Paper No. 330

Working the Right Bays of Balloki Barrage

By

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Introduction :—

Balloki Headworks stands across the Ravi River at 41 miles from Lahore where two canals take off namely, the Lower Bari Doab Canal, which along with the Barrage itself was completed in 1913 and forms one of the 3 constituents of the Triple Canal System, and the B.S. Link, which is an after partition project and was completed in April; 1954. Balloki Barrage has 35 bays each of 40'0, span with a pier thickness of 7'25 ft : The Barrage piers also carry a single lane road bridge Warren Girder type which provides an important link between Montgomery Bhai Pheru and Mangtanwala Lyallpur road.

On the U/Stream side the river approaches the head-works between the two right and left flood embankments. From the flood embankments protrude spurs, eight in number, which have helped in keeping the water edge away from the flood embankments in the past. They have been numbered according to their age and their position is clearly shown in the plan attached as figure I.

One spur also stands on the D/stream side which was constructed to keep the river away from the Main Line of L. B. D. C., and is named spur No. 7, being 7th : in the series of spurs constructed.

More than half of the right side of the Barrage had heavily silted up over the past many years and a high bela had been formed opposite bays 15-35.

More than half the Barrage was thus practically out of action. A number of attempts were made to work up the right side which proved abortive for one reason or the other.

This paper deals with the methods and means with which this problem has finally been overcome and the principles of design and

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execution under-lying the same. It further discusses the extent to which the new methods after execution have been successful in putting the right bays back into action.

Brief History :—

The formation of an Island opposite the U/S right side of the weir and efforts to wash it away range as far back as the year 1918-19 when an attempt was made for the first time to wash away the Island by digging a diversion cut through it but as there were no floods that year it did not prove to be a success. Ever since the construction of the Headworks in 1913, the river stream showed a tendency to hit the left bank and therefore the U/stream left guide bank continued to be under heavy attack during every flood season. The U/stream left guide bank was originally made 1100′ long parallel to the wings and then splayed at 1 in 5 for 900 ft : The river channel was guarded by 4 spurs placed two on each side of the flood embankments i. e., Nos 1 & 2 on the left side and 3 & 4 on the right side.

The idea was to direct a straight approach of the river on the weir but this did not serve the purpose and the channel continued to hug the left bank thus bringing the U/stream left guide bank under action. This continous drifting and deepening of the channel on the left resulted in the silting up of the channel opposite the right bays which gradually developed into a large bela masking the right side of the barrage.

Since severe action on the head of the left guide bank persisted during every flood season proposals were put forward to link up by a bund the U/stream left guide bank with spur No. 1, and thus to check the tendency of the river to work behind the former which had been apparant during the previous flood seasons. By 1923 this work of extending the guide bund had been sanctioned and completed at a cost of Rs. 81563/-

Since nothing materially was done to check the bela and shoal formation on the right and instead attention was paid to maintain the left guide bank against the attack of deep river channel on the left, the bela continued to form into an Island locking the entire right side of the Barrage. During the flood season of 1926 Mr. N. Gopal I.S.E., attempted to erode this Island which masked more than half of the barrage on the right side by drawing the flow as far as possible to that side with proper gate regulation of the barrage.

This naturally resulted in a severe cross flow in front of bays 17-20 as the bela edge then stood opposite these bays and it was anticipated that the floor there might have been damaged but during closure no damage was located, By 1929 this bela had become a permanent feature at Balloki Headworks and had put the right bays of the barrage quite out of normal action. Due to the progressive growth of this bela river action on the left U/s guide bank continued to increase.

In Nov : 1920 the Chief Engineer decided that no effort should be made to remove the bela masking the right half of the barrage or to clear it of jungle and ordered that the standing orders prescribing the section of the apron along the left U/s guide bank be reviewed to determine if they provided adequate section of the apron in view of additional river action on that bank owing to the presence of the bela. Finally 20 ft : width of the apron with its top R.L— 623·0 was laid down to be maintained.

In the year 1930 apron was widened from R. D. 2200 to 2550 and again from R.D. 2550 to 2850 under orders of the Chief Engineer.

The total width of the apron was made 66·0′ with a thickness of 3·0′ at the toe of slope and 5·0′ at the river end.

By 1931 the bela U/s of the barrage and on the right bank of the river had gradually grown up to R.D. 4000.

By 1933 this bela had extended up to R.D. 7000 and continued to extend further into the river channel thus pushing the river further towards the left U/S guide bank. In 1941 the main channel so developed on the left was taking over 95% of the discharge when Mr. K. A. Ghafoor I. S. E., the then Executive Engineer of Balloki Division again dug a leading cut through this bela in an attempt to work up the right bays. This action taken during 1941 proved to be a very timely one because the super flood of 133000 Cs (barrage has been designed for a discharge 139500 Cs), the highest over recorded till then, was received on 24·8·42., and a part of this discharge was passed from the right side through this cut. This high flood also washed away a good portion of the bela U/S of the barrage forming a regular channel on the right side.

During the subsequent months, however, this bela was reformed making the position same as before.

Another attempt of a similar type was made again in 1954 when a cunette was excavated in the bela U/s of the barrage which connected it with the natural depression below spur No. 3. During floods of the year 1954 this cunette did develop but during falling river supplies it silted up again leaving the position same as before.

Model Experiments for Improving River Approach :—

This problem had turned into a serious one as the inactivity of the right bays amounted to the cost of half of the barrage being wasted and incurring of additional expenditure due to frequent damages of the left side which had to bear the strain of that porition of discharge which normally would have passed through the right side.

The problem was further aggravated with the construction of B. S. Link regulator designed for a Max : discharge of 15000 Cs. Since the main river channel approached the left guide bank and then hugged along it before feeding L. B. D. C. it was feared that with a concentration of flow on the left side persisting and with the construction of B. S. Link Head Regulator and a consequent increase in the discharge of off-takes to over 22000 c s under F. S. conditions, the river channel would further stabilise there and heavy action would occur at or above the new regulator, more especially when the B.S. Link regulator had been set back by about 110 ft : for facility in construction.

It was therefore, dceided to conduct model experiments at the Research Institute.

In order to improve the general approach conditions to the weir such that keeping the main channel and curvature of flow on the left side as it is even now, some relief could be afforded by decreasing the concentration of flow on the left. This could be achieved, by diverting a part of the flood discharge on the right by artificially bifurcating the currents at some point upstream while—maintainance of the curvature of flow on the left side was considered necessary to avoid excessive silt entry into the Canal.

The problem was tackled in two ways (1) by shifting the position of the head of spurs No. 1, 2, 3 and 4 to improve general approach condition to the weir so that at higher discharges we could divert more of the flow toward the right enabling it to erode the bela and straighten the flow to some extent to the weir (2) By construction of a Pitched Island with a cut through the bela on the right. By diverting a part of the flow to the right in higher flood it would relieve concentration on the left though the main channel would still remain on the left side.

The Model :—

The model of river Ravi comprised about 3 miles stretch of the river above weir.

The Balloki weir along with the B. S. Link Head Regulator was constructed on a scale of 1/500 horizental and 1/25 vertical as shown in figure 2. River hydrograph for the year 1950 was selected for tests.

Experiment No 1 :—

Improving river approach by shifting position of the spur heads:— The following changes in the position of spur heads were tried in the Research Institute with a view to spreading out the flow more towards the right during the floods.

(a) Original position of spurs as shown in figure 1.

(b) Spur 1 & 3 at original position, spur No. 2 advanced by 500 ft : and spur No. 4 receded by 500 ft :

(c) Spur No. 2 advanced by 300 feet : Spur No. 3 receded by 150 feet and spur No. 4 receded by 300′

(d) Spurs 1 & 2 advanced by 500′ and spurs 3 & 4 receded by 500.′

The following results were achieved :—

Original Position of Spurs :

The current direction showed a heavy concentration of flow along the left side with practically no straight current on the right side in all the 3 cases of low, high and super high flood discharge.

Tests on Shifting the Position of Spurs.

In the 2nd : series of tests in which spurs No. 1 & 3 were kept in original position and 2 and 4 advanced in series, the current direction showed no appreciable change in either the flow or the general bed configuration.

In the third series in which spur heads 2,3 and 4 were shifted the concentration still kept towards the left, rather it got more towards the left guide bank.

In the 4th : series with spur No. 1 & 2 advanced and spurs 3 & 4 receded it showed the current concentrated to the head of B. S. Link. It also showed a tendency for spurs No. 1 & 2 to cause more action with little improvement in the general approach to the weir.

Experiment No. 2 with the Pitched Island.

It was contemplated that if a long Pitched Island was constructed at such a position that bifurcation would occur at the Island diverting a part of the flow in high floods on to the right, some relief in concentration could be achieved on the left side.

In the 1st series of tests under this head an Island semicircular in shape with a chord length of 500 feet was constructed near the edge of the channel on the centre line of the weir, a little above the nose of the right guide bank.

A cut 50 feet wide and about 2 feet lower than the crest of the weir was made. Flow conditions with low, medium, high and super high flood discharges were examined. It was seen that at higher discharges bifurcation did occur though the main channel remained on the left.

The configuration of the bed, however, showed that the development of the cut was not satisfactory, in fact the cut silted up considerably.

The development of the cut to enable it to take appreciable discharge can take place only in the initial stages of the rising discharge. In this case water can be passed on the right by closing the river channel on the left side in the rising stage of the river. It was therefore considered essential that a temporary bund starting at the back of the pitched island and connecting it with the left side guide bank be constructed to force supply through the cut on the right side in the initial stage. The bund was considered necessary to be maintained up to 20000 cs, only. But since the maximum off-take discharge of the two canals when running full supply was about 23000 cs the construction of this bund meant that the river discharge would first pass through the cut and in developing it, would pick up lot of silt. The model showed that this silt remained in suspension and the silt laden water passed into the canals through the canal regulators. The silt entry into the canals thus remained more than twice that under normal tests. This proposal of constructing the temporary bund was therefore dropped particularly when silt entries into the canals could not be decreased by suitable regulation alone because the effect of it was not felt right up to the Pitched Island.

Experiment No. 3 with a Pitched Island and a Bund Linking it with the Central Pier of the Weir.

As a natural corollary to the above experiment, a new test was planned with a pitched Island having a bund connecting the back of the Island with the central pier of the weir, thus divding the river into two portions. This proposal was considered to have the following advantages.

(i) The channels on the left side and right side could be developed at will.

(ii) The effect of regulation would extend right up to the Pitched Island as the connecting bund would prevent any water from the left side of the weir going to the right.

Instead water would come from above around the Pitched Island. This scheme would therefore make the regulation of the weir more effective.

(iii) Past investigations have shown that a Pitched Island can function only if strong water currents are made to hit against it, otherwise away from the control works in a high and dry spot it can never function properly. The shank of this Pitched Island would ensure strong currents and flow around the Island Head by extending the effect of regulation up to the Pitched Island and thus allowing bifurcation to occur at the Island Head itself.

(iv) Having bifurcated the flow at the Pitched Island it could be possible to maintain correct curavature of flow towards the off taking canal so that they could take off on the outer curve to reduce silt entry.

(v) The two channels of the river flowing between the shank of the Pitched Island in the centre and the two unerodable guide banks on either side would become more stable.

Tests for different positions of the Pitched Island with its shank and a cut on the right were tried. In the first run the shank was made to breach at 3000 cs: discharge but this resulted in a silting up action behind the Pitched Island. In the second run the position of the Island was shifted downstream by 200 ft : and the closing bund or the shank was not breached so that two independent channels could be maintained, one on either side with the bela in the centre. In this test the head across the link bund or shank was kept limited to one foot. Two bays on either side of the shank were kept partially closed even at high discharge. The weir bays were kept closed and the supply was let into the B. S. Link and L.B.D.C. till when the discharge exceeded their requirements where after the balance supplies were passed through the right side to develop the cut. The regulation was done so as to keep the head across the shank of Pitched Island one foot or under. It was noticed that although the main channel above the Pitched Island remained on the left side a channel did appear on the right with the development of the cut. Another point to note was that under the above worst conditons with main channel completely on the left discharge in the ratio of 2 : I only could be passed on the left and right sides respectively. This however, could be increased if the head across the shank or link bund was made to exceed one foot. Velocity observations behind the Pitched Island and along the shank showed that the shank was subjected to high velocities only for a length of 600 feet above the barrage where it had to be protected, and the remaining 700 feet out of its total 1300 ft : length could remain unprotected where action was not considered to be severe.

The test also showed that silt going into the canals was excessive in the first season due to erosion at the Pitched Island but in subsequent years it would not be more than the normal silt entry experienced.

Hence from all these experiments it was finally concluded that the best measure, which perhaps was the only sure method to maintain two channels, one on either side and the bela in the centre, was to have a Pitched Island connected with a shank to approximately the central pier with a cunnette on the right side of the barrage. The position of the Island and the shank is shown in figure :— 2

Construction and Programme of Execution :—

The Upstream floor of the barrage had suffered heavy damage during the unprecedented floods of the year 1954 and 1955. This had been mainly due to the heavy concentration of flow passing through bays 1-14 as a results of the absolute inactivity of the remaining 21 bays on the right owing to the presence of the bela in front of them. Twice in successive years the government had to bear a colossal expenditure in repairing the upstream floor of the baarage. Therefore it was only natural that proposals in the light of findings of the model experiments were pushed through as early as possible, in order to avert dangers similar to those experienced in the past two years, before the first flood of 1956, arrived.

It was proposed to construct a bund with a top width of 15 : feet: and top R.L. of 638·5 i.e., 3 feet above the flood level of 1955 flood (635·5). Although the designed H.F.L. with afflux U/S of Balloki Barrage is 637·0 it was considered safe enough to provide free board over the 1955 flood level rather than the designed H.F.L. The bund was given side slope of 2 : 1 as usual and was proposed to be 1500 ft : long. The pitched island itself was proposed to be semicircular in shape with a base of 400 feet: and a radius of 200′

The length of the shank itself was thus 1300 feet, out of which 600 ft: length from the barrage end was proposed to be protected on both sides. Therefore a loose stone apron 30 feet wide with an average depth of 4·5 feet on both side of the bund and an apron width of 50 feet: all along the nose of the semicircular Pitched Island were provided in the design and estimate to check up a constant heavy attack on both. It was also decided to provide both sides of the shank with stone pitching 2·0 ft : thick in the 600, ft : length from the barrage end as per standard design of spurs i. e., 1·3 stone over 0·7′ thick spawl.

A counnette 50 ft : wide was also proposed to be excavated with its bed R.L. at 622·5 i.e., about the same as the crest level of the weir. A Plan showing the position of the Pitched Island with its shank and a cunette on its right is attached as fig: 2. A typical cross section of the bund is also showin in fig: 2

It was not till May, 1956 when approval to start this work was obtained which left a very gloomy picture regarding the completion of this work before the coming flood season because there was every possibility for the first flood to arrive as early as the end of June. Nevertheless, the work was started with our bid to complete it before the first flood on-slaught and by early June 1956 the progress was in full swing. Most of the labour available was employed on the work of "Repairs to Upstream floor of Balloke Barrage damaged by the floods of 1955" while the rest worked on the work of "Repairs to Upstream left guide bank" as the stone apron of left guide bank had also been damaged during 1955 floods.

It was therefore endeavoured to collect as much labour as possible from the adjoining areas to be able to finish this work by the end of June.

Earth work was allotted both to the contractor and the machines. Whereas the cotractor's labour was primarily engaged in completing the earth work of the shank, the excavators were put on the job of excavating the cunette at head as also digging earth down to the required level for the purpose of laying stone apron all along the head of the Pitched Island. This earth excavated for laying apron was in turn used for constructing the head of the Island to the required level.

(I) Head of the Pitched Island :—

It was proposed to lay the stone apron around the Pitched Island with its top R.L. 621·00. The average N.S.L., of the bela being 631·00 this meant that about 14·0' of excavation would have to be done to reach R.L. 616·5 before laying $4\frac{1}{2}'$ thick apron. In order to feed the L B.D.C., and B.S. Link a pond level of 632·0 was being maintained U/S of the barrage. Therefore slush earth work was encountered just after a foot or two depth of excavation. Although about 4 No. dragline excavators were available for use at site not more than two could be put to work at a time. The fact was that all of the machines were too old and continous progress from them was not possible. Half of the machies or even more remained out of order with one defect or the other at a time.

The boom length of two of those was 35.0' and the other two had a boom length of 50 ft. Great difficulty was encountered in excavating the slush earth especially when the time for the completion of this work was limited to just a month and a half. It was therefore decided that due to lack of time it would even suffice to make the excavation down to R.L. 621 and lay the apron thereon thus bringing the top R.L. of the apron laid around the semicircular head of the Pitched Island to R.L. 625·0 against R.L. 621·00, originally proposed. It was also decided to curtail for this reason only, the 50' width of the apron around the nose to only 15·0' in order to be able to complete this work in time i,e, before the 1956 floods. After laying this 15·0′ apron all around this semicircular head, stone pitching was completed up to R.L. 633·0. Although it was required to be raised to R.L. 638·5, it was considered safe enough for the time being to leave it up to R.L. 633·0 only as the high flood level U/s Balloki Barrage seldom exceeds this figure during normal floods.

Shank

The shank was originally proposed to be constructed against peir 19 but at the time of construction this was shifted to peir No. 20 in order to save the fish ladder which has been constructed adjacent to the 19th: pier. As Earthwork of the shank progressed stone pitching was started side by side from the barrage end. This Pitching was proposed to be raised to R.L. 637 but was limited to R.L. 633·0 for that year in order to save time and for reasons already elaborated above.

The impeevious floor U/stream of the Barrage extends up to 216·0 ft : from the weir crest followed by a 30·0′ width of stone apron beyond it. This saved the necessity of laying 30·0′ wide stone apron in 246 ft : length of the shank on either side. Bound by the limitation of time the target of completing the apron and pitching in a length of 600 ft : was reduced to 300 ft: for that year. As will be clear from the attached fig: 2 bela with slush earth stood on both sides of the shank and it was a problem to remove this slush down to R.L. 616·5 to start laying the apron as no working space could be found for the excavators to work. With difficulty this excavation was completed in a length of 65 ft: on the right side by means of excavators of 50·0′ boom length and stone apron 4½′ deep 30·0′ wide with a top R.L. of 621·0 i.e. same as the U/stream floor level, was laid and stone pitching raised there-after in the side slopes up to R.L. 633·0. Thus in about 300 ft: length pitching with apron was completed on the right side of the shank according to the fixed target. On the left side, however, the stone pitching was completed up to 164 ft: from the gate line. Beyond it stood the ring bund constructed for the purpose of repairing the damaged U/s floor opposite bays 6-14 one end of which butted with the shank. U/stream of this ring bund the slushy bela along the left side of shank was all under water where pitching could not be laid without constructing a secondary ring bund and dewatering the area for which there was no time. It was anticipated that with the presence of the bela along the shank and the remains of the ring bund protruding from the shank acting as a spur action on this unprotected portion of the shank would not be severe under normal high flood conditions. The remaining portion beyond 164 ft: length was therefore left unprotected for the time being.

(G) **Cunette :—**

The work for excavating the cunette was started from both sides. From its head near the nose of the Pitched Island it had been excavated to its required 50·0′ width and depth in a length of about 375·0′ and from the barrage end in a length of about 300 ft: when the monsoonic rains set in and it was feared that a flood discharge at Balloki might reach any time. Therefore work was rushed up so that the two excavated portions could be connected at least by a 15·0′ to 20·0′ wide channel before the first flood arrived, which could have the possibility of developing itself when water was forced through it. Working round the clock the two ends of the cunette were connected by a 20′ wide channel ready to meet the first flood of the season.

Whatever might have been the working of this channel aided by the Pitched Island one fact was significantly evident, that while the past damages to the U/S floor of the barrage were due to the diversion of the channel towards the right just near pacca floor U/S bays 5-14 thus causing parrallel flow over the weir where a scour pit developed in 1955 to a level of 585·00′ this development of scour and parrallel flow could now be averted by keeping the scour develompent away from the floor that is at the head of the Pitched Island.

From now on any thing happening would be well away from the vulnerable points that is it would be at the Pitched Island where any river attack would be accepted and fought.

The following gives the quantities of various items of work done.

Earthwork through contractor :—				Earthwork through excavators.		
E/Work dry	Slush	Wet	Total	Slush	Dry	Total
(I) E/Work 1085760 Cft:	200388 Cft:	26169 Cft:	1312317 Cft:	349054 Cft:	338984 Cft:	688038 Cft:

G. Total : 1312317 + 688038 : 2000355 Cft:

(2) Stone dumping in apron : 261641 Cft :

(3) Spawl filling under stone pitching 20001 Cft :

(4) Stone pitching on slopes 30977 Cft :

The above statement will show that completion of this work in a little over a month is a good progress.

Development of the Cunette During Flood Season of 1956-57.

(I) The first flood of the season was received at Balloki on 5.7.56. The bund in the cunette head was cut on 6.7.56., and as much as 12000 cs: passed through it on 7.7.56.

The observations of the cunette taken after the passage of 12000 cs : discharge through it on 7.7.56, are shown in the attached fig : 2.

It will be seen from the attached plan that the cunette worked very successfully and attained a width of 160′ in some reaches and even more in other reaches by scouring out the bela from the sides. The L. Section showed that the cunette in its development had also attained a considerable depth all along and a scour down to R.L. 607·0 developed in the cunette near its head.

To develop the cunette even further the discharge passing through it was further increased by increasing the gate openings of the right bays and about a fortnight later as much as 25000 cs : passed through the cunette. This widened and deepened the cunette even more.

The position in plan plotted after passing 25000 cs : through the cunette is shown in the dotted black line in the same figure from which it is clear that at places the cunette widened and deepened about one and a half times to what it was when 12000 cs : passed through it. A deep scour howevei, developed in the cunette near its head.

The main reason for the success of cunette development lies in the construction of Pitched Island with its shank at peir No. 20 U/S Balloki Barrage. With this it was possible to create a difference of levels between the left and right bays by suitable gate manipulation and also to have sufficient head across the head of the cunette and its tail at crest of the weir for the flow to continue in full force.

It, was however, understood that as far as possible, mean velocities through the cunette especially over the weir floor would never be allowed to exceed 10 ft : per second even in high floods.

In order to further develop the cunette it was decided to raise the discharge through the cunette gradually up to 35000 cs :

This resulted in the erosion of all the bela on the left side of the cunette up to the nose of the newly constructed spur and the left half of its semicircular head was subjected to severe action by the water entering the cunette from the main channel of the river. To reduce action on the nose so that no serious damage would occur to the nose and also to ease up the carriage of the stone from right guide bund, by boats, to the nose of the Island spur the cunette had to be reduced to about 27000 Cs : Immediately which was then gradually lowered to about 10000 cs : and maintained as such.

Extensive stone dumping was continued in front of the left half on the semicircular head and an additional quantity of approximately 46000 cft: stone was dumped in this season in a length of about 300 ft: on the left side of the Pitched Island head.

The Deputy Chief Engineer, Lahore had verbally orderd the Executive Engineer, Balloki Division, to complete about 300 cft: per foot run of stone in this reach of the head. The quanitty was made up by end of year 1956-57 in the left quadrant of the semicircular head of Pitched Island.

After having developed into greater depth and width the cunette was bound to silt up when discharge was reduced from 35,000 cs: to 10,000 cs: and kept steady there.

X-Section and L-Section plotted on 10.8.56., showed that the cunette silted up to some extent. However, keeping in view the advice of A. C. E. Development that narrower and deeper channels are easier to develop and maintain than comparatively wider and shallower channels, efforts were made to manipulate the gates on the right in such a manner that deeper though narrower channels developed within the cunette.

In any case this silting up of the cunette during the falling supplies in the river was not of much concern for as long as a difference of levels could be maintained between the right and left pond levels with the aid of the shank of Pitched Island and between the head and tail of the cunette with proper gate regulation, the channel on the right side could be made to work again at any time when supplies were available.

Creating a level of the right pond a foot or two or even more lower than the the left side meant providing a steeper slope for the water to flow on the right as compared with that on the left which resulted in a greater passage of discharge thorugh the right side.

Working the Right Channel During the Floods of July and August 57.

During the preceding winter season the head of Pitched Island had been made sufficiently strong to face high floods by extensive stone dumping in the left quadrant to the tune of 300 cft: per foot run and in addition stocking about 50,000 cft: stone as a reserve stock on top of its head.

The channel was kept clear of silt to a good extent by running excessive winter supplies through it. The first flood of this season arrived on 25.7.57., which rose to a high flood stage i. e. about 60000 cs: on 26.7.57. About half of this discharge was passed through the right side which worked very satisfactorily.

By 29.7.57. the discharge at Balloki was 107000 cs and was rising, out of which 43000 cs : were let in through the right bays which worked satisfactorily. The peak discharge of 127000 cs : occured on 30.7.57., against the designed capacity of 132500 cs : available after allowing for the two closed gates sealed against the shank.

At this stage the working of right bays became non modular owing to a high D/S water surface level and comparatively low U/S pond level which had to be kept about 2·0′ lower than the left pond level in order io force 43000 cs : through the right side. On the left side, however, the working continued to be modular because the U/S Pond level was about 2·0′ higher and therefore the drowning ratio of the weir on this side remained well within 85% Given below are calculations for working out the drowning ratio to illustrate the modularity condition or otherwise of the left and right sides.

Left U/S Pond	632·5
Right U/S Pond	631·3
Left D/S Level	630·8
Right D/S level	630·7

Drowning ratio for the left weir :

$$\frac{630{\cdot}8 - 622{\cdot}5 \times 100}{632{\cdot}5 - 622{\cdot}5} : \frac{8{\cdot}3 \times 100}{10}$$

: 83% less than 85%

∴ Modular working

,, ,, ,, ,, the right weir

$$\frac{630{\cdot}7 - 622{\cdot}5 \times 100}{631{\cdot}3 - 622{\cdot}5} : \frac{8{\cdot}2 \times 100}{8{\cdot}8}$$

: 93% i.e., greater than 85% ∴ Non modular. working.

Thus under the non modular conditions the discharging capacity of the weir on the right side was reduced and U/S right channel showed signs of silting up. This condition was however, improved to some extent by raising the left pond level by another foot which consequently made the right pond to rise by an equal height and thus reduced the drowning ratio and improved the working of the weir on this side. With a fall in the D/s W.S.L. the working of the right bays again revetred to modular condition.

Soundings taken after the passage of this flood have shown that the right side is very much clear of silt and a deep channel has been formed opposite bays 30-33 with a bed level of about 613·00 at a safe distance of about 450 ft : above the end of pacca floor which is at R.L. 621·00. Opposite bays 25-30 the channel is also in a satisfactory condition with a water depth of about 8 ft giving a bed level of about 622·0 to 624·00. L-Section and X-Section of the channel as these stood after this flood are shown in fig. 3.

Record Flood on 30.8.57.

The writers were on the verge of completing this paper when the river at Balloki rose to the high flood on 26.8.57., and a record flood of 1,68,700 Cs passed down the barrage on 30.8.57., against the designed capacity of 132500 Cs of the barrage i.e. (capacity with two gates sealed) A round the clock day and night watch was made by the Executive-Engineer, and Sub Divisional Officer, Head Works, while this record flood dischargeed through the weir. Hourly observations of velocities upstream of the weir were taken to ascertain that the mean velocities U/s of the weir were limited to 10 ft / Sec. By careful regulation no oblique flow was allowed to occur over the upstream floor. Although the safe designed capacity of the barrage had exceeded, uniform velocities over the weir were maintained which did not exceed a maximum of 10 to 11 ft/Sec. The proposal of making a cut in the right flood embankment was therefore considered and dropped espacially when the river at Shahdara had fallen and was also likely to start falling at Bolloki before the cuts in the right flood embankment could develop and start affording relief to the main stream of the river. During this flood the right side functioned very satisfactorily although its working did become non-modular when over 125000 cs: was passing over the weir.

The condition was partly improved by raising the Upstream pond level. Fig. 5 (photograph) taken during this flood shows the satisfactory working of the right side of the barrage which helped a good deal in reducing the pressure on the left channel. Preliminary probings taken after this record flood show that the U/S floor is still intact having withstood the test remarkably well. However, there were frequent slippings of stone pitching at head of Pitched Island which were controlled by dumping stone. Another important point noticed was that during this record flood the whole length of the shank had come under severe action which had to be protected by putting in chappas along its entire length. The chappas, in turn were tied down by rope to killas driven on the top of the shank.

In view of this action it has now been proposed to extend the pitching up to the entire 1300 ft: length of the shank instead of limiting it in 600 ft: length as originally depicted by the model studies.

Flow Pattern of Bifurcating Current at Head of Pitched Island

Although the pattern of flow fluctuates with the discharge off-take on the right side the normal flow pattern prevailing at the head of Pitched Island is illustrated in fig 2 & 4, A perusal of these figures will show that bifurcated current hits the left quadrant of semicircular nose along an outer curve which is subject to heavy scouring action. Beyond this the current takes a sinuous turn and flows along an outer curve towards the right guide bank. This brings the right quadrant of the Island head along the inner curve which has silted up and there is no action on it whatsoever. The current after crossing the centre of the Island head, has been drifting farther and farther towards the right and has brought the right guide bank into action after 40 years which previously was hundreds of feet away from the river edge. Thus it will be seen that the deep channel on the right does not now exist where the cunette was originally excavated but a considerable distance away from it on the right side.

The river edge as it existed after the flood season of 1956 and as it existed after passing a high flood of 127000 cs this year during July, 1957, has been marked on the same plan. It is anticipated that if the conditions at Headworks remain as they are at present heavy action on the left quadrant of this Island head will continue to persist for all times to come and the right quadrant of it will remain without action and ladden with silt, till the river straightens itself upstream of the head of the Pitched Island eroding the bela in front of spur No. 3.

Fresh Proposals

The construction of the shank of Pitched Island which butts against peir No. 20 has permanently closed bays No. 20 and 21, one on each side of the shank. This means that although the lost capacity of the right bays has been regained still two bays namely bays No. 20 & 21 have been permanently sealed. In other words the cost of almost 2/35th of the barrage has been wasted. The 1950, 1954, 1955, & 1957 floods have shown that the designed capacity of the barrage was cxceeded in these years therefore it is only impertive that the barrage capacity should be utilized to its fullest possible extent.

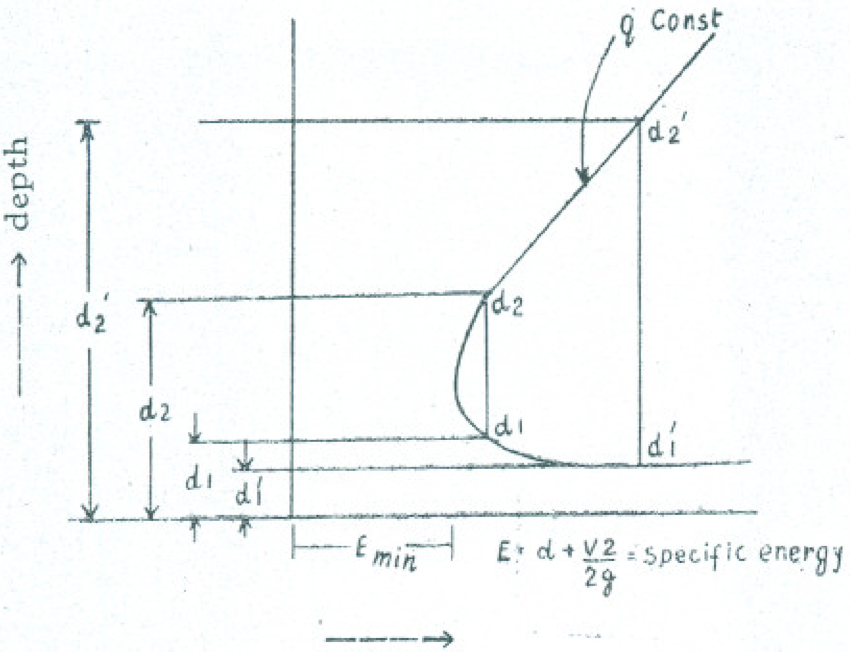
I. It is therefore proposed to extend peir No. 20 up to the U/S end of impervious floor i.e., upto 216 ft: from the gate line wherefrom the earthen shank should continue as it is now with stone pitching on both sides. This peir extension will act as a divide wall and in addition to having all the advantages of the earthen shank will be immune from river action in this 216·0 length and it will also open up the said two bays.

II. As a result of the inactivity of the right bays over the past many years the river channel opposite these bays on the down stream side has also silted up and bulk of the discharge after passing through the barrage is carried by the left main channel of the river. By continuously passing supplies through the right bays during the last winter and the current year's floods the down stream bela has been eroded in a considerable length, However to accelerate the normal river action it is proposed to make a diversion cut through the silted river bed on the right aided by a bund in the main channel on the left in order to work up a channel on the right side. If this works it will, in turn, reduce the burden on the left side and thus prevent spur No. 7 lower down from coming into severe action every year.

Limitations in the Weir Design.

The river bed has shown a tendency to rise in the past few years down stream of this weir with the result that the downstream flood level attained in super floods of over 1,00,000 cs. discharge is very high which leaves comparatively a small working head across the weir. This condition is further aggravated by the slope of the glacis which is as flat as I in 15 as against I in 3 to I in 5 according to modern design practice.

The flow over this glacis is therefore in a 'Mildly rapid' or "Mildly hyper critical" stage due to which the corresponding change to the "Sub critical" stage is not as abrupt as would be if the flow over the glacis was highly 'Hyper critical." Hence the hydraulic jump formed is not a very defined one but is to some extent undulatory. This point is illustrated by the specific energy diagram shown below :—



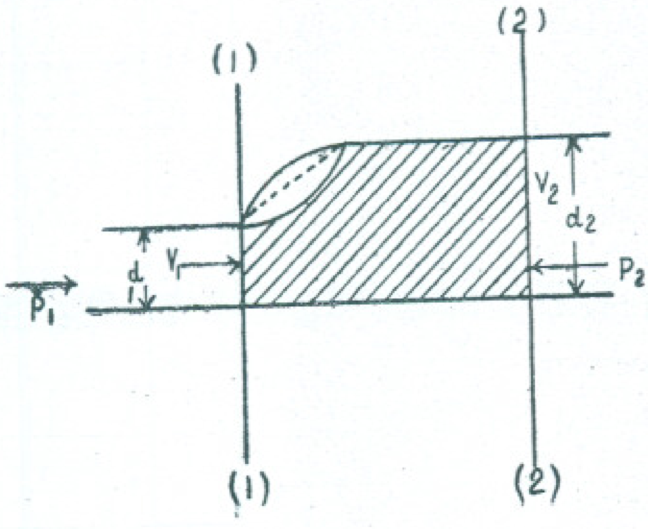
For one particular discharge q/ft run and for any specific energy content above a certain minimum value, two "alternate depths are possible, that is, the given rate of flow may take place at a small depth and high velocity when it will be called" Hyper critical flow or at large depth and low velocity when it will be know as "Sub Critical" flow. In between the two is the "Critical stage" of flow against which the specific energy contents are a minmum. Now the local phenomenon by means of which the flow changes, in an abrupt manner, from the "hyper critical stage" to the "Sub critical" stage is called 'Hydraulic jump" or a "standing wave." Greater the differences of depths before and after the jump more abrupt and defined will the jump be.

For instance, as shown on the sketch, the difference between the "alternate depths" d_1 and d_2 in a change over from the moderately hyper critical" to the corresponding "sub critical stage" is less compared with the difference of d_1^1 and d_2^1 when this change over takes place from a "high hyper critical" to a "high sub critical stage." If d_1, d_2 and d_1^1, d_2^1 be taken to be two pairs representing depths before and after the jumps disregarding the energy dissipated in the formation of the jump (Actually "sequent depth" d_3 or d^1_3 after the jump corresponding to a depth d_1 or d_1^1 before the jump will be less than the "alternate depth" d_2 or d_2^1 due to the energy loss in jump formation), the first pair representing the change over in a region closer to the critical flow as compared to the second which is farther removed from the "critical stage" it will be seen that the jump formation will be more abrupt in the latter case in comparison to the former. The hydraulic jump will continue to form at a greater depth d_2^1 than the depth d_2 required in the former case.

Thus it implies that smaller the value of d_1, depth before the jump greater will be d_2 depth required after the jump for its formation.

Again flatter the slope of D/s glacis, smaller the hyper critical velocity and greater the value of d_1, for anyone discharge q/foot run with a consequent smaller value of d_2 at which jump will form and vice versa. Hence at any arbitrary discharge q, if the down stream glacis was steeper the depth of flow on the downstream floor required for jump formation would also be greater, consequently the standing wave will continue to form up to a comparatively higher down steream level.

This point can also be elucidated by considering the equilibrium of the mass of water between two vertical sections (1) and (2) one before and the other after the jump, consider unit width of channel.



Now, average $p_1 = \frac{wd_1}{2}$

and average $p_2 = \frac{wd_2}{2}$

Horizontal Force on section (2)

$$= p_2 \times \text{cross sectional area}$$

$$= p_2\, d_2 = \frac{wd_2^2}{2}$$

Similarly, Horizontal Force on section (1) $= \frac{wd_1^2}{2}$; Now Force = change of momentem/sec. = mass per sec. × change of velocity that is,

$$\frac{wd_2^2}{2} - \frac{wd_1^2}{2} = \frac{wq}{g}(v_1 - v_2) \qquad \text{...eq. (1)}$$

but, $\frac{q}{d_1} = v_1$; and $v_2 = \frac{q}{d_2}$. Supstituting in eq. (1)

$d_2^2 - d_1^2 = \frac{2q}{g}\left(\frac{q}{d_1} - \frac{q}{d_2}\right) \quad \therefore \quad \frac{2q^2}{gd_1d_2} = d_2 + d_1$; or $\frac{2\,q^2}{g} =$ $d_1\, d_2\, (d_2 + d_1)$ that is $d_2^2 + d_2\, d_1 = \frac{dq^2}{gd_1}$ Solving this quadratic equation.

$$d_2 = -\frac{d_1}{2} \pm \sqrt{\frac{2q^2}{gd_1} + \frac{d_1^2}{4}} \qquad \text{...eq. (2)}$$

The maximum designed capacity for Balloki Headwork is 100 C.F.S./Ft. run.

Therefore, for this value of q in a high flood discharge.

if $d_1 = 1.0$ ft., d_2 works out to be equal to 24.5 ft.

if $d_1 = 2.0$ ft., d_2 works out to be equal to 16.7 ft.

This again proves what has already been established with the specific energy diagrem on the previous page that smaller the value of d_2, greater the value of d_2 required and vice verse. Now $d = \frac{q}{v}$ and v is proportional to the square root of water slope.

Therefore steeper the slope smaller the value of d_1, and in turn greater the value of d_2 required for jump formation. Hence the jump would continue to form up to a higher down stream water surface level on the floor in comparison to the case when the slope is flatter. This inherent defect in the design of Balloki Barrage with a low crest and gradually silting down stream river bed, in the opinion of the writers, results in the non modular working of the weir under super high flood conditions. That is why even in the record flood of 1955 when the down stream flood level rose as high as 635.2 against an upstream high flood level of 635.5 the working of the whole weir became non modular which in turn reduced its discharging capacity. This feature if an when removed will, it is hoped, distinctly help in the working of the Pitched Island, till then the upstream pond level will have to be kept as high as possible during super high flood conditions for improving the conditions of modularity for whole of the barrage in general and the right-bays in particular.

Conclusion.

"The proof of the pudding is in the eating"

The 1956 and 1957 floods were most successfully passed over Balloki Headworks. Although only a max : discharge of about 75000 cs; was passed in 1956 but almost the full supply designed capacity of 127000 cs. and a record flood of 1,68,700 cs. successfully passed in July and August 1957 respectively.

A comparatively lower max: discharge figure for the flood season of 1956 can be taken as a boon for the development of the right channel because proper development of the cunette could be undertaken better in a steadily increasing discharge of a moderate intensity rather than in a sudden super high flood discharge.

The secret of success, however lies in the maintenace of of the Pitched Island. Frequent slippings at its nose during every freshet as experienced in the last two years and as is anticipated to happen in future on the one hand, and our endeavours to strengthen the the Island by extensive stone dumping and reserves on the other will remain a cause of great concern to the Engineers-in-charge of Balloki Headworks for at least the next few years. But perhaps this was not unexpected even at the time of framing the original proposals, this challenge of the mighty waters has therefore to be accepted and defended.

Scope.

The trial of the Pitched Island with shank has opened up a new feature in the Indus Basin Barrages which on collection of more field data over a number of years, will be of positive value in overcoming similar troubles at other places.

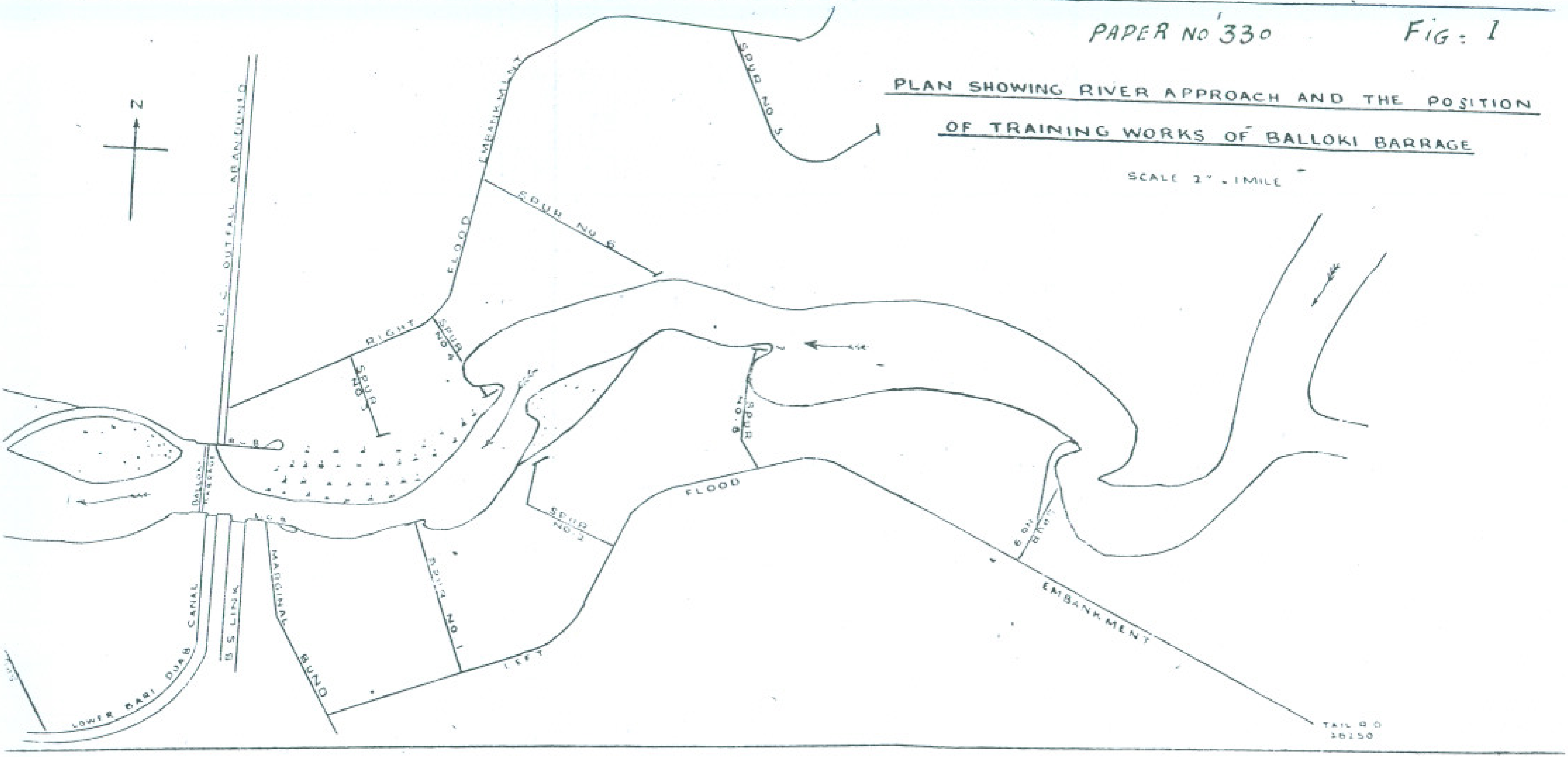
Acknowledgement.

The writers are particularly grateful to Syed Ejaz Hussain P.S.E. (I) Supersntending Engineer, Lower Bari Doab Canal Circle for rendering his valuable advice during the construction and planning of the Pitched Island. Sincere appreciation is extended to Mian Muzaffar Ahmad P.S.E. (I) Director, Irrigation Research Institute, Lahore for making available certain Photographs taken at Balloki Headworks and in affording access to necessary model experiment data. Thanks are also due to Ch. Abdul Majid O.E.S., Overseer Balloki Headworks for assisting in the collection of necessary data,

PAPER NO 330 Fig: 1

PLAN SHOWING RIVER APPROACH AND THE POSITION OF TRAINING WORKS OF BALLOKI BARRAGE

SCALE 2" = 1 MILE



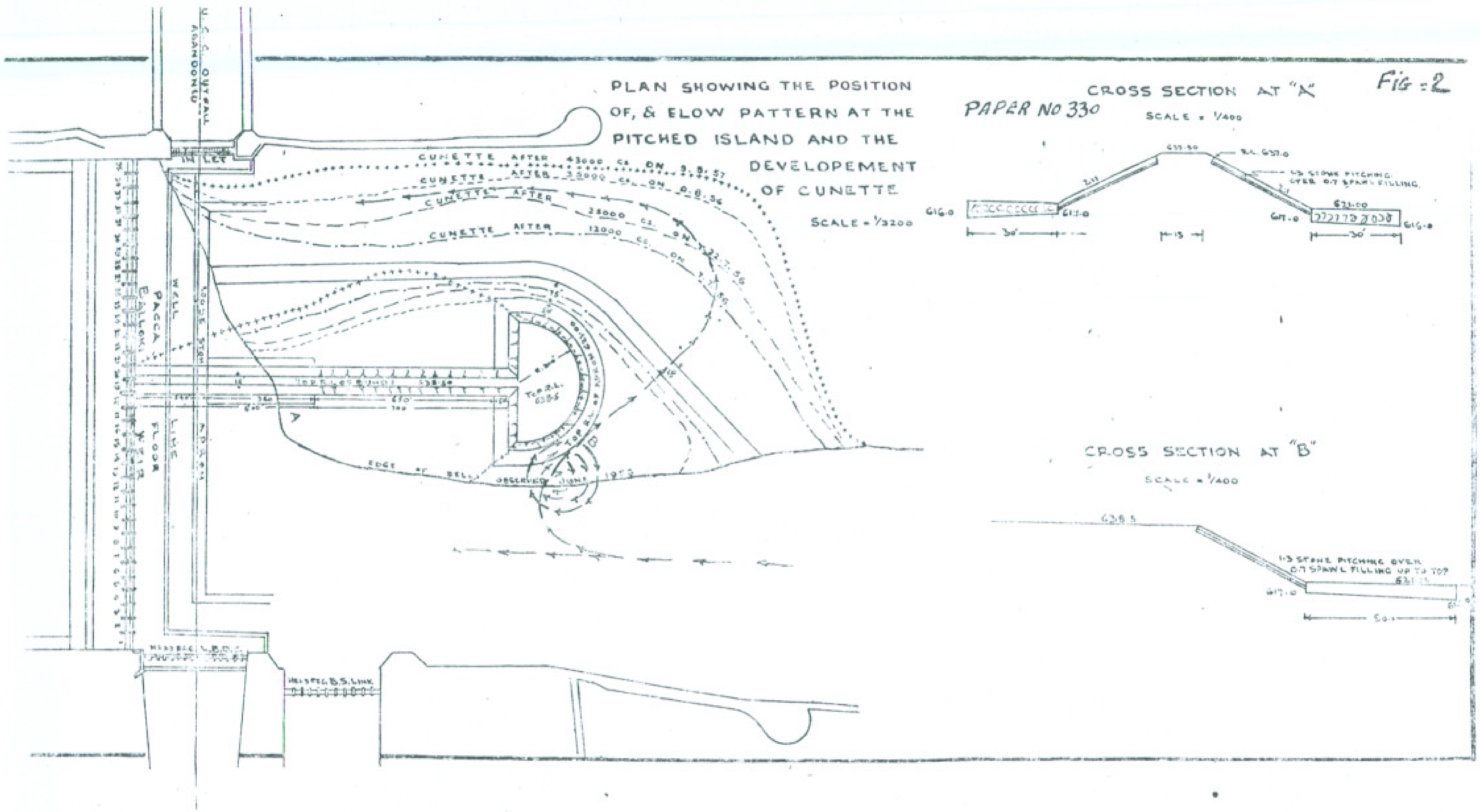
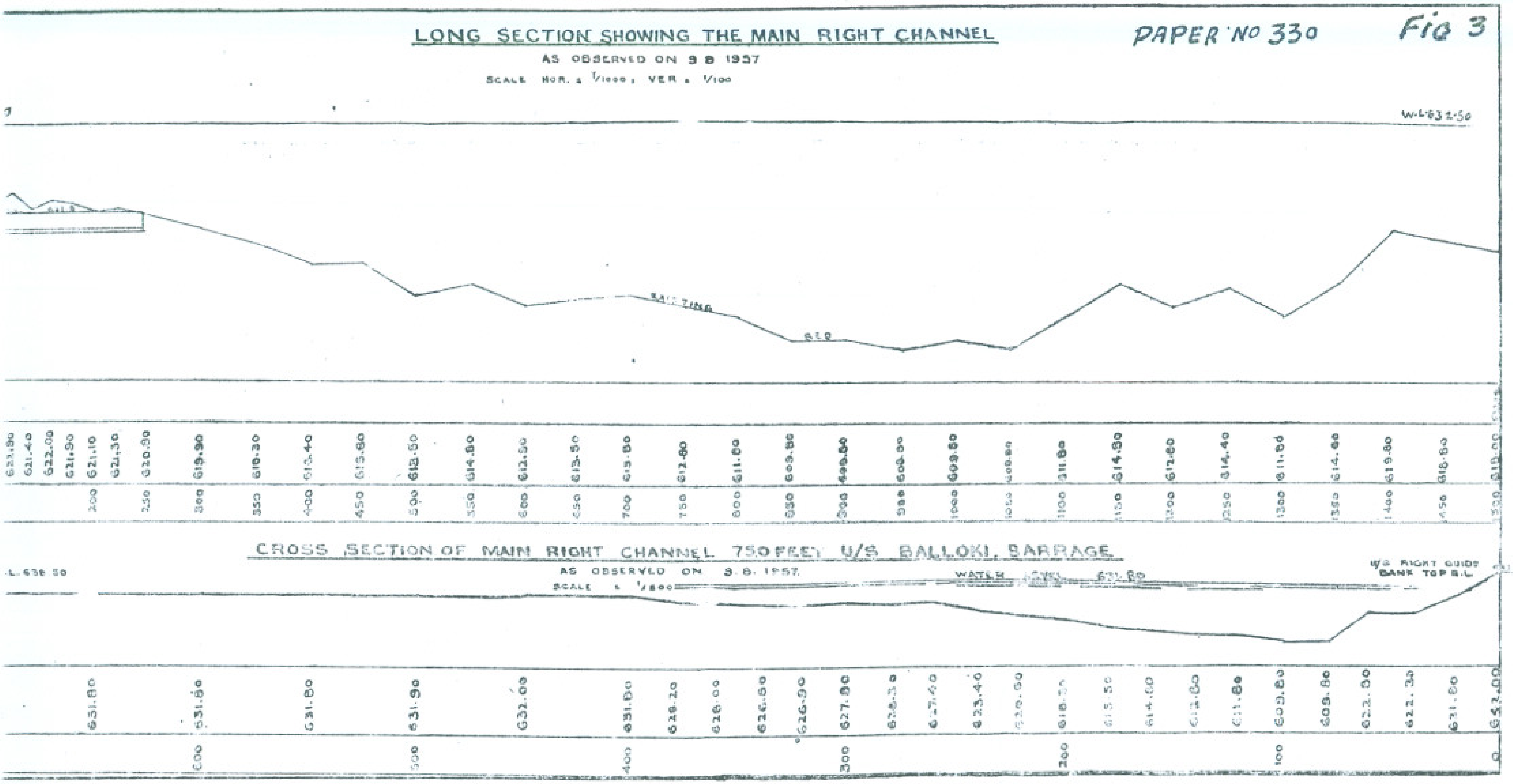
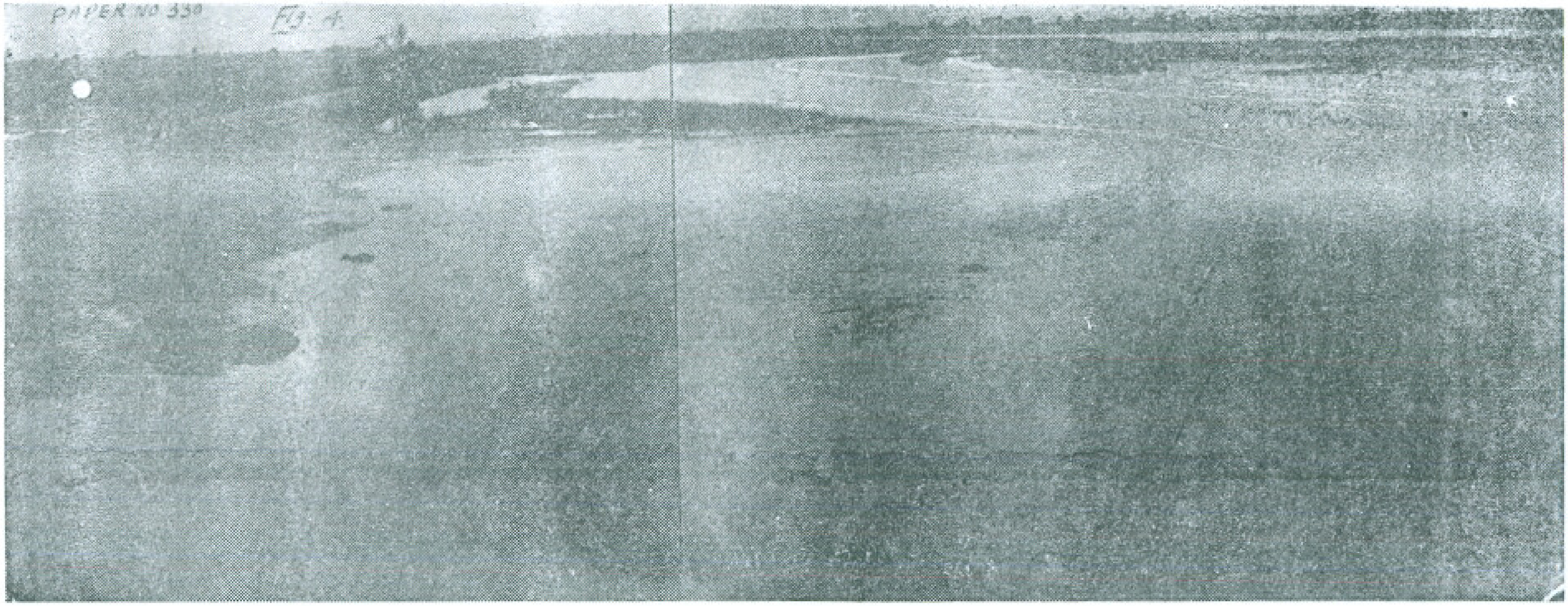


Fig - 2
PAPER NO 330
PLAN SHOWING THE POSITION OF, & FLOW PATTERN AT THE PITCHED ISLAND AND THE DEVELOPEMENT OF CUNETTE
SCALE = 1/3200
CUNETTE AFTER 43000 CS. ON 3.8.57
CUNETTE AFTER 35000 CS. ON 0.8.56
CUNETTE AFTER 25000 CS. ON 22.7.56
CUNETTE AFTER 12000 CS. ON 7.7.56
U.C.C. OUTFALL ABANDONED
INLET
PACCA BALLOKI FLOOR WEIR
WELL LINE
LOOSE STONE APRON
EDGE OF BELA OBSERVED JUNE 1953
TOP R.L. 638.5
A
B
CROSS SECTION AT "A"
SCALE = 1/400
616.0
613.0
633.50
R.L. 637.0
1:3 STONE PITCHING OVER 0.7 SPAWL FILLING
621.00
617.0
616.0
30'
15
30'
CROSS SECTION AT "B"
SCALE = 1/400
638.5
1:3 STONE PITCHING OVER 0.7 SPAWL FILLING UP TO TOP
617.0


LONG SECTION SHOWING THE MAIN RIGHT CHANNEL
AS OBSERVED ON 9 8 1957
SCALE HOR. 1/1000, VER. 1/100
PAPER NO 330
Fig 3
BED
CROSS SECTION OF MAIN RIGHT CHANNEL 750 FEET U/S BALLOKI BARRAGE
AS OBSERVED ON 9.8.1957
SCALE 1/800
U/S RIGHT GUIDE BANK TOP B.L.


PAPER NO 330
Fig. 4

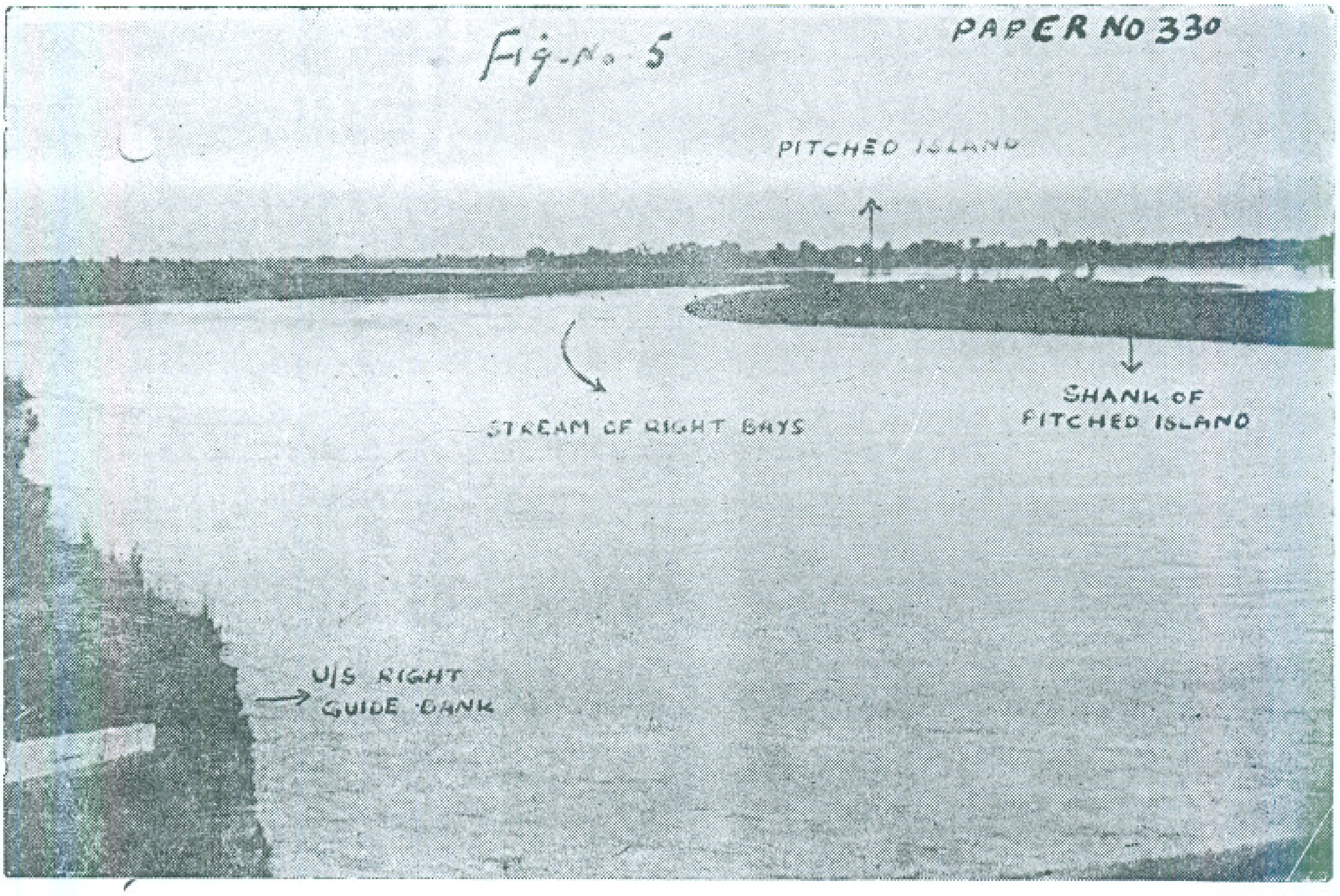


Fig-No. 5
PAPER NO 330
PITCHED ISLAND
STREAM OF RIGHT BAYS
SHANK OF
FITCHED ISLAND
U/S RIGHT
GUIDE BANK