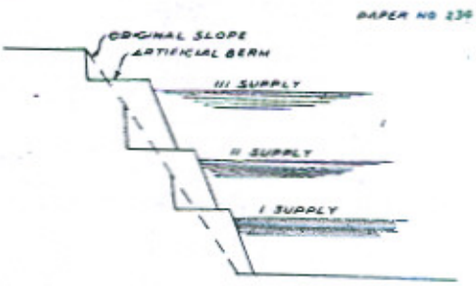
which 58,194 acres is new and 236,102 acres old. The provision for this at Project rates is Rs. 881,225/- against actual expected expenditure of Rs. 600,000/-. There is thus a saving of Rs. 281,225/- on distributaries. To the above should be added the saving in establishment charges accruing due to completion of works in half the time.

The progress on the works was also remarkable. Practically the whole of the work on the Branch and its distributaries was designed and completed in the working season of 1938/39. In all about 12 crores cubic feet of earthwork, 350,000 c.ft. masonry and 250,000 c.ft. concrete were executed in one season. All these quantities were scattered in out-of-the-way places and consisted in 170 miles new and 201 miles old channels, about 200 masonry works and 1000 outlets. The staff was busy day and night in office and out in the field. We had to fight against time and had to complete channels to receive Trimmu water immediately after the crop-cutting season.

Working of channels.

The Shujabad Branch and its distributaries lie in the already well developed area of the inundation canals, to which water had to be supplied in full immediately on opening of the channels. Any delay in raising the channels to full supply would have caused a lot of discontentment among the irrigators, who were already feeling perturbed over the seeming decrease in water allowance. The following steps were taken to raise the supply and levels in these channels rapidly :—

(*i*) For raising supplies in new channels in filling, the process of forming artificial berms was introduced by the Superintending Engineer, K. B. Mian Iqbal Hussain. In order to prevent leakages through fresh earthwork a consolidated surface was needed in contact with water. For this purpose when supply was let into the the channel, a step was cut out of the bank as shown in the figure, and a berm about 3′ in



case of distributaries and 5·0′ in the case of branch was formed. This was rammed with wooden mellets, about 9″ square, and 4″ thick. The step of the berm was kept about 6″ above the prevailing supply. The ramming of wet earth formed a consolidated film adjoining the water and prevented leakages. The process was repeated when the supply rose as shown in figure, usually in 3 stages. This artificial berm proved to be very effective in preventing leakages and in raising of the channels to full supplies within a record minimum period. The Shujabad Branch, which ran in very heavy filling, in many reaches, and had banks of very bad soil, was raised practically to full supply within a little over a month of opening, and so were all its offtakes raised. Thanks to this ingenious method devised by the Superintending Engineer, we were able to meet the demand of the zemindars, who at the time being perturbed with the rise in rates, were getting excited over the slightest short-comings in the running of these channels.

(*ii*) This artificial berm, however, could not form a permanent remedy which consisted in developing natural berms. In front of this artificial berm, therefore, cross spurs were put in throughout the reaches in filling. These consisted of two rows of pegs, with the interspace filled with jungle and brush wood, which consisted of trees, bushes, jawan, and even 'pohli'. This formed a very effective permeable obstruction. The distance apart of these spurs was about 50′ or 7 times their length. The result obtained was marvellous. In a little over a week, on the Shujabad Branch, a beautiful natural berm in front of the

REMODELLING AND DESIGN FORM FOR MATOTALI MINOR OF PANJANI DISTRIBUTARY.

Discharge at outlet head $\frac{6'8}{8'0}$ cusecs per $^{m}/_{m}$ acres of gross area.

Serial No. of Outlet.	R. D. of Outlet.	CAPACITY OF OUTLET. Bank Left or Right.	Gross Area.	Discharge of Outlet.	DESIGN OF CHANNEL. Absorption at 1/8 or 0"5 according to Standing Orders.	Discharge of outlet including absorption.	Discharge at head of watch.	Lacey's f.	Slope per $^{m}/_{m}$.	Bed width.	F. S. Depth.	R. L. of bed supply.	WORKING HEAD OF OUTLET. R. L. of ground covered points.	Distance of control point from Outlet.	Water level ab head at outlet course (column 5 x 0·7 plus 0·1 ft.)	Working head (col. 15 – col. 14).	DESIGN OF OUTLET. H.	T.	H.	M. H. Head (= 0·75 d).	M. L. of Crest.	Type.	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		Head Regulator.										71·76											
1	4950	L	460	3·30	·46	3·76	69·76	·70				71·92	66·6	4200	67·2	0·12	·53	·51	2·3	1·12	68·73	B3	·98
	4966	V. R. Bridge and span of			15·0'							74·98											
2	7000	R	418	3·16	·38	3·54	67·40	·75	·17	16	3·65	70·37	66·9	5000	67·2	0·33	·23	·74	2·3	1·17	68·25	B3	·98
3	7966	L	406	3·05	·21	3·26	69·03					70·41	67·2	3500	67·6	0·43	·23	·69	2·3	1·21	68·11	B3	·98
4	11966	R	365	1·74	·15	1·89	69·77					69·75	66·4	3500	67·1	0·73	·33	·91	2·3	1·50	67·43	B3	·98
5	12966	R	703	3·46	·41	3·71	69·80	×	×	×	×	69·55	66·8	6500	67·2	0·43	·5	·71	2·3	1·27	67·35	B3	·98
6	13800	L	688	4·10	·62	4·28	67·16					69·41	66·9	4200	67·1	·25	·45		2·3	·14	67·23	OP	·98
7	14300	R	134	·73	·1	1·83	66·37	·75	·170	15	2·50	69·21	66·5	1500	66·1	0·23	·2	·5	2·3	1·33	67·12	B1	·98
8	14800	L	135	1·61	·03	1·77	51·52					69·5	66·5	2000	67·3	0·9	·32	·53	2·3	1·52	67·1	B3	·98
	14445	V. R. Bridge and	Head R	egulator T	o sub-culvert.							209·3				·6	3·37		1·36	·51	207·76		
				Fall 14·16	1·43	15·59	49·33					209·7 249·3				·72	3·6		1·54	·31	207·24		
												165·55											
9	16700	L	239	1·15	·12	1·27	54·16					69·15	66·6	2000	66·9	0·33	·25	·38	2·3	1·11	66·16	B3	·91
10	22644	R	575	2·76	·28	3·04	66·68					67·03	62·5	1500	66·1	0·53	·34		1·94	·38	62·09	OP	·85
11	23344	L	339	1·63	·16	1·79	69·54					69·32	65·6	1000	66·00	1·03	·32	·73	1·85	·69	66·25	SS	·6
12	24680	L	290	3·63	·37	4·00	28·05	·75	·19	10·5	2·4	69·64	64·3	6000	65·3	·94	·45		1·93	·38	64·71	OP	·98
13	24700	L	458	2·19	·23	2·41	24·00					66·64	63·3	6000	65·4	·24	·18		1·9	·38	64·74	OP	·98
14	25000	L	887	1·06	·16	1·76	51·26	×	×	×	×	66·06	66·0	500	66·4	1·5	·85		1·97	·34	64·92	OP	·8
15	25850	R	862	5·79	·58	3·01	19·80	·75	·5	7·5	1·5	69·55	65·5	3000	66·2	·83	·42		1·7	·34	64·93	OP	·8
16	26600	L	450	3·05	·31	3·37	10·73	×	×	×	×	66·20	63·7	7000	65·4	·8	·51		1·5	·3	64·05	OP	·9
17	27010	L	699	3·30	·34	3·72	14·61	1·5				65·15	65·0	9000	65·9	·25	·61		1·5	·3	64·05	OP	·83
18	27250	R	161	2·21	·22	2·43	10·51	·75	·22	6·0	1·8	66·03	64·4	2000	65·3	·99	·5	·7	1·45	·28	64·59	AS	·83
19	27300	R	676	2·25	·23	2·51	2·1 6·13	×	×	×	×	66·09	63·9	2000	64·6	1·43	·5	·7	1·5	·6	64·59	AS	·83
	27500	V. R. Bridge and	Fall.									66·99				3·21			1·82	·29	65·88		
												66·55											
20	28700	TR	551	2·65	·26	2·92	5·93	0·75	·25	3	1·7	69·5	62·6	2000	63·5	·93	·88		1·9	·2	62·5	OP	·6
21	28700	TL	552	2·65	·27	2·92						69·5	62·6	2000	63·5	·90	·88		1·9	·2	62·5	OP	·6
	Total ...		10·63																				

Approved.
(Sd.) IQBAL HUSSAIN, IS
Superintending Engineer, II Hazari Circle,
Multan.

(Sd.) S. L. MALHOTRA,
Executive Engineer,
Shujabad Division. SS-9-51.

NOTES.—Column 1 will give serial number of outlets in their and of channel all-values in red ink and sequence of reduced distance.
R. D. of all masonry works should be given in red ink in sequence of reduced distance in column 2, without any entry in column 1.

Complete data of masonry work should be recorded on the form in red ink. In the case of bridges, clear linear waterway at bed level and the distance, between abutments at bed and full supply level should be given. In case of control points, complete data, upstream and downstream of control point should be recorded in two lines in columns 18, 19, 20, 21 and 23.

(For convenience in printing antique type is used in place of Red).

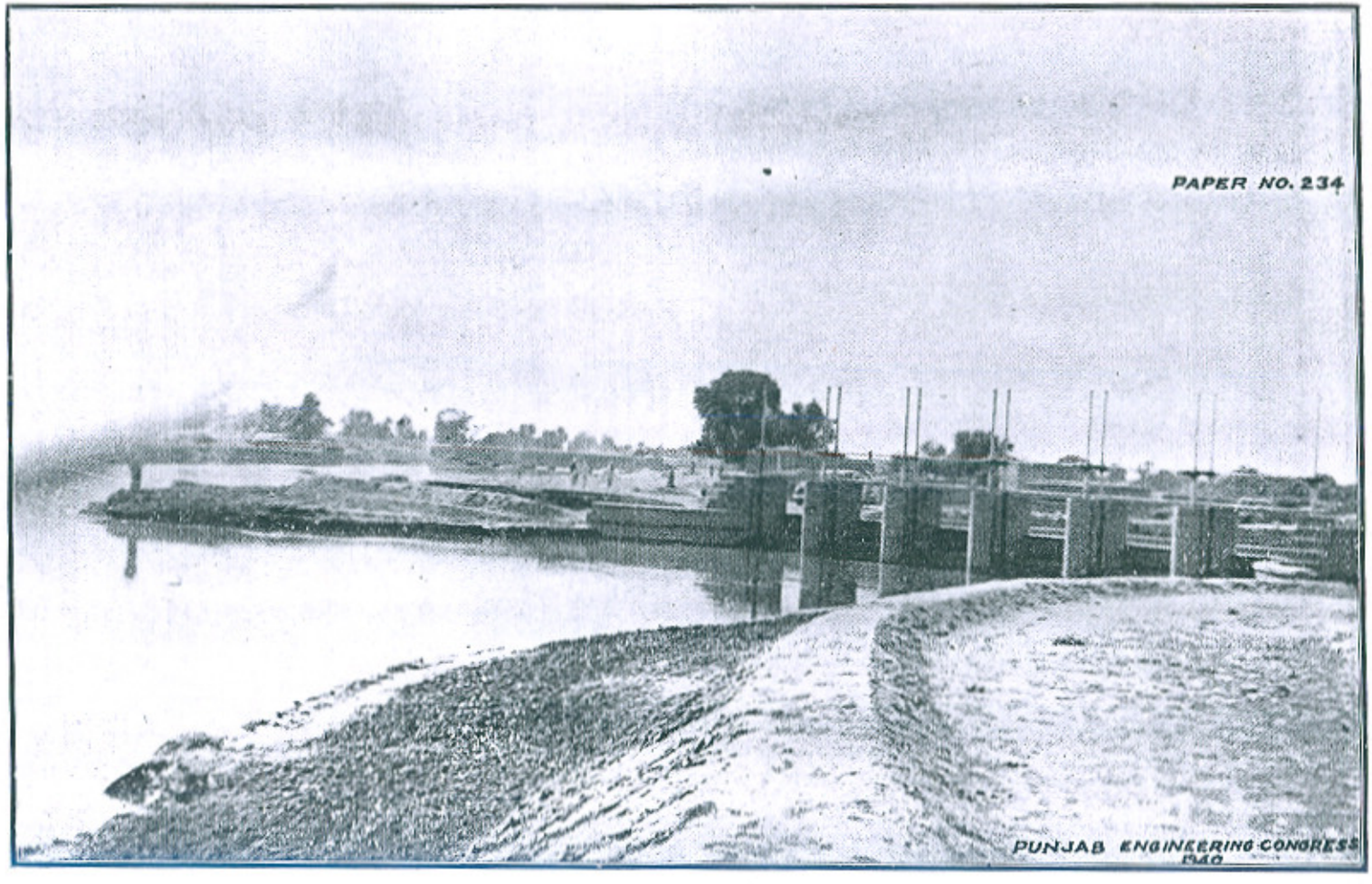


Photo No. 1. Head Regulator Shujabad Branch Upstream.

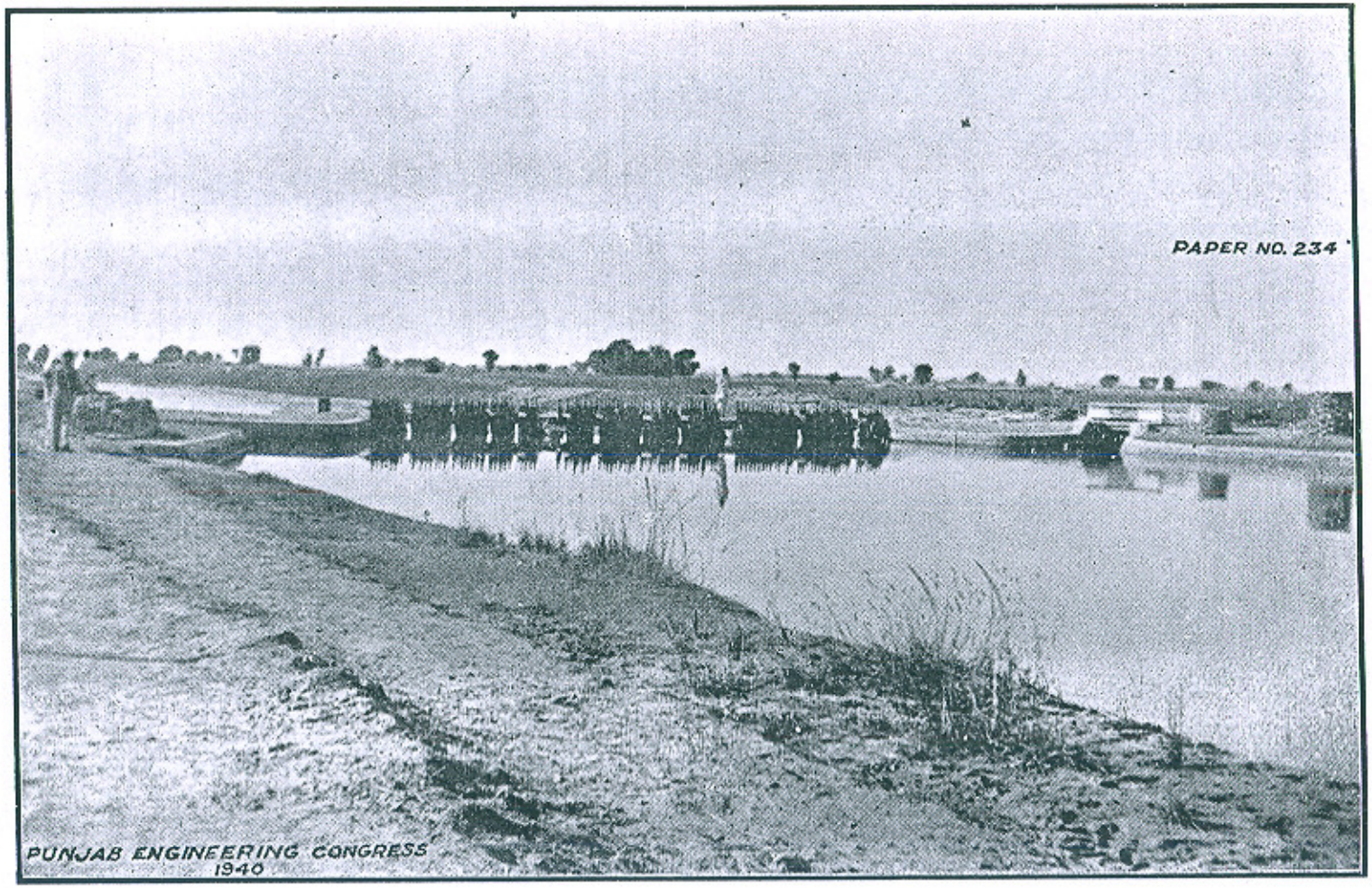


Photo No. 2. Regulator R. D. 123,500 Upstream with Heads Khadal and Baggar Distributaries.

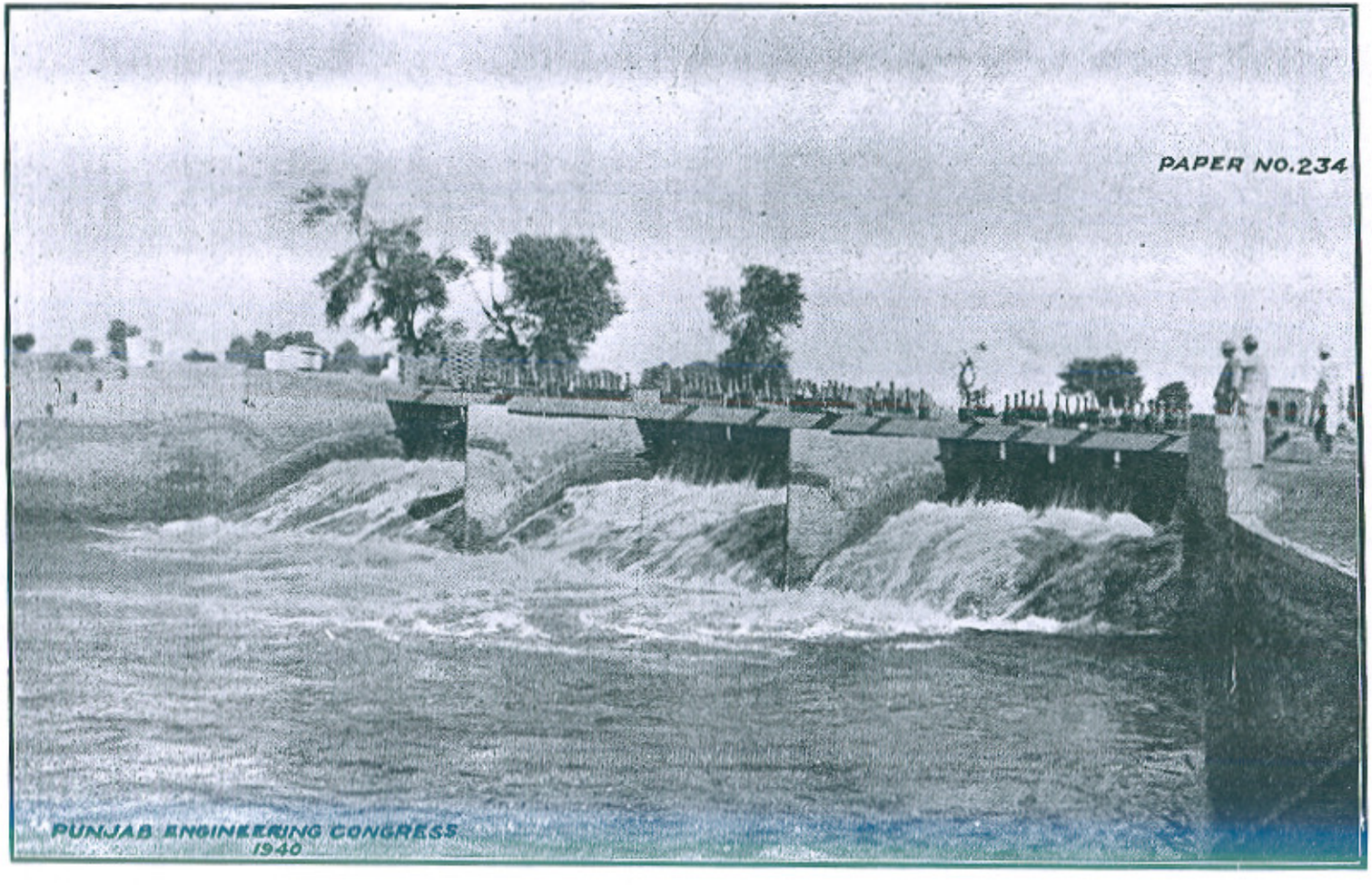


Photo No. 3. Regulator R. D. 123,500 Downstream.

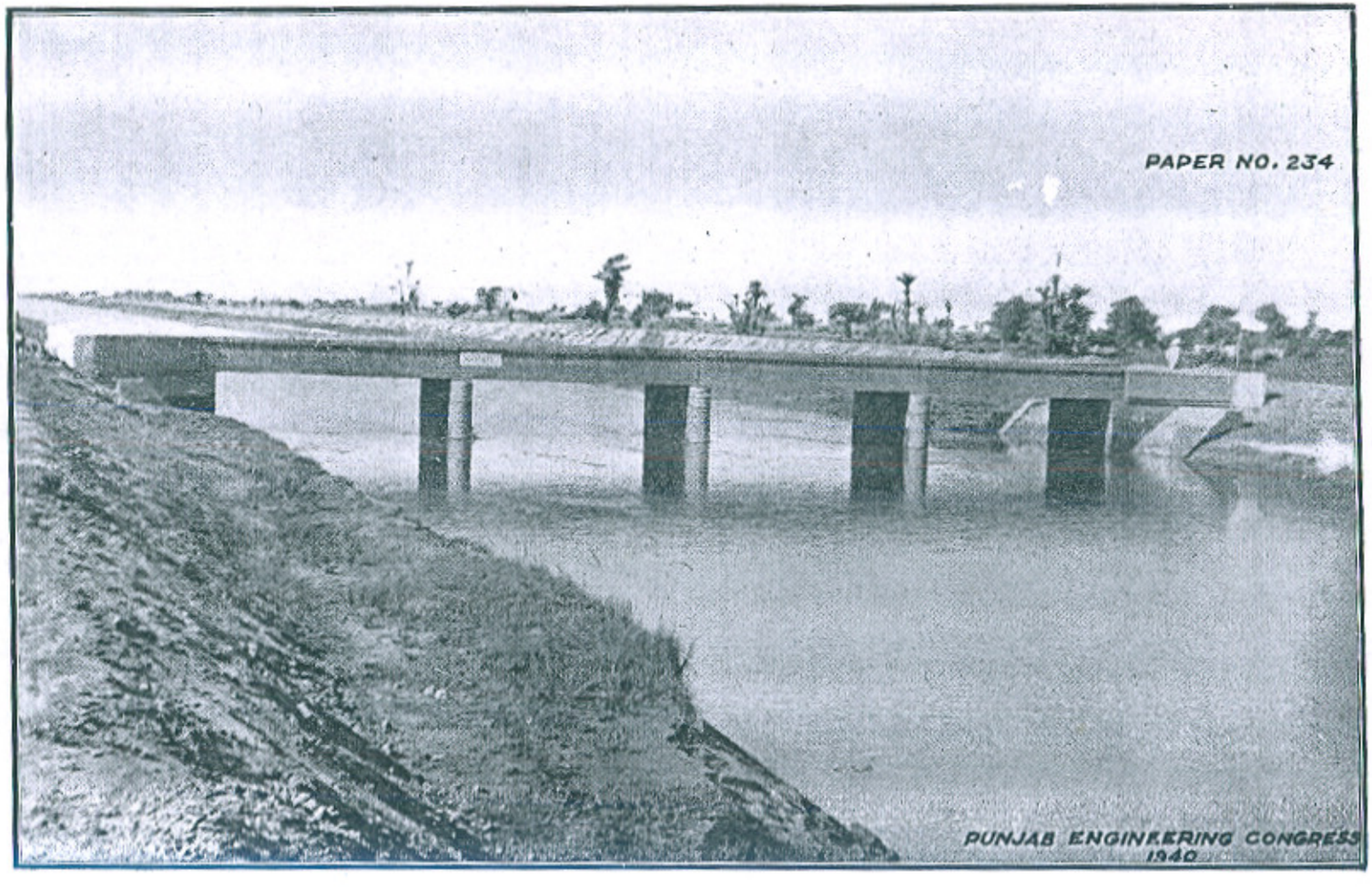
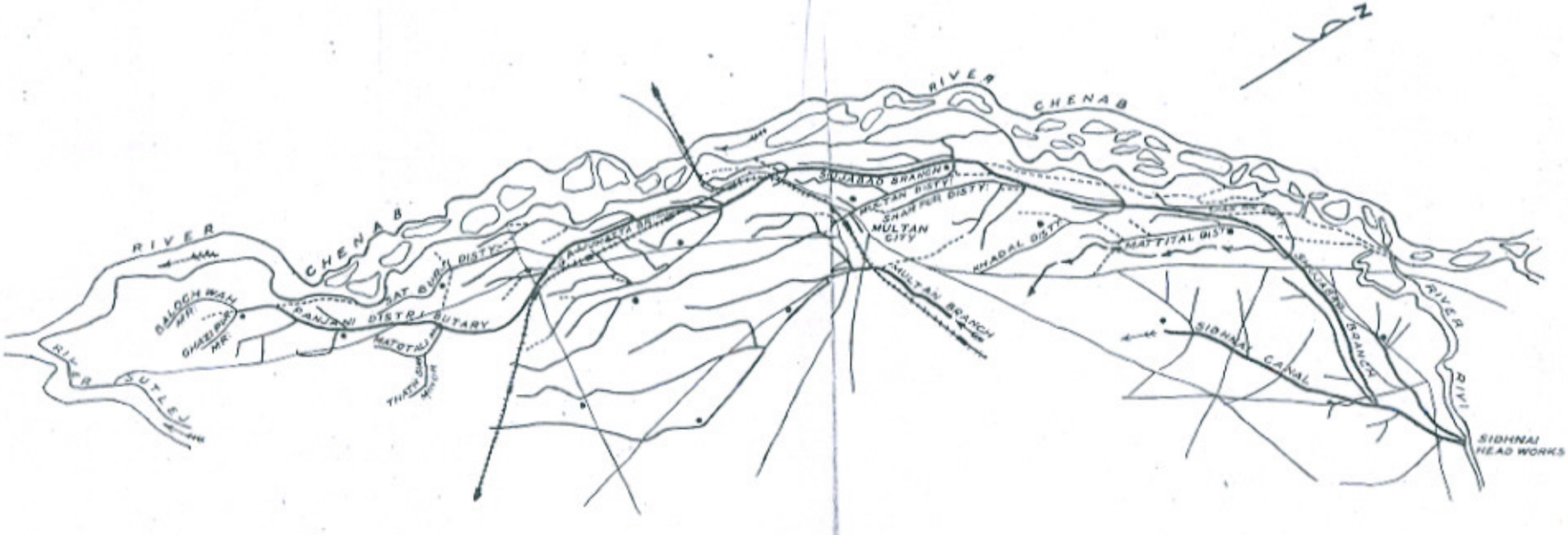


Photo No. 4. Parapet Girder Bridge R. D. 87,970.

INDEX PLAN
OF
SHUJABAD BRANCH AND ITS DISTRIBUTARIES
SCALE = 1" TO 8 MILES

PLATE I
PAPER. NO. 234

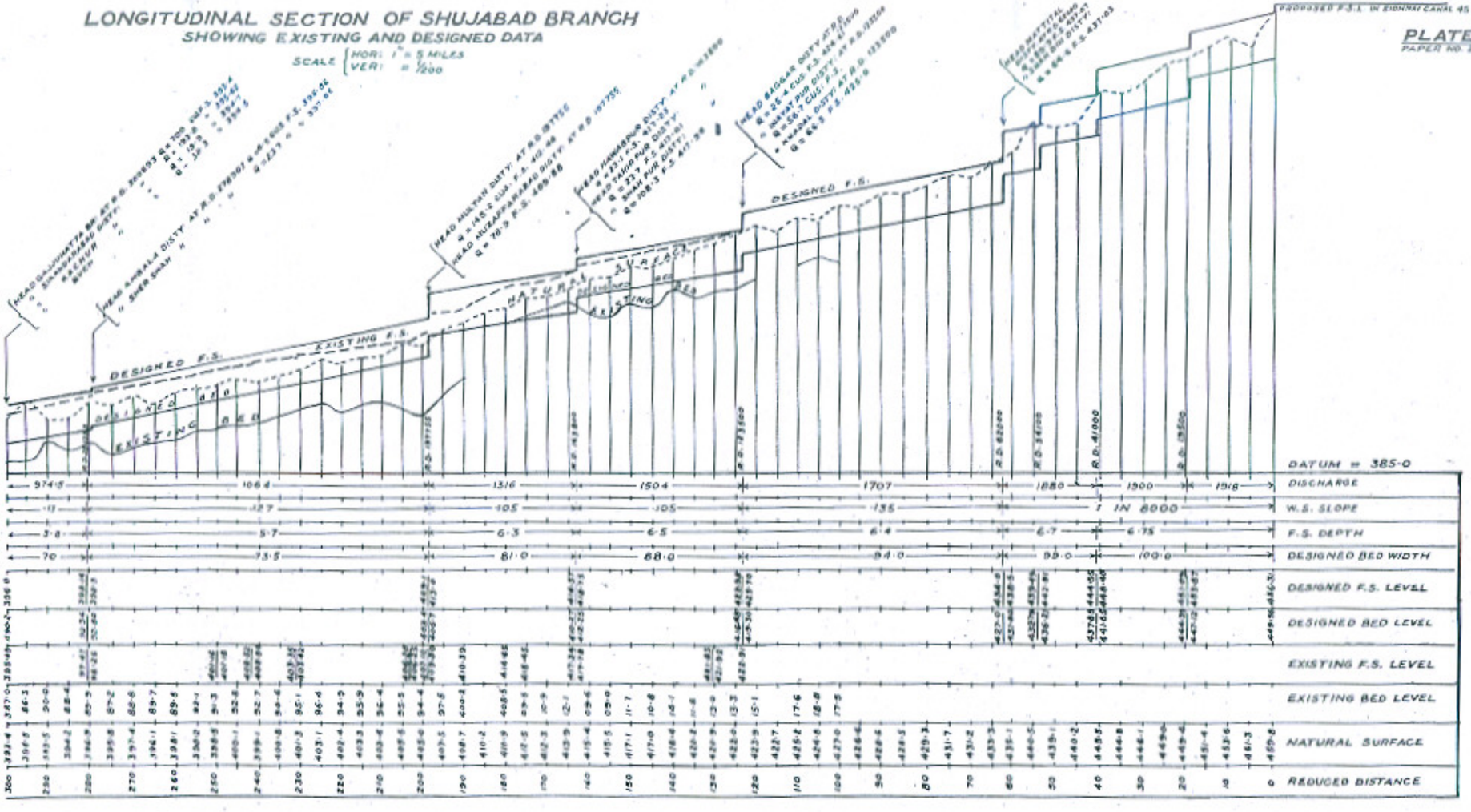


PUNJAB ENGINEERING CONGRESS
1940

LONGITUDINAL SECTION OF SHUJABAD BRANCH
SHOWING EXISTING AND DESIGNED DATA

SCALE { HOR: 1" = 5 MILES
VER: = 1/200

PLATE II
PAPER NO. 234



SHUJABAD BRANCH

REG: FALL AND V.R. BRIDGE COMBINED WITH HEAD REG: OF KHADAL (L) BAGGAR (R) AND INAYATPUR DISTYS:

SCALE = 1/500

DATA

SHUJABAD BRANCH U/S	SHUJABAD BRANCH D/S	KHADAL DISTY. L.	BAGGAR DISTY. R.	INAYAT DISTY. R.
1655	1051.0	61.5	30.0	53.0
93.0	83.0	15.0	9.5	14.5
6.4	6.3	2.5	2.1	2.5
425.63	422.93	425.01	424.63	424.7
13.23	416.63	422.51	422.53	422.2
SPAN OF 16' EACH = 5.5'		8.0	5.0	6.0
1.33 + 0.1 = 4.23		WITH RESPECT TO MINIMUM HEAD UP SUPPLY 2.35	WITH RESPECT TO MINIMUM HEAD UP SUPPLY 1.85	WITH RESPECT TO MINIMUM HEAD UP SUPPLY 2.26
3.09				
421.5		423.0	423.0	423.0

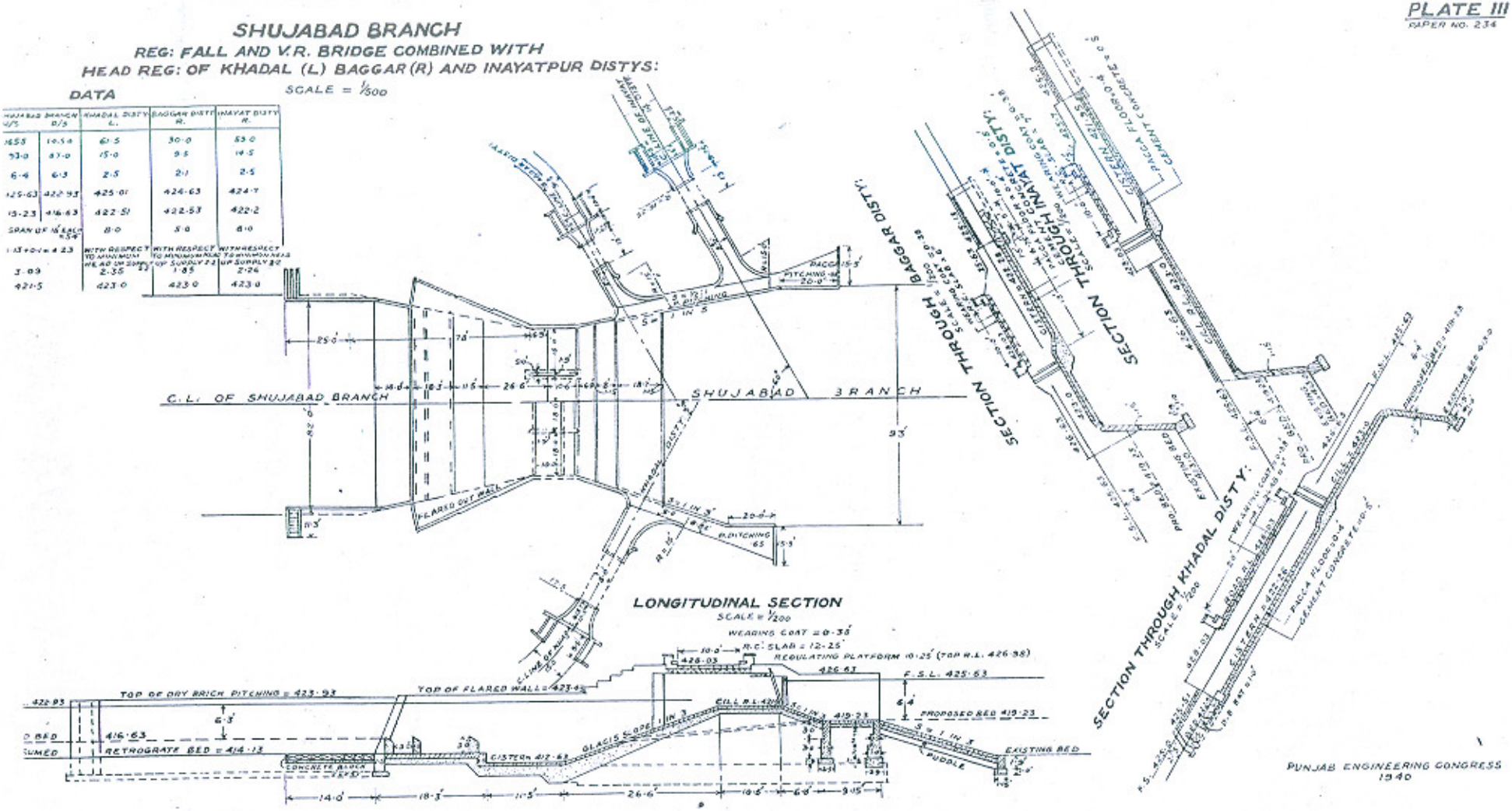


FIG. 1 TYPE DESIGN OF FALLS
FIG. A BELOW 3′ & FIG. B ABOVE 3′ FALL

FIGURE A

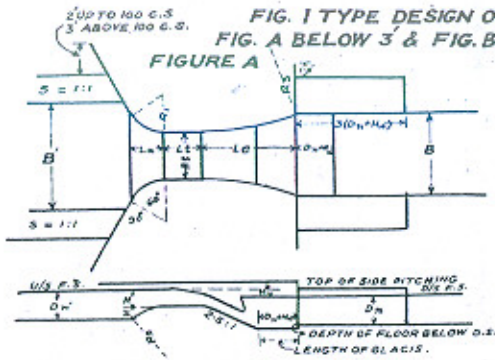
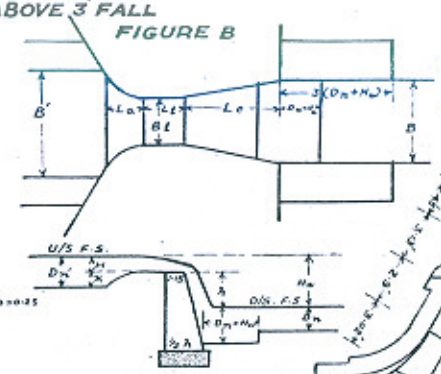


FIGURE B



Q = C × Bt × H^1.5
Bt = ·68
Lt = 2H
R1 = RADIUS FOR JOINING CREST WITH U/S FLOOR = 2H^1.5
X = HEIGHT OF CREST ABOVE U/S BED
R2 = (La² + X²) / 2X
LENGTH OF GLACIS 2·5:1 SLOPE
Le = 3(B − Bt)/2 OR GLACIS + CISTERN WHICH EVER IS GREATER
R3 = RADIUS OF EXPANSION = (Le² + ((B − Bt)/2)²) / (B − Bt)
LENGTH OF CISTERN = Dn + Hw
SIDE PROTECTION D/S = 3(Dn + Hw)
BED PROTECTION D/S = (Dn + Hw)

FIG. 3
HEAD REGULATOR & V.R.B OF KOTLI ADIL SUB MINOR

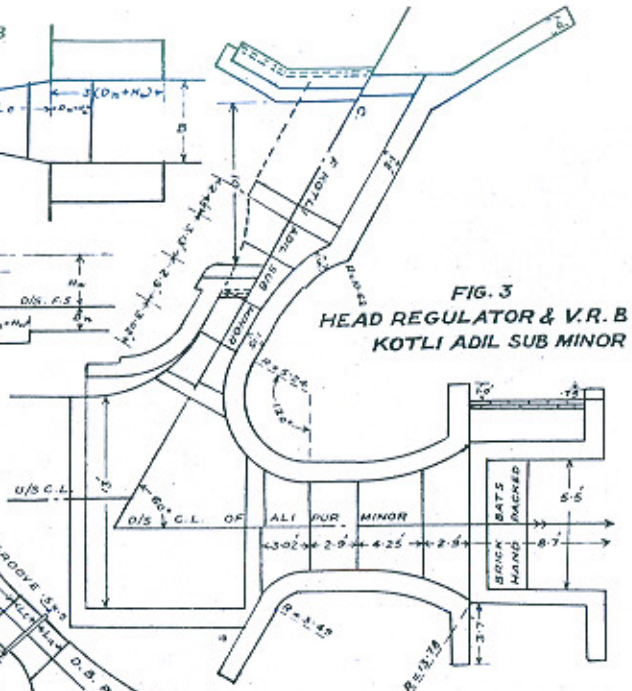


FIG. 2
TYPE DESIGN OF DISTRIBUTOR

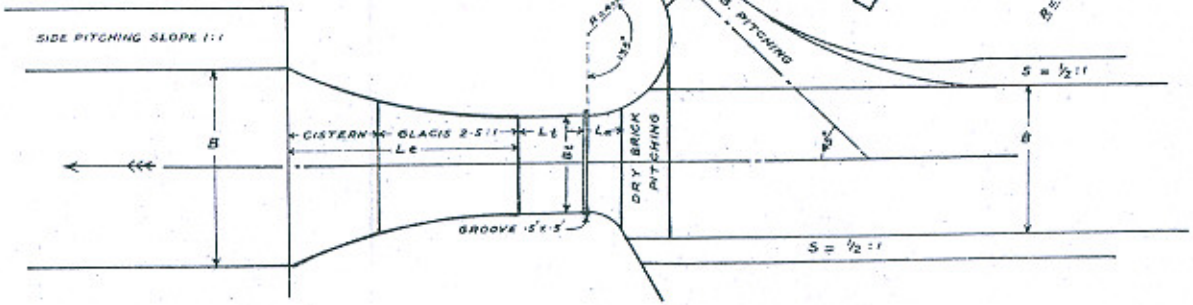


FIG. 4
TYPE DESIGN OF A.P.M. OUTLET BELOW 2′ F.S. DEPTH

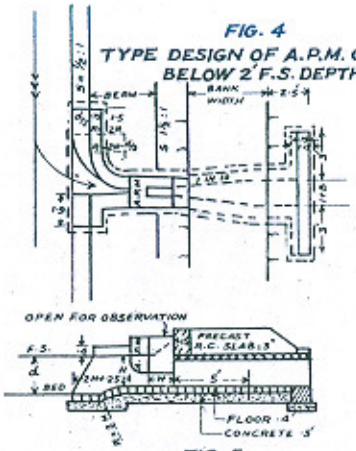
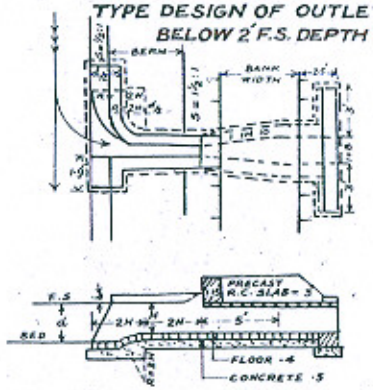


FIG. 5
TYPE DESIGN OF OUTLET BELOW 2′ F.S. DEPTH



DISCUSSION.

Introducing his Paper the **AUTHOR** said that it dealt with the latest methods of design and construction of modern irrigation channels as followed on the Haveli Project. This project was the first in the Punjab on which the design of works was entrusted to a Central Agency, resulting in uniformity, economy and speed. The actual methods followed in design and constuction had been explained in detail in the Paper and needed no further comments. The Author, however, stated the main features which were the use of Lacey's data in the design of channels (the limiting value of the silt factor being regulated by silt exclusion at the head of the main canal), the adoption of standard economic designs for masonary works, and the framing of chakbandi acceptable to the cultivators. It was explained to the cultivators that the scheme aimed at improving their lot and that the financial results of the project were only a secondary consideration. The working of the system during the first season brought home to the people the advantages of an improved system of distribution provided for them and there were spontaneous expressions of gratitude and appreciation from them.

To attain full supply levels in old channels which were comparatively wide and deep was a most difficult job. Temporary *daffs* of various types were tried with a partial success only. Finally a *pacca* type of *daff*, consisting of a two brick thick wall built right across the channel was evolved. In this wall holes were left giving enough waterway to pass the required discharge with the upstream water level kept at designed full supply level. This type of *daff* required no downstream protection, as there was practically no scour. These were very successful. The *imdadi* shoots allowed in reaches of low levels to start with were all removed, and designed levels were attained at all sites of outlets. Such heading up arrangements also helped in silting up the old and unproportionately big sections to new conditions with remarkable speed.

The Author further stated that the masonry works on the Shujabad Branch worked very well in the first flow season, and no damage worth the name occurred on any of them. In conclusion he remarked that the system had been an unqualified success.

Mr. Ishar Dass referring to the statement on page 103, 6th line from bottom, "Which for a discharge of 5,000 cusecs in the main line gave value of CVR as ·905" said that this value of C. V. R. had been arrived at by taking square root of $f=0.82$. Again on page 104—6th line, it had been stated "It was, therefore, laid down by the Chief Engineer that the whole canal system should be designed with $f=0{\cdot}80$."

These orders the speaker said had not been followed in the design of the Shujabad Branch, the data of which he exhibited on a black board. The value of f ranged from 0.801 to 1.057. There were abrupt changes from 0·936 to 1·025 and again from 0.899 to 1·057. He asked the Author to throw light as to why he could not stick to the values of f as ordered by the Chief Engineer. In the opinion of the speaker it was not possible to do so. By adopting a particular slope as the Author had done for different discharges, one value of f was not possible. Again by adopting a particular value of f for different discharges one could not get the desired slope. This was a great difficulty.

About eight years back the speaker had to face a similar difficulty when engaged in the remodelling of channels on the Lower Jhelum Canal. For a time he was in a dilemma. He studied the subject again and again, Lacey's diagrams and Kennedy's diagrams both failed him. He had great admiration for Lacey's equation $P_w=2{\cdot}67\sqrt{Q}$. But he found that the co-efficient 2·67 in the equation was not absolutely correct, and to get a zone of selection he plotted the equations $P_w=2{\cdot}5\sqrt{Q}$ and $P_w=2{\cdot}8\sqrt{Q}$ on Kennedy's diagrams and thus got over the difficulty to some extent. Copies of these improved Kennedy's diagrams had been supplied to many

Engneers. These diagrams also showed the curves of $\sqrt{f}$ and $\sqrt{R}$.

The speaker had derived a slope formula through a process of juggling with Lacey's formulæ and those of others, which was

$$S=\frac{Q}{32,000\ R^{1\cdot0}}$$

The formula purely from Lacey's data would be—

$$S=\frac{\cdot0167Q^{\frac{3}{2}}}{R^5}$$

Having fixed up the slope as the Author did, R, B and D for different discharges could be obtained from the improved Kennedy's diagrams. In this way the design of the Shujabad Branch was worked out by the speaker and elucidated on the black-board. The speaker then compared the two designs and stated that the original design was too tight.

Mr. Gerald Lacey—remarked that the Author was to be congratulated on a very interesting and useful Paper. He was very glad to see that the entire Haveli Canal had been designed by adopting the Lacey silt factor and the Lacey diagrams as a guide. The Author had referred to the grade of silt which it was proposed to admit to the canal, and this governed the entire design irrespective of the precise equations which might be employed.

In 1930 the speaker had put forward as a very rough qualitative formula for the diameter in inches of the predominant type of bed silt transported, the equation :—

$$f=8\ d''^{\frac{1}{2}}$$

in which equation d'' was given in inches. This was based largely on the conclusion of the speaker from the very scanty evidence then available that a silt factor of unity corresponded very nearly to a grade of bed silt of

0·40 millimetres. In metric units the equation could be re written

$$f = 1{\cdot}58\ m^{\frac{1}{2}}$$

in which 'm' was the diameter in millimetres.

Mr. C. C. Inglis had discovered some time ago, that the numerical constant in the equation required modification and had suggested the equations :—

$$f = 9{\cdot}4\ d''^{\frac{1}{2}}$$

or in metric units

$$f = 1{\cdot}86\ m^{\frac{1}{2}}$$

The speaker in Paper No. 233 had shown that the co-efficient varied, from 1·54 as a minimum to 2.13 as a maximum. The best fitting value was approximately 1·76 and that meant that the silt exclusion would have to be regulated in such a manner that the bed silt was not coarser than 0·22 instead of the 0·27 calculated by the Author. It would be found that the Bose equation, with a slope of 0·095 per thousand, and a discharge of 5,000 cusecs also gave a value of 0·22 millimetres.

There was, however, always the difficulty that for an assigned value of the bed silt grade, and an allotted discharge, the slope demanded might prove higher than the equation gave.

Thus the main line of the Lower Chenab Canal had a discharge of 4387·9 cusecs and a bed silt grade of 0·4108. According to the Bose equation that slope should be 0·168 per thousand. As a fact the slope was 0·200, markedly higher. If the speaker's equation was used the slope should be 0·170 per thousand. The example was admittedly extreme but it showed that whether the Bose equation or the Lacey equation was employed, large canals might demand bigger slopes than anticipated.

That meant that if—

$$f = k\ m,$$

was the general equation the value of k for main canals

might be as high as 2·00 and that was probably due to a heavy silt charge, or bed silt waves or both.

When designing new canals it was desirable for uniformity to employ a constant relation between the wetted perimeter and the discharge as given by the equation $P = 8/3\, Q^{\frac{1}{2}}$. When remodelling, it was obviously inadvisable to "cut up" well established sections in order to secure exact conformity. The constant might vary between 7/3 and 9/3 as extreme limits. The point to remember was that whatever value was adopted, so as to fit, the values of V, R and S must be selected to conform with the Lacey equations.

Mr. B. L. Uppal, referring to Appendix I, said that the following defects were noticed in the form :—

1. Year of approval of the design form had been omitted by the Executive Engineer and by the Superintending Engineer.

2. Discharge per 1,000 acres of C.C.A. was 4·8 cusecs. The significance of the figure 3·0 shown as denominator of 4·8 was not clear.

3. The section was changed very abruptly at R.D. 25,000 where there was no control point from 10·5′ x 2·2′ to 7·5′ x 1·9′. In other words bed-width was changed by 3·0′ and F.S. depth by 0·3 simultaneously.

4. Similarly, the proposed W.S. Slope was changed at R.D. 25,000 from 0·19 to 0·21 per 1,000, and at R.D. 26,800 from 0·21 to 0·22 per 1,000, without any control points.

5. A. P. M. outlets in the head reach were shown to have very good working heads. Their setting was 0·88, whereas it could have been 1·0.

6. Minimum Modular head for open flume outlets appeared to have been taken as 0·2H which should have been expressed in the heading of column No. 21. The heading should have been :—

M.M. head for A.P.M. ·75 *h*,
for O.F. 0·2 H.

The speaker continued that on page 117 it had been stated :—

"The Type Design for distributors issued by the Central Design Office was amended by K. B. Mian Iqbal Hussain for better silt distribution arrangements. The centre line of the downstream channel of the parent was shifted slightly towards the side away from the Minor offtake so as to give a larger area of influence to the offtake. The outer edges of the bed lines both upstream and downstream coincided."

The last sentence was not very clearly expressed. It appeared that by shifting the centre line to the right side or away from the minor offtake, the idea was that the right bed line upstream would be in line with the right bed line on the downstream of the parent channel. The speaker did not know how far this was justified or desirable, but he liked to point out that the design of the distributor was defective, as it provided unnecessarily greater width or sectional area at the distributor. Increase in area tended to lower the velocity (Discharge being constant), and hence there would be a tendency for the silt to deposit in the space between the two flumes, which would be liable to be sucked into the minor.

Continuing the speaker drew attention to the remarks on page 118 that the actual cost of the Shujabad Branch on completion would be about Rs. 6,25,000/- against the estimated amount of Rs. 20,41,647/- or a saving of Rs. 14,16,647/- and stated that much had already been said in the press, and on the platform about the tremendous savings effected by the Engineers in charge of the First Haveli Circle, and the officers of the Second Haveli Circle should not lag behind to show their achievements. The Speaker concluded by saying that the Project estimate with which the figures of actual expenditure were being compared was very inaccurate and unreliable and the Head of the Project should have seen that fairly correct working estimates were prepared.

Dr. N. K. Bose said that the only paragraph in this Paper with which he was concerned was design of channel on page 103. The Author had stated that the design of a channel depended mainly on the quantity and grade of silt in water. So far the Author was correct but when he proceeded to say "which determines the value of silt factor of Lacey" he was on very uncertain grounds. It had been found from regular observations on 42 Punjab Canals in regime that there was no correlation between d and f whatever value of f may be taken.

If $f=·82$ calculated from the discharge and the slope available, and $d=·27$ mm. calculated from $d-f^2/64$ (d means average diameter not a maximum diameter) were correct, then no silt exclusion was necessary at the Head as the silt available in the river at Trimmu had got an average diameter size of ·25 mm. The very fact that very elaborate arrangements for silt exclusion at the Trimmu Head had been made by the designers showed that in spite of Lacey they had a shrewd suspicion that channels designed on $f=·82$ would not be able to carry silts whose average diameter were smaller than those demanded by Lacey.

The Author had said that the same f was taken all over the system though the silt varied from 0·25 mm. in the Main Line, to ·15 mm. in the Ravi above Sidhnai and ·13 mm. in the Sidhnai Canal. The speaker asked the Author if he expected to run those canals in regime ?

Mr. Radha Kishan Khanna said that he had been told by a responsible officer that when on the hue and cry of the zamindars of the *illaqa*, the Deputy Commissioner of Multan went with the Executive Engineer on a visit of inspection to the Shujabad Branch, and enquired from him as to how it was that the crests of outlets were in many cases above the water surface level of the channel the Executive Engineer replied that they had designed the channel on the basis of a recognized theory of flow of water, so he was unable to understand why water would not rise sufficiently high to feed the

outlets. The speaker desired to enquire from the Author, if there was any truth in this statement and if so, all would be interested to know exactly how the mishap took place, and how it was that they had omitted to take steps beforehand to ensure that designed water surface levels were attained in the Shujabad Branch on the arrival of water in it. Did the zamindars lose a considerable portion of their sowing period because water would not flow through their outlets ?

As a matter of purely scientific interest, the speaker enquired, did they make observations of surface slopes and bed-widths, depths, etc., to find out values of '*f*' or C.V.R. before and after taking those measures, also how exactly did they calculate the values of *f* in cases in which the bed-widths and depths of channels were different from Lacey's particular bed-widths and depths, for any given discharge and surface slope ?

The speaker further stated that in his paragraph on design of channels the Author had calculated the value of '*f*' on the basis of the available fall and discharge of the canal. Main Line was a lined canal. Did the same silt factors hold good for earthen channels as for lined channels ? Also was it possible for them to design the whole canal system with $f = \cdot 8$? He remembered that Fazilshah, Kuranga and Abdul Hakim Canals taking off from the banks of river at Sidhnai, had been working to slopes which gave value of *f* of ·5 or so : and even with the proposed raising of the Sidhnai dam they could not attain a higher value of *f* than ·6 unless they cut out large areas from canal irrigation. Did they cut out large areas from canal irrigation, or did they content themselves with smaller values of *f* and wait for those canals to silt up ? Similarly he remembered that it was not possible to design Chaupratta disty. of Sidhnai Canal taking off near the offtake of Shujabad Branch, to the requisite value of *f*—What he wanted to know really was as to how channels with values of '*f*' lower than ·8 were behaving ? From the flat levels of the country he was sure that there must be some channels in Mr. Malhotra's division with values of *f* less than

·8 : and it would be interesting to know whether they were resorting to further silt exclusion at the heads of such channels or were the channels silting up for want of requisite slopes, or on account of lower values of '*f*' than ·8 ?

Another point of scientific interest was as to what possible effect the values of *f* of the Main Line could have on the values of *f* of the canal taking off from the River Ravi at Sidhnai. The value of *f* of the River Ravi in the straight reaches of four or five miles below the outfall of the Main Line, was in the vicinity of ·5. How was it, concluded the speaker, that they considered it necessary to design the canals taking off from the river with higher values of *f* than that in the river itself ?

Mr. G. R. Sawhney thanked the Author for writing a rather useful Paper concerning every day work of a Canal Engineer and said that the saving made in the remodelling of the Sidhnai Headworks showed that the spending of money was in safe hands, but he thought that the screw was tightened a bit too much in the case of the Shujabad Branch not being given a separate head regulator. The combined channel was sure to give a good deal of trouble and also cost a good deal in maintenance every year.

Reduction of working heads into the offtakes to 0·4' only was not the correct thing to do. Experience had shown that in case of high areas even outlets with 0·4' working head could not function properly.

The speaker said that every Engineer tried to design his channels on the principle of balancing depth if there was no other important factor against doing so. Radii for curves should not be fixed on the basis of discharge only. The nature of soil, the slope for which a channel was being designed in that reach, and the grade of coarse silt that water was likely to carry were the points which must also be considered before fixing radii ; otherwise the regime of a channel in reaches immediately above the curves, in the curves, and below these curves would be seriously upset. The speaker suggested

that a special study of effects of curves and how their radii should be selected to suit different conditions should be made by Engineers as well as the Research Institute.

Continuing the speaker said that the inter-spaces left between adjacent wells were very narrow and could not be filled satisfactorily with cement concrete. He further asked as to why the waterway below the fall at R.D. 123500 was kept so narrow when it was already expected that the designed surface level would not be attained for many years. The speaker considered that to keep the waterway practically equal to the designed bed was a step in the right direction. He did not think it was correct to allow the same stresses for Jhama ballast as were allowed for stone. For reinforced work, the concrete should not be mixed in batches of 25 to 30 c. ft. at a time, if proper mixing was to be ensured for each basket that was to be dumped.

The speaker objected to treating minors as outlets for the purpose of giving allowance for absorption. In practice some minors had bigger discharges than even certain distributaries. Hence the distributary with no minors had been too much favoured. In his opinion even sub-minors should be given some extra allowance if they happened to exist and the percentage of such allowance should be fixed for each channel which should be based on its section and slope. Notwithstanding the fact that experience had shown that narrow flumes were not too good, distributors had still been made on the narrow side.

The speaker considered that the adoption of 0·2 H as M.M.H. for open flumes was on too low a side, and this was sure to cause trouble in the case of outlets with high area and at the tails of channels. He was further of opinion that C for open flume outlets should have been fixed as per Chief Engineer's latest orders and not 3·0 for all such outlets irrespective of their B.

The speaker concluded by saying that the Paper no doubt clearly demoustrated how well the *bandobast* and design for these works had been thought out and how

ing to some two years previously without any modification of the head regulator or outlets on the channel.

It was stated that practically on all channels both old and new modular outlets had been constructed from the very start. This was a departure from the old practice of first putting in pipe outlets when the channels first start functioning. This would have been all right if it was certain that the slopes adopted in design were actually going to be attained. If designed slopes were not attained in actual practice, it would soon be necessary to adjust the outlets. On channels of the S.V.P. which were being remodelled after running for over 12 years, the orders were that the outlets were to be constructed after observing the actual water surface levels obtained by running the exact discharge at each point. Thus on the S.V.P. channels which had been running for a number of years the designed water surface levels were not being depended upon. It did not therefore seem sound policy to construct *pacca* outlets on channels about the running of which there was lot to be yet determined.

In conclusion he enquired from the Author if actual hydraulic data of the channels was observed after running, and if so how did the observed water surface slopes compare with the designed slopes.

Mr. B. S. Talwani said that Mr. Malhotra had contributed a very instructive Paper from the practical point of view. He requested him to elucidate a few points :—

1. Under the head Design of Channel, the Author had stated that it was laid down that the whole canal system he designed with, Lacey's $f = 8$. This was possible only for the new channels. With the old channels which were running for the last so many years, and which had to be remodelled to the new capacities, it was necessary to study their prevailing slopes, discharges and cross sections and then find out theoretically what was the value of Lacey's f with which they were actually working. These channels should then have been designed with that prevailing value of f, and in their case at least

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it would have been certain that they would work as designed. The Author had said that in reaches of old channels, which were too big for the new discharges, value of '*f*' was kept below ·8.

In the Shujabad Branch a new channel was dug from R.D. 62,000 to R.D. 100,000 and an old channel was used from R.D. 100,000 to R.D. 125,000. Thus in the reach 62,000 to 125,000 two values of '*f*' were adopted, *viz.*, ·8 from R.D. 62,000 to 100,000 and ·6 from R.D. 100,000 to 125,000. It had not been made clear how these two values would work in one and the same reach and further how the value of ·6 for *f* was obtained. Did the channel actually work to these values ?

2. The most important work on the Branch according to the Author was the regulating fall at R.D. 123,500. The designed bed of this fall was above the existing bed 6 ft. on the upstream side to 4 ft. on the downstream side. The spring level was very high. It was practically at existing bed level at the time of construction, and must be higher still in summer. From a study of the design of this work one felt that something was lacking. The upstream curtain wall was sufficiently deep, but the two curtain walls between which sand filling was done were not sufficiently deep. One wall was only 1·25′ below existing bed *i.e.*, even the whole depth of concrete was not boxed below bed. The second wall was only ·75 ft. below the bed with similar condition. As regards the downstream side there was no deep curtain wall at all, which was rather dangerous for the whole work.

The speaker had seen that on the distributaries of of this very branch, where the retrograted bed was lower than the designed bed, and where the downstream curtain walls of the falls were not sufficiently deep, the whole of the curtain wall and downstream floors were damaged. It was once found on Khanwah Branch where a bridge only and not a fall was built on retrograted bed without sufficient depth of downstream curtain wall, that after the first supply the downstream floor and

curtain wall were damaged. He asked the Author if this work was ever examined afterwards by unwatering and with what results.

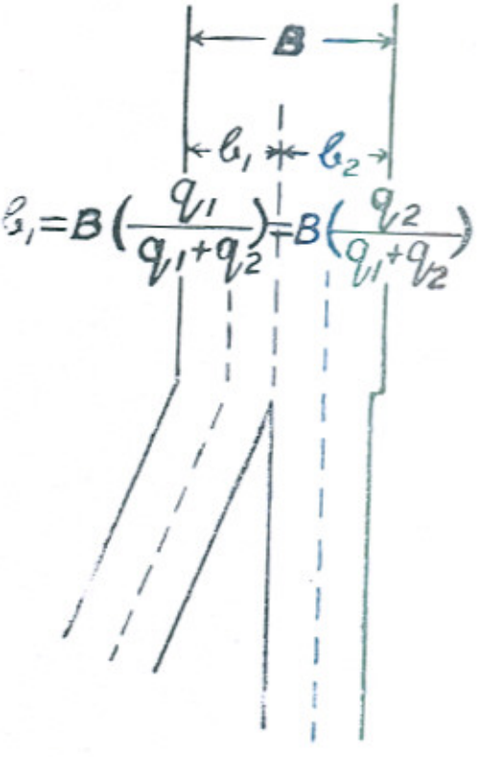
3. The bridges on distributaries had been designed using *pacca* brick ballast as aggregate. The stresses allowed were the same as for stone ballast, *viz.*, 16,000 lbs. per square inch and 750 lbs. per square inch. This was false economy. Fortunately orders had been received not to use brick ballast at all in future for R. C. work. But even if brick ballast was used, the stresses assumed should be for brick ballast.

Tests were carried out in the Thomason College Laboratories at Roorkee by Prof. Bradshaw Smith for comparing compression of R. C. concrete made of stone ballast and coarse river sand and that made of brick ballast and silt from distributaries. This silt of course contained a major portion of fine sand, the sort of which is obtainable in pits in the southern districts of the Punjab. His conclusions were that for the same strength as was required from stone ballast and coarse sand, a beam made of brick ballast and very fine sand would require 25 % more materials and would actually need less steel. As a rough rule he concluded that brick ballast beam if designed with 30 % additional depth keeping the same quantity of steel would be equivalent in strength to an ordinary R.C. Beam.

4. The most creditable part of the construction was that the Shujabad Branch with a discharge of about 2000 cs. was run to full supply level within about two months of its opening for the first time. This was really remarkable, for which all concerned deserved praise. The non-perennial channels were running upto the end of October. The zamindars who were very much discontented in the beginning of the season as they were not sure of the results of remodelling and hence had refused to take canal water were totally satisfied in the end. They had never received water supply for such a long period in any season previously. This showed the great success achieved.

Mr. Kanwar Sain said that Mr. Malhotra had done useful work in collecting together in this Paper the various instructions issued from time to time by the Central Designs Office regarding design of channels and masonry works on the Haveli Project. His only grouse was that he had exposed the Central Designs to criticism on a public platform without offering the Central Designs a chance of scrutinising the Paper beforehand. If this had been done, some of the statements made in the Paper might have been deleted. Also some alterations had since been made in the general instructions regarding the design of distributaries and falls as a result of the experience gained on the Haveli Project. These should have been incorporated in the Paper to make it more useful. Under design of channels where the Author talked of 'maximum size of silt' it should be 'average size of silt.'

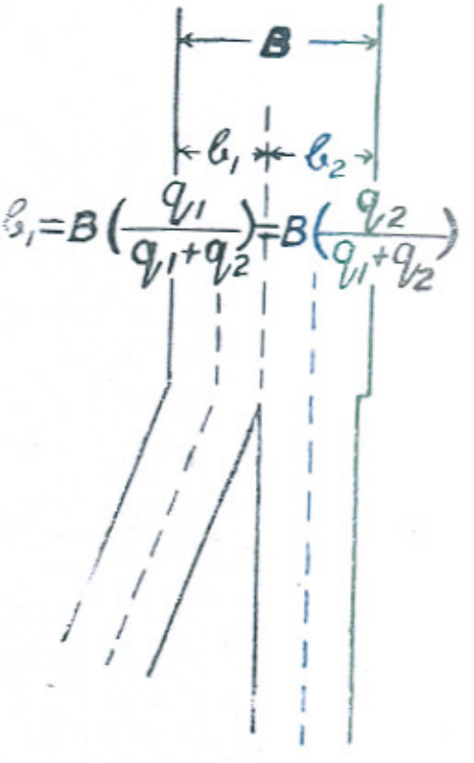
On page 103 the Author had made a statement that the extra cost of providing a separate channel would have been only Rs. 20,000/- a negligible sum as compared to the total cost of the Branch. He had further stated that the suggestion was, however, not accepted by the Chief Engineer. Having been connected with the scrutiny of proposals in the Secretariat the speaker pointed out that there was no authority in the Secretariat files for the statement referred to above The extra cost of providing a separate channel might have been many times more than that stated by the Author.



Regarding the error in the value of H_L referred to by the Author on page 110, the speaker stated that the method prescribed in the instructions was somewhat arbitrary, and as such, the question of error referred to

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Regarding the error in the value of H_L referred to by the Author on page 110, the speaker stated that the method prescribed in the instructions was somewhat arbitrary, and as such, the question of error referred to

by the Author did not arise. The alteration in the design caused by accepting the Author's suggestion would be entirely negligible and of no practical value.

On page 117 the Author referred to an amendment made by K. B. M. Iqbal Hussain for better silt distribution. This, however, was a question which would depend on the alignment of a channel. The best distribution would be that the upstream bed-width of the parent channel be divided in the ratio of discharges and the centre line of the channel downstream of this point should be the centre line of this part width as shown in the sketch.

On page 118 the figures quoted by the Author for comparing the actual cost of the Shujabad Branch with that provided in the 1935 Project were misleading. The figure provided in the 1935 Project estimate included the cost of a separate channel from headworks to the present offtake of the Shujabad Branch. The cost given by the Author did not include even the cost of the extra widening of the Sidhnai Canal in the first few miles. Thus the two figures were hardly comparable.

On page 121 the Author in conclusion had thanked various officers in the II Haveli Circle. The speaker asked if the Author had written the Paper only with the intention of arriving at this conclusion.

As the speaker was responsible for the design work he attempted to reply to the various objections raised by the speakers.

Mr. Ishar Dass had pointed out that value of f on the Shujabad Branch varied from 0·8 to 0·9. In excavation reaches a higher value of f was deliberately adopted in order to reduce the cost of earthwork. As the lower reaches of Shujabad were adapted from old inundation channels, they were wider and deeper and required a lot of silting up to bring them to the designed section. In this way considerable saving was effected.

The beauty of Lacey channels was that for all values of 'f' varying within a reasonable range the bed-width

was pretty constant. It was only the slope and the depth of the channel that varied. If the channel had been designed to Lacey sections, slight variation in values of '*f*' would not affect the position of banks or the bed-widths. Dr. Bose had pointed out that the authorities responsible for the design on the Haveli Project were not sure of their design as they had provided a silt excluder in the pocket and two silt ejectors at the head of the canal. The provision of these measures in the first instance involved comparatively a small amount of expenditure. Any alteration at a later stage would have naturally involved a much bigger sum. The speaker pointed out that the art of silt exclusion had not yet reached the stage of cent per cent confidence. Some basis was adopted and silt ejectors were provided as an extra precaution.

In reply to Mr. Sawhney the speaker stated that stresses in Jhama brick concrete were based on Blaker's experiments. Mr. Blaker had carried out a large number of experiments at Rasul School of Engineering to determine such stresses.

In reply to Mr. Moti Lal Aggarwal he stated that the value of '*f*' for main line and branches and minors varied on account of unequal distribution of silt. If a perfect system of distribution of silt could be assured in all channels the same value of '*f*' could reasonably be used for the whole system. It was, however, suggested that there were some channels on each system which could digest more silt and these might be provided with such Head Regulators as would draw more than their fair share of silt. These channels should be designed to a flatter slope than could be adopted generally on the system. To enable them to run to a flatter slope it would be necessary to provide them with a suitably designed silt selective head.

On the Haveli Project the design of A.P.Ms was such that the discharge could be varied within a reasonable limit by adjusting the roof block of the A.P.M. The advantage of fixing A.P.Ms in the first instance was

that the usual objection of the cultivators to the change in the type of the outlet was eliminated.

The Author in replying to the discussion said that R. S. L. Kanwar Sain, was mainly responsible for all the designs and had therefore replied to most of the objections raised by the members.

In reply to Mr. Ishar Dass, the Author said that variations in value of '*f*' had intentionally been made to avoid excessive diggings downstream of falls and to give steeper slopes to develop scouring velocities in such reaches. Mr. Lacey had in the discussion further elucidated the relation between his silt factor and diameter of silt entering the canals. The design of the system under discussion had however been based on Mr. Lacey's original equations.

In reply to Mr. Uppal, the Author said that the design form as presented had been used on the entire Haveli system. Regarding the defects pointed out he replied as follows :—

1. Year of approval would be needed only in future remodellings and could be introduced when necessary. The present was simultaneous remodelling of the entire system.

2. As the form was applicable to all channels, in the printed copy 4·8 applied to non-perennial and 3·0 to perennial, channels.

3 and 4. The changes in section and slope were rather big and could certainly be eased out. The Author thanked Mr. Uppal for his valuable suggestion.

5. The setting of A. P. Ms had been limited by the Chief Engineer to a maximum of 0·9 and ·88 practically coincided with that.

6. The form could be improved by addition of M. M. H. for open flumes, but full instructions on design of outlets had been issued by the Central Design Office as stated in the Paper.

7. Regarding the design of the distributor the waterway upstream was not increased and the centre line of the downstream reach of the parent was shifted. There was thus no likelihood of silting as pointed out by Mr. Uppal.

Regarding the savings, the Author said that as stated by Mr. Kanwar Sain, a greater part of the seemingly high saving was due to shifting of the Head of Sidhnai, and with it that of the Shujabad Branch to the existing Sidhnai Head Works. This had been omitted by the Author through an oversight.

Regarding Dr. Bose's remarks the Author agreed that in the equation $d = \frac{f^2}{64} d$ means the average diameter and not the maximum. Regarding the lower grade of silt in Ravi, the Author said that the channels had to be designed on the basis of Chenab supplies from Trimmu which was the main source for these channels. Finer silt of Ravi for a few months in the year could not upset the designed data appreciably. That appeared to be the idea in laying out principles of design for the Haveli System.

In reply to Mr. R. K. Khanna, the author said that as explained in the opening remarks the main problem was to head up supplies in the old inundation canals and effective steps had been taken in time to avoid loss to irrigators. It was yet too early to observe hydraulic data of these channels, and the only information available at the time was that channels were working fairly satisfactorily to designed data and distribution was as desired.

In reply to Mr. Sawhney the Author said that on channels with low working heads, silt excluding head regulators had been provided. The interspaces between wells were just wide enough to admit of effective filling with cement concrete up to the bottom. The absorption allowance for minors, by treating them as outlets was quite liberal and reasonable. Sub-minors had been similarly treated. The M. M. H. for open flumes was

suitable for the type design used and value of C as 3·0 for all open flume outlets was quite suitable as B was limited to a minimum of ·2′, up to which this value was true.

In reply to Mr. Aggarwal, the Author said that his points had been answered by Mr. Kanwar Sain. Further, the value of '*f*' in old reaches had been lowered, as for some years to come, such reaches were bound to run with very flat slopes and adhering to higher '*f*' would be misleading. These values were close to existing values of '*f*' for such channels. Actual hydraulic data had not yet been observed, but levels on distributaries showed that designed conditions were generally suitable.

Regarding the points raised by Mr. Talwani, the Author said that value of '*f*' as low as 0·6 had not been adopted in the Long. Section anywhere. This value had been assumed for calculating retrogression below the fall R. D. 62,000, as the reach from R. D. 100,000 to 123,500 the next control point—consisted of an old inundation channel with bed 6·0′ below the present designed, and with three times the new bed-width. This assumption therefore was justified in calculating level of retrogression for this fall. The fall at 123,500 had worked very successfully, and there was no damage worth the name to the masonry portion. The only trouble was side scour below the downstream dry pitching as stated in the Paper.

In reply to Mr. Kanwar Sain, the Author said that he had an idea of getting the Paper scrutinized by him before submission but lack of time was responsible for this omission, which had unfortunately resulted in the latest improvements in the instructions for designs being left out. Regarding the extra cost of a separate channel, the figure quoted by the Author was certainly very rough and low as no detailed estimates had been worked out. Regarding the amendment in the design for distributors, it practically agreed with Mr. Kanwar Sain's suggestion and the shift in the downstream centre line was practically the same as proposed by him. In the figures quoted for savings, the cost of extra length in the original

estimate should have been deducted for the sake of comparison. Regarding the concluding paragraph of the Paper, the Author explained that by "conclusion" he meant concluding remarks or acknowledgments and not the inferences drawn from the Paper. In the end the Author thanked R. S. L. Kanwar Sain for the promptness with which designs for works were supplied, which resulted in their timely completion.