Experiments carried out at Malikpur during the last two months had shown that out of 88 tests on energy dissipators made on a model of Trimmu weir, staggered blocks gave the best results. The position and the arrangement of blocks at both the places was verified by these tests. For the first row of blocks, the optimum position was just upstream of the toe of the glacis. This confirmed fully the findings of this Paper. It also amply indicated that the results obtained on small scale models in the laboratory were borne out by similar tests on a bigger scale and therefore it could be concluded that the results would be applicable to the actual works.

Recent experiments in Sind on a model of a Regulator at the 28th mile of Begari Canal (carried out in the Developments and Research Division at the Karachi Testing Station) had shown that the adoption of Punjab blocks reduced the scour from 22·5 ft. to 4 ft. measured below the floor level, i.e., 82·2% reduction in scour. Still, it had been reported by Mr. Bushby that the Punjab blocks were unsatisfactory because of the high bed velocities on the left side of the model. It had been mentioned by them that when staggered blocks were constructed in a baffle wall, the scour was still further reduced by about 3 feet. Regarding the high velocity on the left side it was suggested that the bed might not have been level, otherwise there was no reason why the velocity on the right side should be lower near the bed and on the left side that it should be higher. For the blocks mounted on the baffle it might be said that this amounted to the raising of blocks by the height of the baffle. If blocks alone of the combined height were constructed, better results would have been obtained. This arrangement suggested by Sind officers had been tested in the laboratory and found to be inferior to blocks alone. The Sind design gave scour of 3·68 ft. while the Punjab gave 3·48 ft., 6% more in case of Sind arrangement. The height of the obstruction should be fixed at a minimum because of the cost and the wavy action produced on the downstream water surface. The blocks were a device for the dissipation of energy and the maximum effect was only obtained when it was put in at the correct position. In the dissipation of energy, eddies and turbulence would take place and the floor should be properly built. In the case of Jaba level crossing, Upper Jhelum Canal, the velocity was of the order of 20 to 25 feet per second and the blocks had stood the test. Similar was the case of the blocks on the Salampur Feeder falls. It was over two years since the blocks were constructed and they were still intact.

Briefly, the Authors said that they had put forward in this Paper the results of over three hundred experiments extending over five years and from which rules of thumb had been derived.

Mr. **Montagu** referred to the statement on page 107 that " it was found that only a small portion of the kinematic (sic) energy was dissipated in the formation of the standing wave."

enchanced friction. If they were placed below the standing wave, they only performed the function of the friction blocks advocated by the Speaker ten years ago. If they were placed in the hypercritical stream, *either* they became impact blocks and were subject to excessive wear, *or* they destroyed just sufficient energy to prevent the formation of a standing wave and in that case were a downright danger.

In support of this statement, the Speaker quoted the experience of the engineers in charge at Panama. The Gatun spillway depended on impact blocks for the destruction of energy. The action was terrific and the cost of maintenance high. The Madden dam on the other hand depended on the standing wave and an upward sloping floor and natural roughness. The Madden spillway design was a complete success.

The Speaker ventured to record a word of warning against placing too much faith in model experiments unless the limitations were thoroughly understood. Mr. C. C. Inglis probably knew more about this subject than anyone else in India, and possibly as much as anyone in a wider field. The inherent mistake in the model experiments which formed the basis of this Paper, was the failure to recognize that it was impossible to reduce friction on a model in the same proportion as the scale ratio between model and prototype. In support of this, the Speaker referred to his Paper No. 126 of 1929, read before this Congress. Therein, he had quoted the actual analysis of losses over his model weir. They amounted to 35% of the total energy available, before the wave occurred. In the subsequent discussion, it became clear that so high a proportion of losses would not occur in the proto-type. This was amply confirmed by inference, in the experiments which formed the subject of the joint paper No. 141 by Mr. Bedford and himself in 1930.

The Speaker concluded by repeating his warning that the present hydraulic experiments in the Research Institute paid insufficient attention to the effect of scale and consequently were apt to be misleading. He ventured to record his personal opinion that reliance on impact blocks and arrows without adequate design in other respects, was fundamentally unsound and might lead to unexpected consequences.

Mr. **Blench** expressed his interest in that, some 10 years after friction blocks had been devised by Mr. A.M.R. Montagu, they were still being advocated with such little modification. These blocks were described by their inventor in the Central Board of Irrigation Publication on "Irrigation Canal Falls." Mr. C. C. Inglis had experimented on them several years ago, *vide* Bombay P.W.D. Technical Paper No. 44.

On a weir, the abstraction of energy by friction downstream of the standing wave was small compared with that by the wave, *e.g.*, the Authors' Plate I of Marala Weir showed 16·6 feet depth on the d.s.

floor, giving a velocity of 9·8 feet per sec. The rate of abstraction of energy by friction was given by S from

$$V = 120\, R^{3/4}\, S^{1/2} \qquad (1)$$

or any similar exponential formula using $R = 16{\cdot}6$ and $V = 9{\cdot}8$, S was of an order of about 1/10,000. So, on a weir floor 100 feet long the abstraction would be only about 1/100 feet, and enhancement by blocks would be negligible.

In such circumstances friction blocks could be made to serve their second purpose of upsetting the velocity distribution near the end of the floor, by slowing down the bed filaments and speeding up the surface ones, so that scour was advanced beyond where it could be dangerous.

On the glacis, where the tremendous jet-speed and small depth might make friction comparable with subsequent wave loss, friction blocks might make all the difference between a wave forming on the floor, or off it. Unfortunately jet speeds of 15 to 25 feet a second might play havoc with projecting blocks, and a sound design would arrange for the downstream floor to be at such a level that the standing wave would not go off it.

Within the standing wave a compromise was struck. The blocks were not so liable to damage, and could still abstract a noticeable amount of energy by shock; and they diverted flow upwards, thereby bringing negative gravity impulse into play and causing wave formation a little upstream of where it would otherwise occur.

On the glacis of a canal fall friction blocks helped the jet to diverge, to suit the masonry divergence.

Blocks could not, however, compensate for a bad design which, by high downstream floor level, allowed the wave to form beyond the floor (or prevented its formation at all).

It was most unfortunate that the Authors had not studied standing wave mechanics, set out so simply in the various Central Board of Irrigation publications on the subject. An appreciation of it might have prevented the misstatement that "only a small portion of the kinetic energy was dissipated in the formation of the standing wave" which was disproved by an analysis of their own Plate I, although their models and the prototype were not similar as regards friction. In fact Plate IV (attached) showed the analysis carried out. Assuming the gauge in the scour hole, the velocity head was 0·5 feet giving the downstream total energy line (T.E. 2) a level of 810·9. It could be taken as horizontal, as friction loss had been shown, above, to be negligible. The depth just above the wave scaled about 6·5 feet, giving a velocity of 25 feet/sec.

and a velocity head of 9·7 feet. Add to this the depth 6·5 feet, and another 1 foot to allow for the fact that the trough was probably not clear, but contained some air-water mixture (see Photo No. 3 in which, incidentally the supply corresponding to 162·5 did not seem to have been running) and we found that the R. L. of the upstream T. E. line, just above the jump, was 814·2 feet. The velocity head at the upstream gauge site worked out at 1·0 feet, giving the upstream end of T. E. 1 at level 815·5.

So we had:—

Friction and shock loss above standing wave	815·5 – 814·2 = 1·3 feet
Loss in Wave	814·2 – 810·9 = 3·3 feet.
Loss after wave ..	about 0·01 feet

If the experimenters had their downstream gauge on the *pacca* floor instead of in the scour hole, as assumed, then 811·8 replaced 810·9 for the level of T. E. 2, and the wave loss would be 2·4 feet.

A similar analysis of Plate I (c) would show the trifling difference in energy caused by the blocks.

If glacis and general upstream friction be found direct from equation (1) using as low a coefficient as 90, it only came to about 0·2 feet. Whether the difference between this and the 1·3 shown above was due to (*a*) shock at crest or (*b*) the assumption of only 1 foot of superload in the trough or (c) a genuine change in friction owing to the major irregularities of the glacis being undulations at low speeds, and true roughnesses at high speed must remain conjectural. The analysis was merely intended to disprove the statement that standing wave loss was unimportant.

If the Authors would obtain the dimension D by accurate measurement, and also the amount of superload due to water-air mixture in the trough, they would be doing a very useful piece of energy distribution analysis.

Mr. **G. R. Sawhney** congratulated the Joint Authors on reading before the Congress a really interesting Paper full of useful information and very well illustrated.

The word "intuition" was very cleverly introduced by the Authors, the Speaker said, to define an impulse which had no explanation. In his opinion "intuition" might be acted upon on the spur of the moment when one was faced with actual danger and was not sure what was the best thing to do; but not when designing protections, in order to repair damage that had already occurred or to guard against damage which was apprehended. In such cases only the properly tested and universally accepted safe methods should be used.

The apparatus used for measuring, observing, and recording various results were, no doubt, very up-to-date and ingenious and the results obtained very interesting but our main troubles were concerned with sand, either under the foundations or in suspension in flowing water, and this sand could not be dissected to the size to which the various models were made.

The facts brought out in the Paper clearly showed that a good deal of more accurate research work must be carried out before we could be sure that we had found some definite solutions to the various problems that were facing us. This object could only be achieved if complete geological and physical data concerning each model under test were accurately collected and the various sites also inspected, both upstream and downstream of the works and the actual condition of the works noted and all actions and reactions thoroughly grasped before experiments were started in the laboratory. Also local officers in charge of such works should be kept in touch with these experiments while they were going on.

He was sure that staggered blocks, as suggested by the Authors, would help in dissipating the energy more efficiently than was being done by any other method that we had so far employed.

As a proof of the effectiveness of staggered blocks, the Authors quoted a reference to these in the Administration Report of the Government of the Punjab, P.W.D. Irrigation Branch, for the year 1933-34, while only yesterday the Authors of a similar paper referred to the remarks made by the Inspector General of Irrigation (the then supreme authority) about the strong design and excellent workmanship of a weir in 1911 and what happened to the same weir the very next year. Hence the Speaker wished to suggest that such references in Papers should be avoided, till at least the conclusions arrived at by the various Authors had been proved to be absolutely correct and universally accepted.

In conclusion, the Speaker said, as long as loose stone aprons were made at the downstream end of a work they would always become sloping, even if they were made flat at first. How could their becoming sloping be avoided, he asked.

So long as the hydraulic gradients across our works would keep on changing and absolutely ideal lengths of downstream aprons below each work could not be fixed, he was afraid some extensions would be considered necessary and continued to be made.

Mr. **Som Nath Kapur** thought that the Paper illustrated the behaviour of models with various devices and the conclusions arrived at were more or less a question of trial and error to be tested and verified on actual works. It would also have been more interesting if experiments had shown how the various jets or streams behaved by coloured filments which would have demonstrated the differences that take place before scour, after scour and also as they travelled from section to section. This would have indicated the cause of trouble and how it could be stopped.

The Authors had not discussed theory at all, but the main thing to be considered was that, with the creation of a fall, a certain amount of energy became surplus and had to be destroyed.

Overlooking friction as the jet rolled down the glacis, the jet attained a velocity $\sqrt{u^2+2gh}$, where $u=\frac{3q}{2h}$, q being the discharge for foot-run and h being the total energy head on the crest.

The glacis surface provided force which guided the jet along it, thereby converting part of the vertical component of the jet into horizontal. Thus a flatter glacis, though unsuitable from standing wave considerations, was better (from considerations of scour) as it gave a smaller vertical component.

It must be borne in mind, the Speaker said, that at every stage the jet velocity should be resolved into vertical and horizontal components, to determine the scooping and abrasing power of the jet.

With the creation of a standing wave, the horizontal component impinged on the mass of water which changed its direction, partly vertically upwards and partly backwards, and which gave rise to foam, turbulence and eddies and resulting in the destruction of energy. The vertical component however was not affected and the jet, as it left, had the same vertical and comparatively less horizontal component, and there were greater scooping tendencies over shorter lengths.

No experiments had so far been performed to determine the net velocities and resultant direction of a jet before and after the formation of a standing wave and was a subject to be pursued. This could be done by floating a current meter in various planes.

So far as our present designs were concerned we left things at this stage, thinking problems were solved but, as would be seen, the downward jet which was mainly responsible for scour had not been touched at all. If left to change its direction it would require a prohibitive length of floor.

Worse than what was usual was another practice commonly found on Pakpattan Canal.

a low curtain wall was built and left, as shown in fig. The loose earth which covered the curtain top up to bed was probably washed off with the first jet and the water as it emerged from the *pacca* floor had a bigger downward component than the horizontal and having given the jet a downward force it was not correct to assume that the soil would change the direction to the horizontal without letting it scoop its own cistern and it was no wonder that falls on Pakpattan Canal had generally scoured 10 to 20 ft. below them.

Our aim, the Speaker said, was to make the jet leave with a safe horizontal component and no vertical component of velocity.

Breaking up the vertical component could better be done by stages. If therefore instead of a plain glacis we had steps wide enough to completely intercept the jet which would be formed by full supply profile, we would get the required breaking up. The Speaker had found from observations that the coefficient of restitution of water on masonry was 0·66 (nearly), which meant that one-third of available energy was destroyed at each step. So, if we gave four steps h ft. each, the energy lost would be

1st step, $\frac{1}{3}h$	Balance for	2nd step, $\frac{5}{3}h$
2nd step, $\frac{5}{9}h$	,, ,,	3rd step, $\frac{19}{9}h$
3rd step, $\frac{19}{27}h$	,, ,,	4th step, $\frac{65}{27}h$
4th step, $\frac{65}{81}h$		

$$\frac{194}{81}h = 2{\cdot}4\,h$$

or the impact by stepping out destroyed 60% of the total energy straight away.

The last step just before the actual position of the standing wave should be given a very flat sloped face at the downstream end so as to convert residual 40% of the energy to a more horizontal and less vertical composed jet and then a greater portion of the horizontal force would be taken up by the standing wave.

As to the jet beyond the standing wave our problem was to reduce whatever vertical component was left to nothing and for this the Speaker actually examined one of the worst falls at R.D. 15000, Burewala Distributory which had a discharge of 140 cusecs.

Just where the standing wave formed the step was converted into a plain glacis following the general slope of the steps and by a smooth curve whose radius equalled the depth of water. The jet was brought up at an angle of 60°. This deflecting wall intercepted the whole of the jet and left no vertical component downwards. The 60° angle was arrived at to give a horizontal component 3 to 4 ft. per sec. and could be changed to suit each individual case. As this would have some vertical upward component which, when travelling back under gravity, might not be completely destroyed by the thick sheet of water under it, this process of eliminating vertical components was repeated by staggered deflectors of the same section. Though theory would require angles flattening out from 60° to 0°, yet in order to reduce the horizontal component further, 60° was retained.

Scour of 7ft. was reduced to slightly over 2 ft. and the whole jet was a sheet of foam and where things were so bad before, people were found bathing on the *pacca* floor.

As to the height of the deflectors the minimum depth required to pass the discharge was worked out from $Q=2BH^{3}$, and the balance gave the height of the deflector. The idea was not to cause any heading up as was found with baffle walls.

The Authors had discussed arrows as useful measures. His observation of their behaviour on main line falls was that, placed divergently downwards, they did considerable harm to side pitchings by diverting jets sideways which could not be avoided howsoever they might be placed.

The Speaker further remarked that a useful device which he had worked out was to widen and deepen the bed beyond designed width and then contract it again to designed width. This not only provided a stilling chamber but the final direction of the jet was neither to the sides nor downwards and thereby avoided side scour and bed scour.

The right line of design which had to be developed therefore would be a fall with steps wide enough to break up the jet, the last step before the standing wave being sloped down flatly and joined with a curve of radius equal to the depth of water, to a deflector wall which was followed by staggered deflectors of the same section in four lines and then a section wider and deeper than designed and so converging gradually to the designed section.

The actual destruction at each step could be worked out and the Speaker suggested that the experiment so far restricted to models be extended to actual works where effect of each step could be exactly seen.

The Authors attribute no damage at Jaba to these blocks but the fact was that there had been no heavy flood to test their efficiency in controling the standing wave. Having been in charge of the work his opinion was that these blocks did not break the jet so well as they should and they would have worked more efficiently if they had been placed 20 ft. lower down where the standing wave was required and with their vertical faces downstream. To illustrate the above from experiments on Salampur feeder he referred to plate II. The first set of blocks had only changed the direction of the jet. The second was in the right place though for better results we required a deflecting wall. The 3rd and 4th were simple deflectors and should have been higher up.

Mr. **Madan Lal** complimented the Authors on having brought out cleverly the scour protection value of blocks as compared to other devices used for the same purpose on river and canal works, where dissipation of energy of flowing water had to be affected.

The blocks would serve their purpose only if a standing wave formed upstream of them, since the larger part of the surplus energy was best dissipated by the formation of a standing wave. The staggered blocks killed the energy in the high velocity jet along the floor, firstly by throwing up the high velocity jet into low velocity surface water and secondly by making the high velocity water flow through acute bends between the blocks.

The addition of blocks to the downstream horizontal floors of weirs could be made without excessive cost. Their weight could be taken as effective towards balancing the uplift pressures on the floor (as had been done in the Reconditioning of Islam Headworks in 1937-38). In such cases the Speaker said that the whole of the floor downstream of the glacis could be roughened with the staggered blocks of suitable height.

CORRESPONDENCE.

Mr. **A. N. Wilson** wrote that he thought that the Paper seemed to suggest that blocks of the type recommended were necessarily of the best form and that all other types had been found less effective.

Admitting that the rectangular shape was probably better than any other, there seemed no reason for making all blocks 5 feet wide with 5 feet spacing for all works, irrespective of their size, when other dimensions might prove more effective. Actually, after building to these dimensions on two bays of the Jaba level crossing and watching the effect, it was found advisable to build the remainder of the upstream rows 4 feet wide and with 6 feet spacing, so as to relieve the great strain on these blocks. It was suggested by the Writer that the space between blocks should be slightly greater than their width in order to equalize the strain, because with high velocities the forward moving jet between the blocks did not fill the whole space.

Blocks seemed to have been used for two purposes, (1) as impact blocks at the toe of the glacis and (2) as friction blocks at the end of the *pacca* floor.

Impact blocks added to the turbulence and ensured the formation of the standing wave at an early stage, and thus destroyed most of the surplus energy, the remainder being diverted to the surface. As recommended, the blocks worked extremely well, but might be more effective if the width of the blocks bore some relation to the size of the work. And if width were no greater than the height of the blocks, as this would break up the jet more thoroughly, it would produce more violent internal friction and hence destroy more energy. A naturally formed standing wave destroyed a high percentage of surplus energy in high falls, but less in low falls, and in any case the addition of impact blocks seemed to increase the percentage of energy destroyed, but even with impact blocks some surplus energy remained.

Friction blocks were for the purpose of destroying that residual surplus energy, and the blocks recommended at the end of the *pacca* floor might do this to some extent, but their principal function seemed to be to keep the high velocity away from the bed. This might be satisfactory for river works, but on canals it was desirable that all surplus energy should be completely destroyed, for if it was not destroyed there would certainly be some bed scour or tearing down of berms. One of the finest examples of complete destruction of surplus energy in a very short distance was in the flume in which the experiments were carried out, where expanded metal grids were fixed at right angles to the stream. Such grids were not a practical proposition on a canal, but blocks or piers might be arranged to have a very similar effect. It was suggested that four or more well spaced lines of rectangular piers, not too close to the end of the *pacca* floor, with a height of two-thirds of the depth of water, width one-fifth of the depth, length two-fifths of the depth to give adequate strength and space between piers of three-fifths of depth, would be suitable dimensions, and that such an arrangement would create a large number of small eddies in most of the water, and hence destroy all surplus energy after the standing wave, in a similar way to the expanded metal grids.

Mr. **C. C. Inglis** observed that the Authors, after a totally inadequate, and in places incorrect survey of the conclusions arrived at by earlier workers, made a statement:

> "A perusal of the foregoing literature shows that devices developed from time to time for the prevention of scour did not prove to be effective for all the conditions of flow."

This statement was definitely incorrect the Writer said. The Rehbock dentated sill had proved its value, in Europe, for a very wide range of conditions—much wider than tested by the Authors, especially in the case of weirs. The design of dentated sill used by the Authors in their experiments was incorrect. Had they used a correctly designed dentated sill with two lines of teeth, excellent results would have been obtained.

As regards the Writer's design, the Authors quoted a Paper on Falls written in 1931 and published in 1933, which had been superseded by Appendix V of Central Board of Irrigation's Publication No. 10, "Irrigation Canal Falls", (February 1935).

The Writer's design was worked out in connection with Falls and consisted of—

(1) a baffle platform constructed at such a level that the standing wave, even without a baffle, would form at the toe of the fall;

(2) a baffle, of height $=h_b=C\ (d_c-d_2)$, fixed $5h_b$ downstream of the toe of the fall, where $d_c=$critical velocity depth and $d_2=$free flow depth;

(3) a cistern downstream of the baffle platform;

and (4) a deflector $=d_2/12$ at the downstream end of the pavement, d_2 being the depth of water over the pavement.

The baffle dissipated energy and stabilized flow—and was *especially useful, should retrogression occur, when it retained its efficiency.*

The deflector stabilized flow and by creating a roller with horizontal axis just downstream, piled up silt against the end of the pavement.

In this design, optimum conditions were created, and the height and position of the baffle were standardized for a standardized baffle platform. This did not mean that this design could not be adapted satisfactorily to weirs. It could be, and it had been tested against approved arrows and blocks designs and was found to give definitely better results for the conditions investigated—*vide*, for example, Annual Note for the Central Board of Irrigation for the year 1935-36—but the height and position of the baffle and deflector had in that case to be determined by model experiments; and the limitations stated by the Authors to hold for this design (that a baffle$=d_2$ height caused afflux) did not arise.

The first question to decide was, "What are the criteria of a good design?"

The Authors in this Paper had based suitability on depth of maximum scour, which occurred at a considerable distance downstream of the masonry structure; whereas the Writer held that this was unimportant, and that what mattered under three-dimensional field conditions were:

(*i*) Stability and naturalness of flow.

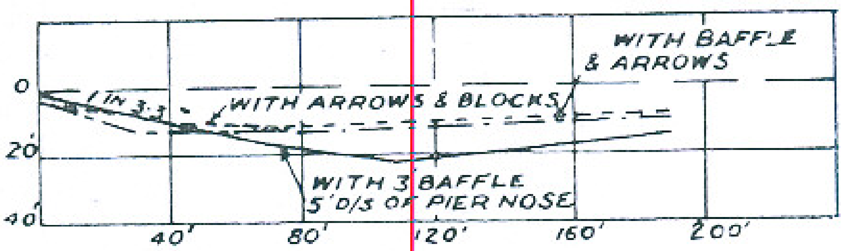
(*ii*) Level of silt *immediately downstream* of the structure,

(*iii*) Satisfactory results, even though there be considerable retrogression.

Regarding (*i*) practically all the experiments were done in parallel sided flumes, which prevented instability and cross flow: so that the conditions which, in actual practice, led to trouble were almost eliminated; whereas isotachs and fluctuations in velocities, which indicated instability, were not observed.

Regarding (*ii*) Fig. 6 of the Paper would explain the point. That figure—like all the long sections in the Paper—was misleading because it had been distorted vertically. Fig. 18 (below) showed Fig. 6 of the Paper redrawn without distortion.

FIG. 18, SHOWING FIG. 6 OF PAPER 214 TO NATURAL UNDISTORTED SCALE



This showed that, whereas sand had piled up against the downstream end of the pavement in the baffle design, there was 3 ft. scour immediately downstream of the pavement with the arrows and blocks design. Now this was with parallel axial flow, whereas with curved, eddying, cross flow, such as commonly occurred at a weir, the scour would be enormously greater, and might be very serious; yet the Authors stated;

> "It will be seen that arrows and blocks gave much better results than the baffle and deflector wall."

The Writer believed that few engineers would agree with th opinion.

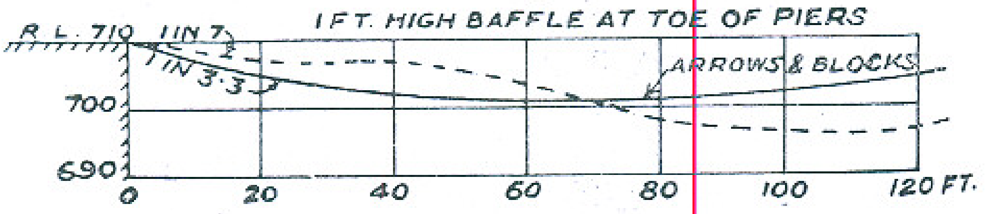
Statement X showed the satisfactory conditions downstream pavements with baffles and deflectors (extracted from Figures 3 and 4

(*iii*) did not seem to have been considered, though it was o great importance and the high efficiency of the baffle design with retro gression was one of its great merits.

The Paper did not make it clear as to what the exact conditions were in experiments shown in Figures 4 and 5; but assuming that they were comparable, (as they appeared to be, all gates being fully open in both cases and discharge the same—110,000 cusecs through one bay) Figure 19 below showed that the best result with a baffle was markedly better than the best result with arrows and blocks.

FIG. 19, COMPARING SCOUR WITH BAFFLE (C.S. 5 OF FIG. 4) WITH SCOUR WITH ARROWS AND BLOCKS (C.S. 3 OF FIG. 5)

SCALE {HOR: VER:} = 1" = 40'



This Paper dealt almost entirely with how to reduce scour below wrongly designed structures, which explained the statement;

> "A quarter of a century back the hydraulic jump or the standing wave was regarded to be a satisfactory means of the dissipation of kinetic energy which resulted from the falling water. Later on it was found that only a small portion of the kinematic energy was dissipated in the formation of the standing wave, the major portion remaining as such."

Killing energy by means of arrows and blocks might be all that could be done with wrongly designed weirs; but what the engineer required was a design in which a natural standing wave dissipated nearly all the energy; baffles, etc., being used only to increase dissipation and to stabilize flow; or (as in the case of the correctly designed baffle platforms) to force the wave to form, even should retrogression occur.

Although there was much of interest in this Paper three-dimensional conclusions had been drawn from two-dimensional work, which was unsound; and the Writer particularly deplored the attempts to

STATEMENT X FOR FIGURE 3 SHOWING DEPTH OF SCOUR, ETC.

	Slope of bed scour downstream of pavement.	Depth of scour immediately downsteram of pavement.	Maximum depth of scour below pavement. (ft.)	Distance of point of max. depth of scour d/s of end of pavement. (ft.)
FIGURE 3 OF P. E. C. PAPER No. 214.				
FULL OPENING (*i.e.*, Q=110,000 CUSECS).				
Cross Section 1 of Figure 3 Baffle 1 ft. high.				
Baffle at toe of glacis.	1 in 5	*Nil.*	14	100
Baffle at toe of piers	1 in 7	*Nil.*	14·5	120
Baffle 5 ft. d/s of toe of piers.	..	1 ft.	12	80
Cross Section 2 Baffle 2 ft. high.				
Baffle at toe of glacis.	..	1·5	16	110
Baffle at toe of piers	1 in 5	*Nil.*	12	90
Baffle 5 ft. d/s of toe of piers	..	1·5	13	40
Cross Section 3 Baffle 3 ft. high.				
Baffle at toe of glacis.	..	2·5	15	70
Baffle at toe of piers	1 in 10	*Nil.*	15	100
Baffle 5 ft. d/s of toe of piers.	..	2·5	15	70
Cross Section 4 2 ft. high baffle & deflector.				
Baffle 2′ high & no deflector.	1 in 2·5	*Nil.*	15	70
Baffle 2′ high & 1′ high deflector.	1 in 3	1 ft. piling of silt over pavement.	13	90
Baffle 2′ high & 2′ high deflector.	1 in 3	Do.	15	80
Cross Section 5 3 ft. high baffle & deflector.				
Baffle 3′ high & no deflector.	..	2 ft.	15	60
Baffle 3′ high & 1′ high deflector.	1 in 4	1 ft. piling of silt.	13	60
Baffle 3′ high & 2′ high deflector.	1 in 4	Do.	13	60

STATEMENT X (*Continued*) FOR FIGURE 4 SHOWING DEPTH OF SCOUR, ETC.

	Slope of bed scour downstream of pavement.	Depth of scour immediately downstream of pavement (ft.)	Maximum depth of scour below pavement (ft.)	Distance of point of max. depth of scour d/s of end of pavement (ft.)
I.—BAFFLE 5′ D/S OF TOE OF PIERS.				
Cross Section No. 2 of Figure 4-5 ft. gate opening (Q=36,000 cusecs).				
2′ high baffle ..	1 in 6·6	*Nil.*	1·5	10
3′ high baffle ..	1 in 6·6	*Nil.*	1·5	10
Cross Section No. 1—8′ gate opening (Q=62,500 cusecs.)				
No baffle ..	..	2·3	7	20
1′ high baffle ..	..	2	5	20
2′ high baffle ..	..	1	1	Immediately d/s of pavement.
3′ high baffle ..	..	2	2	Do.
4′ high baffle ..	..	2	5	20
Cross Section No. 3—full opening (Q=110,000 cusecs).				
No baffle ..	..	4′	18	100
2′ high baffle ..	1 in 3·3	*Nil.*	13	65
3′ ,, ,, ..	1 in 3·3	*Nil.*	14	60
4′ ,, ,, ..	1 in 4	*Nil.*	16	80
II.—BAFFLE AT TOE OF PIERS.				
Cross Section No. 4—8′ gate opening (Q=62,500 cusecs).				
No baffle ..	..	2·5	5·5	20
1′ high baffle ..	..	1	4	20
2′ ,, ,, ..	1 in 5	1 ft. piling of silt.	2	10
3′ ,, ,, ..	1 in 2·5	Do.	4	20
Cross Sections No. 5—full opening (Q=110,000 cusecs).				
1′ high baffle ..	1 in 7	*Nil.*	15	110
2′ ,, ,, ..	1 in 4	*Nil.*	15	110
3′ ,, ,, ..	..	2 ft.	14	40
III.—BAFFLE AT TOE OF GLACIS.				
Cross Section No. 6.—8′ gate opening (Q=62,500 cusecs).				
No baffle ..	..	1	6·5	20
1′ high baffle ..	..	1	6·5	20
3′ ,, ,, ..	..	1	5	20
Cross Section No. 7.—full opening (Q=110,000 cusecs.)				
1′ high baffle ..	1 in 8	*Nil.*	15	140
2′ ,, ,, ..	1 in 8	*Nil.*	12	80
3′ ,, ,, ..	1 in 8	*Nil.*	14	100

reduce this question to the level of "salesmanship" There were at least three designs which gave satisfactory, and almost equally good, results ; one being better for one set of conditions, another for another, etc ; but they all depended on :—

(*a*) improving the dissipation of energy by adding a baffle, dentated sill, arrows, or blocks, *near the toe of the fall,*

(*b*) improving velocity distribution by a deflector, dentated sill, or blocks, *at the downstream end of the pavement.*

It was believed that this dual requirement was first demonstrated and standardized at Poona.

The **Authors** in replying to the criticisms, thanked the members of the Congress who had taken part in the discussion.

Replying to Messrs. Montague and Blench, the Authors said that in most of the cases proper standing waves never formed. The partial type of standing wave that occurred on most of the existing works could only dissipate a small portion of the total kinematic energy. The surplus energy caused big scour holes on the bed and also side erosion. Mr. Montague himself had said, that due to the practice of adopting cheap designs in the Punjab, a proper standing wave could not be ensured. The Paper mostly deal with remedying wrong design which existed in very large numbers in the department.

The staggered blocks advocated in thisPaper were quite different from the friction blocks of Mr. Montagu. The first row of staggered blocks deflected the high velocity filament of water towards the surface. The bed velocities downstream of the blocks were rendered very low by the construction of the blocks.

Regarding the effect of various physical factors on model results it must be said that all the different factors were taken into consideration in model studies that were conducted in the Irrigation Research Institute. The close agreement obtained in many cases between the model and the prototype results justified the reliance which was placed in model tests.

Mr. Sawhney required the sand particles used in the model to be reduced proportionately to the scale. This had already been shown by German and American hydraulicians to be not necessary. To the rest of his criticism it was only necessary to say that the models were tested under all conditions of flow.

The experiments as suggested by Mr. Som Nath Kapur would be tried in the laboratory when time permitted.

Replying to Mr. Wilson's criticism regarding the width of the blocks the Authors said that the width of blocks depended upon the magnitude of the discharge experienced on the work. The arrangement of blocks suggested in the Paper was found from a series of experiments to be the most satisfactory.

Mr. Madan Lal's criticism did not call for any particular remarks.

In reply to Mr. Inglis's written correspondence, the design of the dentated sill tested in the laboratory was obtained from Professor Rehbock through Messrs. Duncan, Stratton & Co.

In a number of cases the baffle as designed by Mr. Inglis had been tested against blocks and in almost all cases blocks gave much better results.

Subsequent experiments in which the sides of falls were made of earth and sand gave similar results, with regard to the blocks, to those obtained in the Paper (Photo No. XII). In these tests, the fluctuation in velocities was observed and the isotachs were drawn. From Plate VI it was shown that the line of maximum velocity in the case of a baffle, shot on to the floor, downstream of the baffle while in the case of a blocks it remained near the surface (Plate VII). The isotachs at similar points were much more regular when blocks were used than when the baffle was placed, at that position instead of blocks. On recent model experiments, observations of the downstream bed of the river at Panjnad weir had shown that on the bays in which blocks and arrows were constructed no scour had occurred, while in those where these were not constructed a big scour hole had formed. These results again confirmed the usefulness of blocks and also that model results obtained in the laboratory were comparable to those obtained on the actual work.

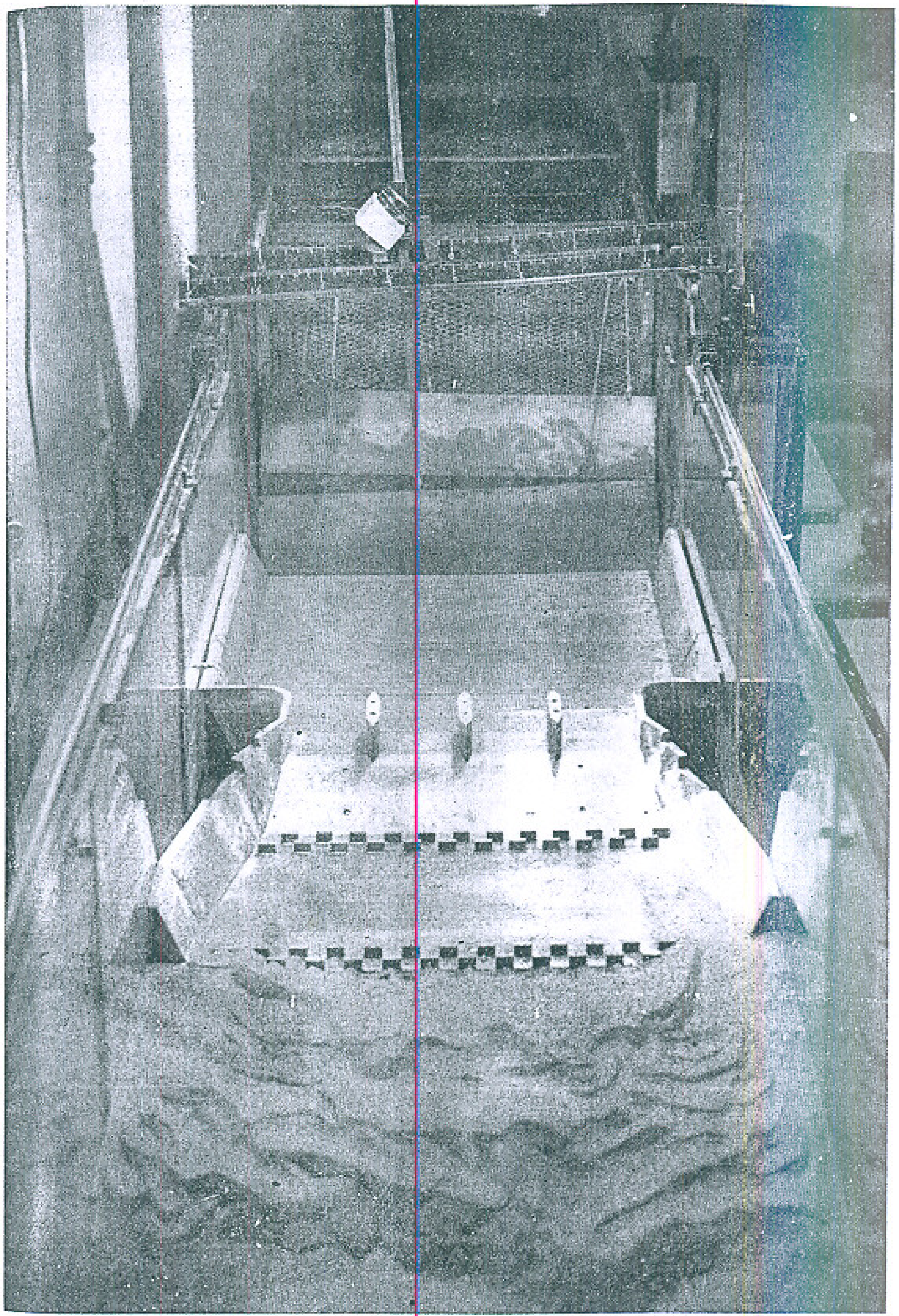
CORRESPONDENCE.

Prof. **Th. Rehbock** thanked the Council for the opportunity of contributing to the discussion on the Paper.

The Speaker said that he had been concerned for many years with Indian Flat Weir problems and had expressed his views on these weirs to numerous engineers from India who had visited him. Since March 1936, he had been carrying out special tests which were directed to the protection of Merala Weir from scour in the River Hydraulics Laboratory at Karlsruhe.

In this Paper the Authors recommended rectangular blocks on the slope of the weir and, downstream, on the pitching in several adjoining rows.

Blocks of such a type, previously used in Europe and America, had had but little success in scour prevention as small, fast revolving eddies



(Photo No. XII). Haveli Project Fall.
Design No. 2.

with vertical axes formed at the side of the blocks which took up gravel and made scour holes in the concrete near the blocks. At Kloster (Granbunden, Switzerland) where the apron had a large number of staggered rows of blocks, many of them had been torn out in consequence of attack on the apron. The owners, Bundner Power Stations, Ltd., in 1924 set the Writer on carrying out model tests which cleared up the cause of these troubles and showed which forms of block were least disturbed by the action; but these tests also showed the unsuitability of this arrangement because a single dentated sill on a reduced apron furnished far better protection from scour than the staggered blocks.

The tests at Lahore dealt exclusively with partial models in glass flumes, a method developed by the Writer in 1905. The instruments used for accurate determination of water levels and velocities were practically the same as designed by him and made by his accurate fitter, Franz Kneller, in Karlsruhe. They were certainly reliable. Check tests of the maximum scours reported from Lahore were carried out in Karlsruhe and showed in general close, coincidence with Lahore observations. One single Lahore scour line showed very considerable deviation from the values found at Karlsruhe, and was surely wrong; it is not mentioned in the Paper.

With regard to these tests, however, it should be noted that the greatest depth of scour on which great stress was laid in Lahore was not the most important factor for a weir. Far more important, in the Writer's opinion, was the angle of the slope of the scour fixed by the tangent from the downstream end of the apron to the curve of the scour, or again, the relation of the greatest depth of scour ot its depth from the end of the apron.

Unfortunately, these readings were not given in the Paper and the accompanying drawings also did not show clearly enough these important values.

The Karlsruhe tests to determine the tangent to the scour curve for the two groups of five rows of staggered blocks at Merala, as per Plate I fig. C., showed a scour tangent of 280 approaching the angle of repose of the sand under water. (See section I of plate VIII). This tangent was so steep that it seemed to the Writer objectionable to rely on it, especially as the specially important three downstream rows of blocks were built not on the solid concrete apron, but on the loose pitching blocks. The Writer arrived, therefore, at the conclusion that the staggered rows of blocks were not hydraulically satisfactory, as he considered the formation of a flat angle of scour (not found in this case) the most important function of any efficient anti-scour apron.

Besides the tests with staggered blocks or arrows and blocks in the Paper, tests on the Writer's patent dentated sill were mentioned; but the Authors had made a serious error here. For whereas his patent specified as an important necessity that the dentated sill should be located at the downstream end of the apron, at Lahore, the dentated sill was 60 feet from the end, vide Plate I, fig. B. In such a position, naturally the dentated sill was quite powerless to prevent scour. In Lahore, the reduction of maximum scour due to this wrongly sited sill with maximum specific flow of 162·4 cusecs, per foot was given, therefore, as 1·85 ft. only.

Although it was clear that the action of a dentated sill 60 feet from the end of apron could not be used for comparison, this was exactly what the Authors had done. On page 145, the Author gave their opinion that the Rehbock sill was inferior to blocks ; on page 120 they mentioned erroneously—" on a model of Marala Weir, the construction of a sill as designed by Rehbock." On this he must make it clear that this totally misunderstood arrangement of the dentated sill which was tested in Lahore, as shown on Plate I, fig. B and directly contradicting one of the most important points of this patent, did not originate with him but was sent to him from India ; he immediately protested on its reaching him.

In the first claim of his Indian patent 11255, he expressed the idea thus :—

> "A low sill disposed at the extreme downstream end of said apron, and at the exit of the water from the surface eddy formed by the water on said apron above the shooting current, said sill being provided with a series of teeth having a steeply inclined face directed upstream."

One of the Authors had informed him that he was unaware that the Writer's patent said anything about the *site* of the sill ; but he considered that the Authors had had sufficient opportunity to acquaint themselves with his specification, and should have done so before they expressed to the Punjab Engineering Congress a view contrary to all previous experience.

Naturally, he found it most unfortunate that an arrangement which had proved itself sound on several hundreds of installations in most civilized countries in the world, should be condemned on the basis of tests made on an erroneous model.

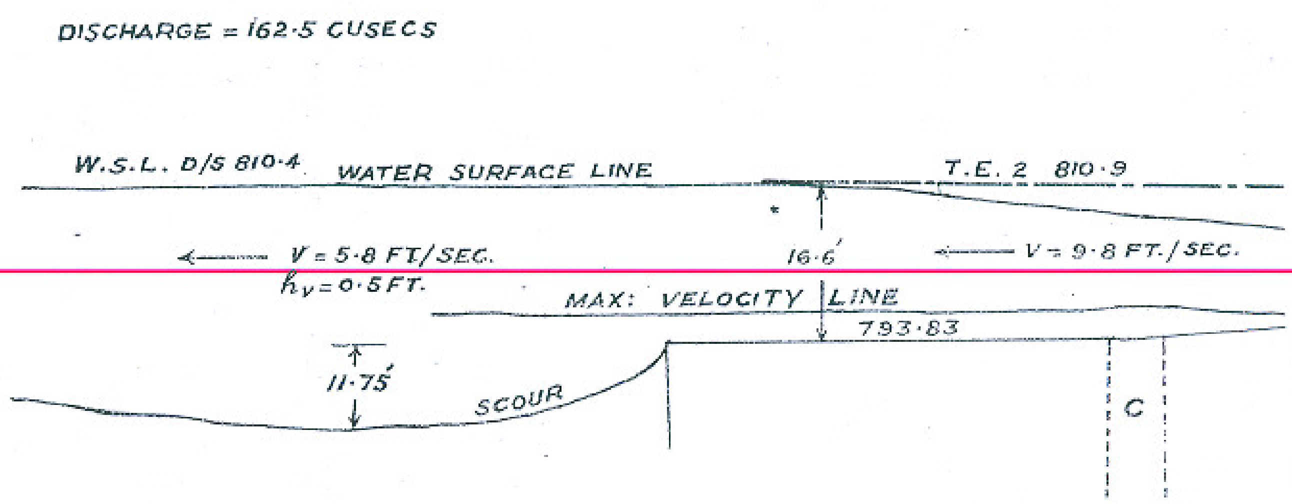
As his tests for the Merala weir showed clearly, it was possible, for example, on this weir by using dentated sills to avoid the need for altering the slope of the downstream side of the weir from 1·15 to 1·4, and the lowering of the apron by 4 ft. with its attendant wet foundation difficulties, and thus to save a large sum. (See section 2 of Plate VIII).

For the tests showed that a satisfactory solution would have been attained with dentated sills which would for *certain* have avoided endangering the weir by scour.

The Karlsruhe tests with dentated sills had not only achieved a lessening of the maximum scour as compared with the staggered blocks, but also reduction of the scour tangent angle from 28° to 12°. The angle of 12° was an angle which excluded all possibility of damage from scour.

He regretted having taken up this attitude in regard to the Lahore tests, since all his earlier communications appeared to have been disregarded, and he was not prepared quietly to accept the publication of these incorrectly carried out tests at Lahore in the Proceedings of the Punjab Engineering Congress, for such publication could have repercussions on him not only in India, but also outside its frontiers.

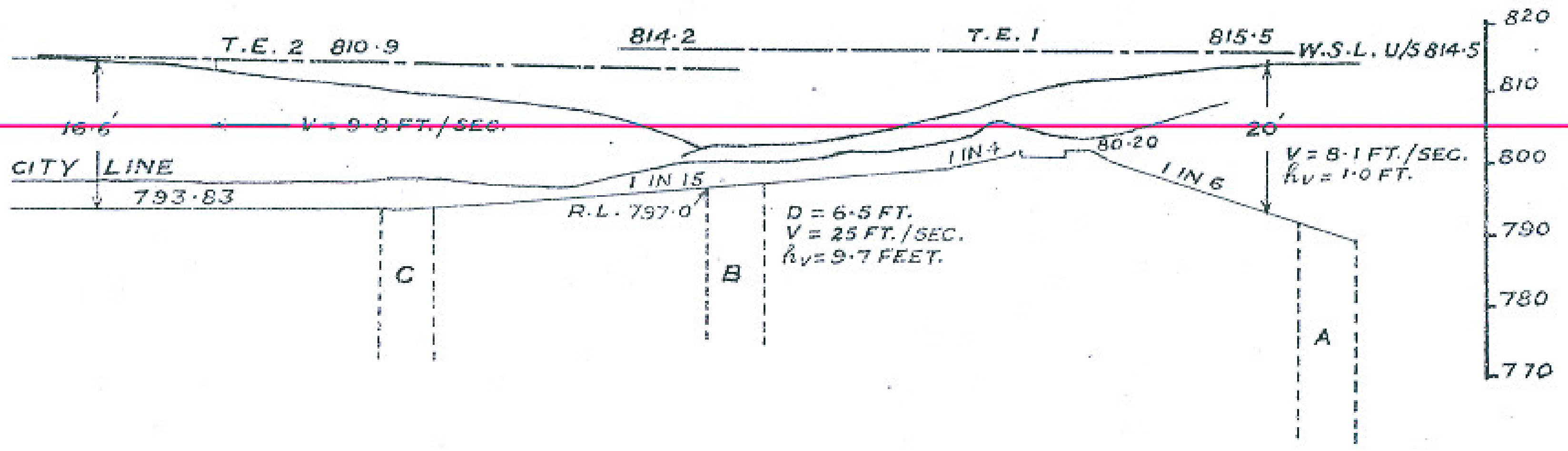
MARALA



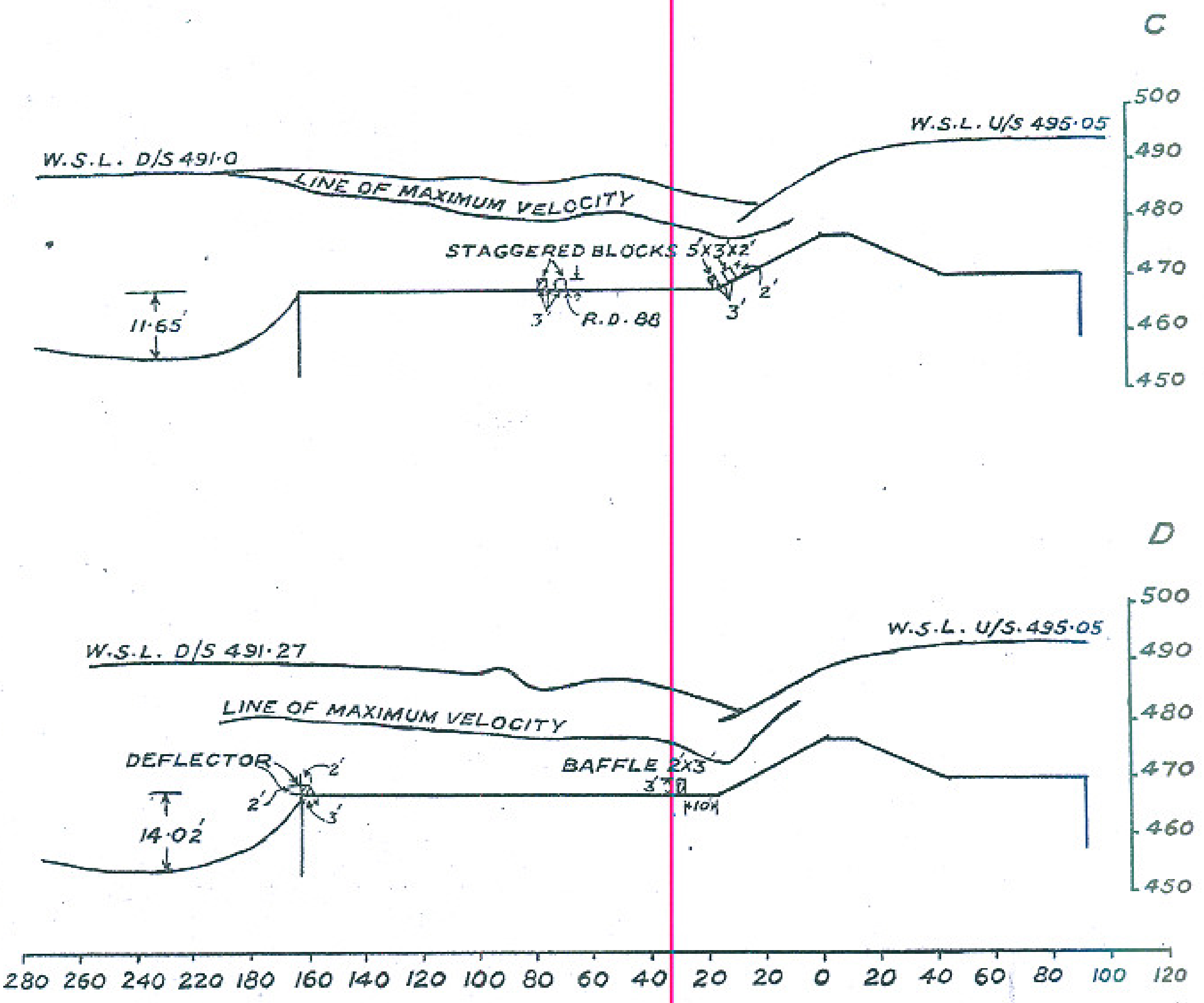
DISCHARGE = 162·5 CUSECS
W.S.L. D/S 810·4
WATER SURFACE LINE
T.E. 2 810·9
V = 5·8 FT./SEC.
hv = 0·5 FT.
16·6′
V = 9·8 FT./SEC.
MAX: VELOCITY LINE
793·83
11·75′
SCOUR
C

MARALA WEIR

PLATE IV
PAPER NO. 214



PUNJAB ENGINEERING CONGRESS.
1938.



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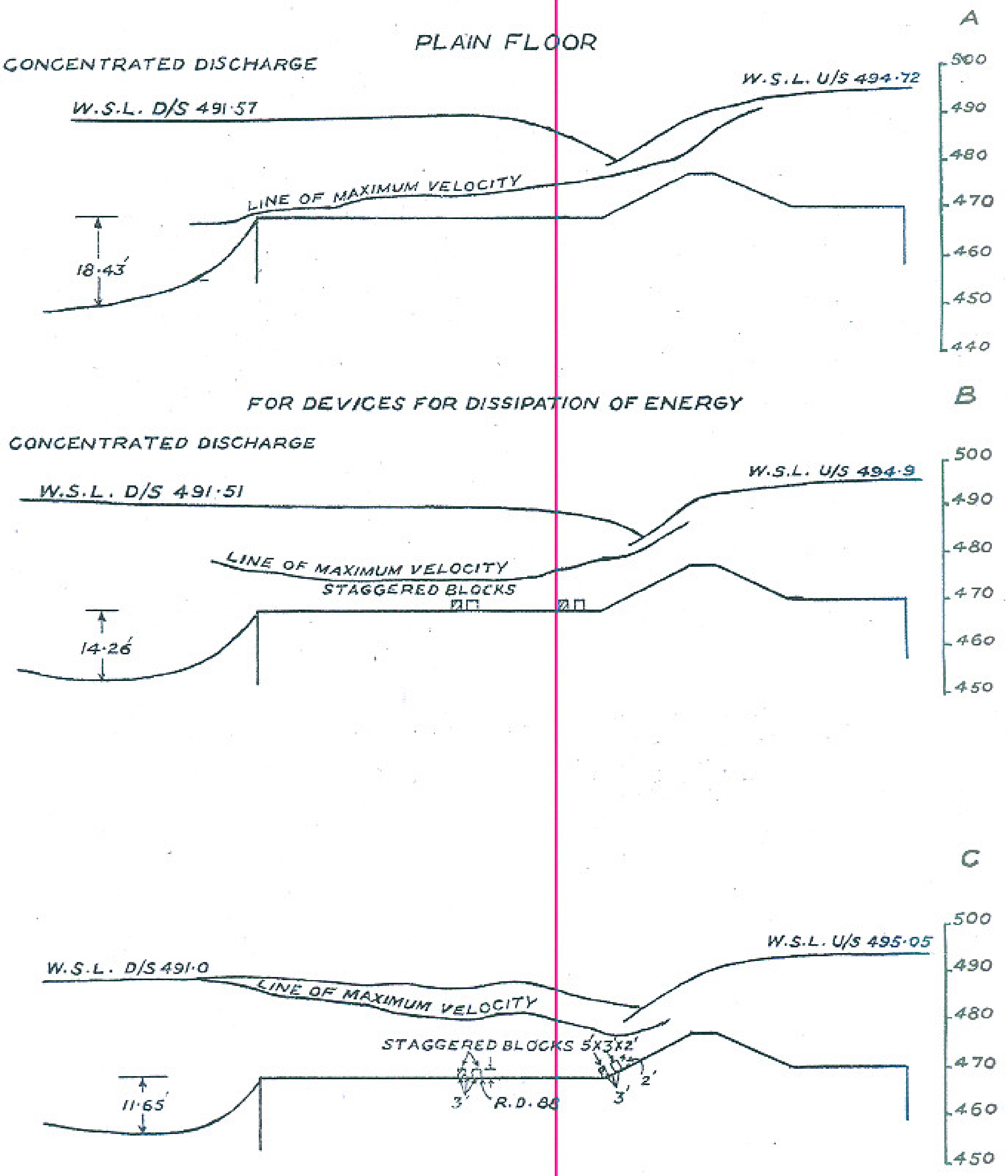


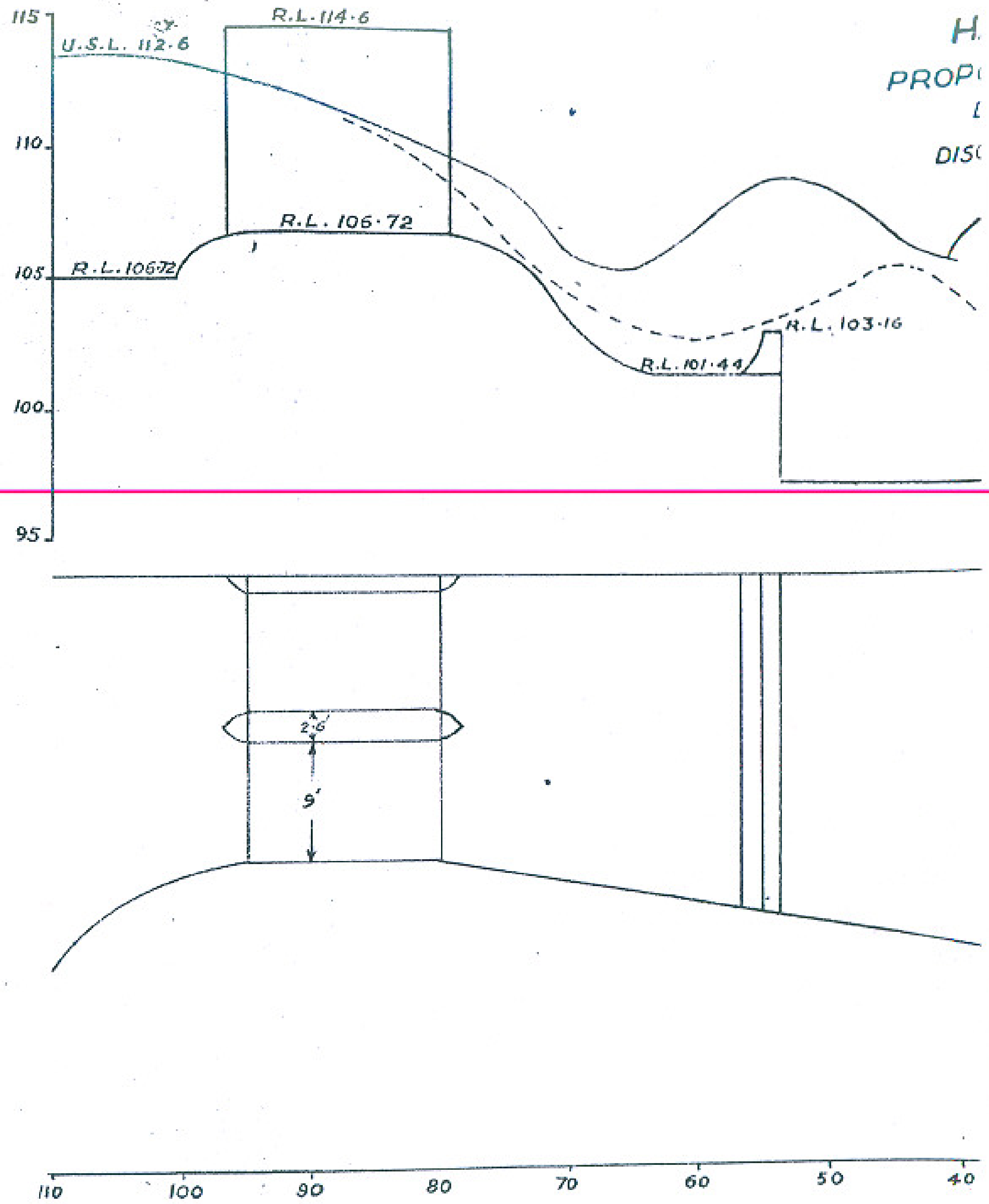

H.
PROP
DISC
U.S.L. 112·6
R.L. 114·6
R.L. 106·72
R.L. 106·72
R.L. 101·44
R.L. 103·16
115
110
105
100
95
2·6'
9'
110
100
90
80
70
60
50
40

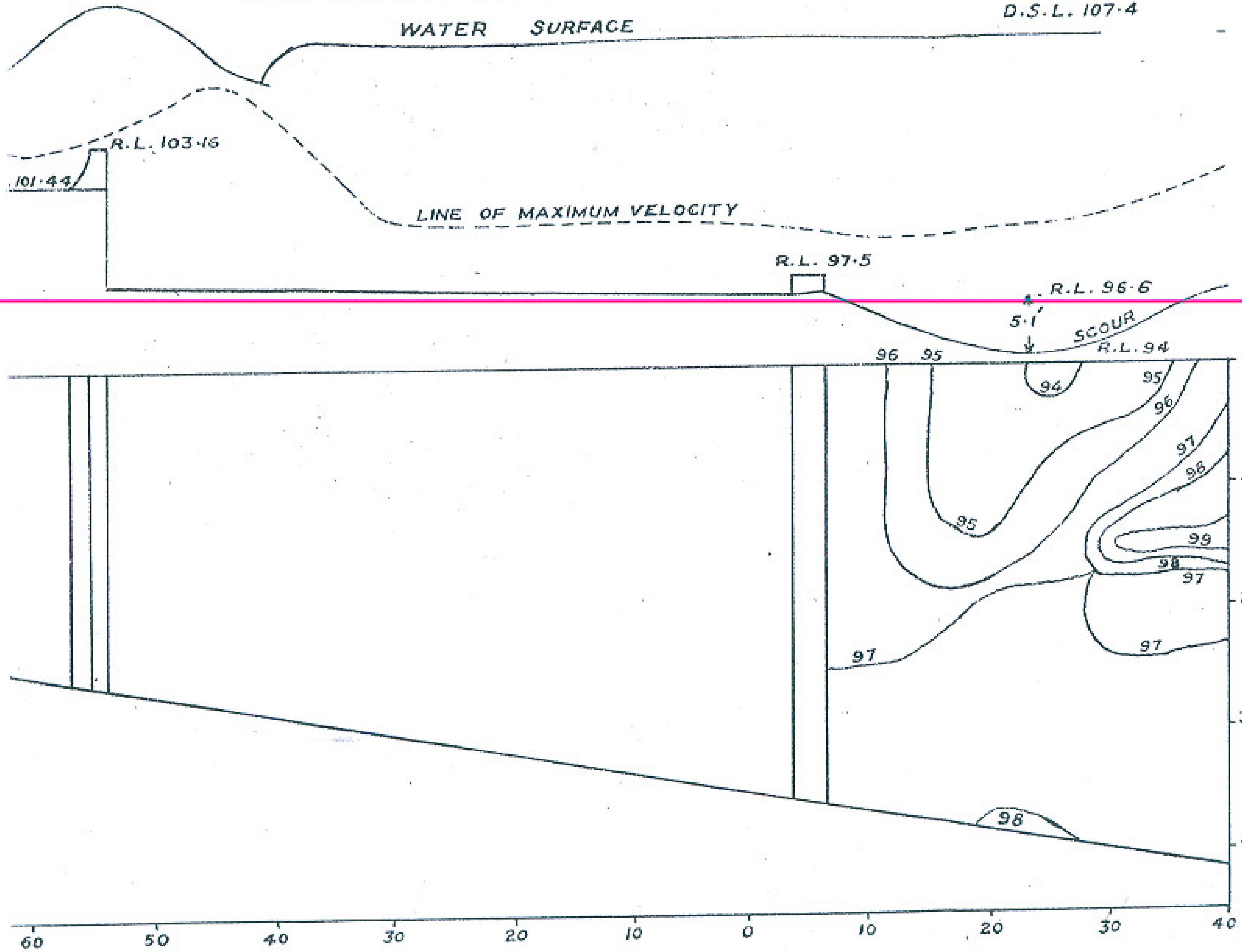
PLATE VI
PAPER NO. 214

HAVELI PROJECT

PROPOSED FALL AT R.D.18000

DESIGN NO. 4 (INGLIS)

DISCHARGE 1930 CUSECS



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1938

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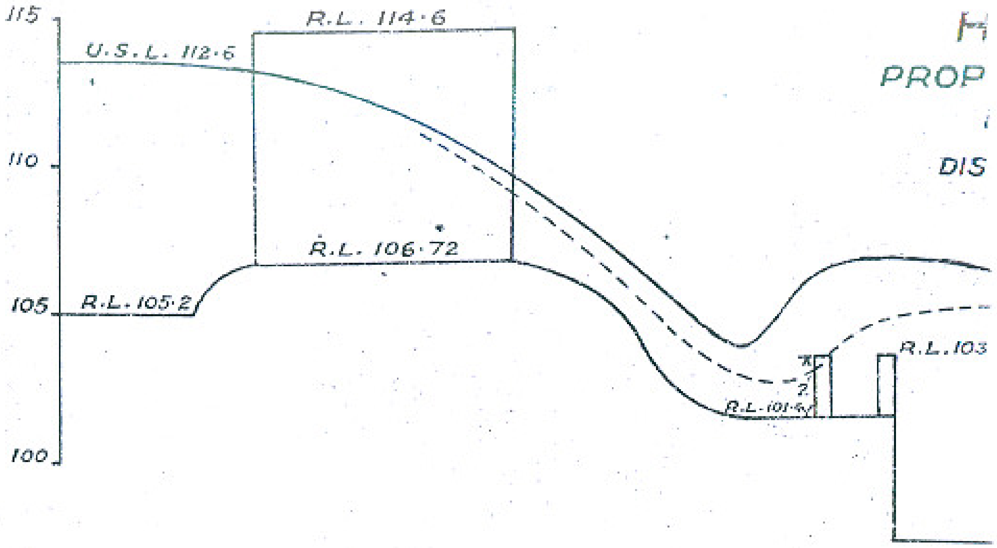
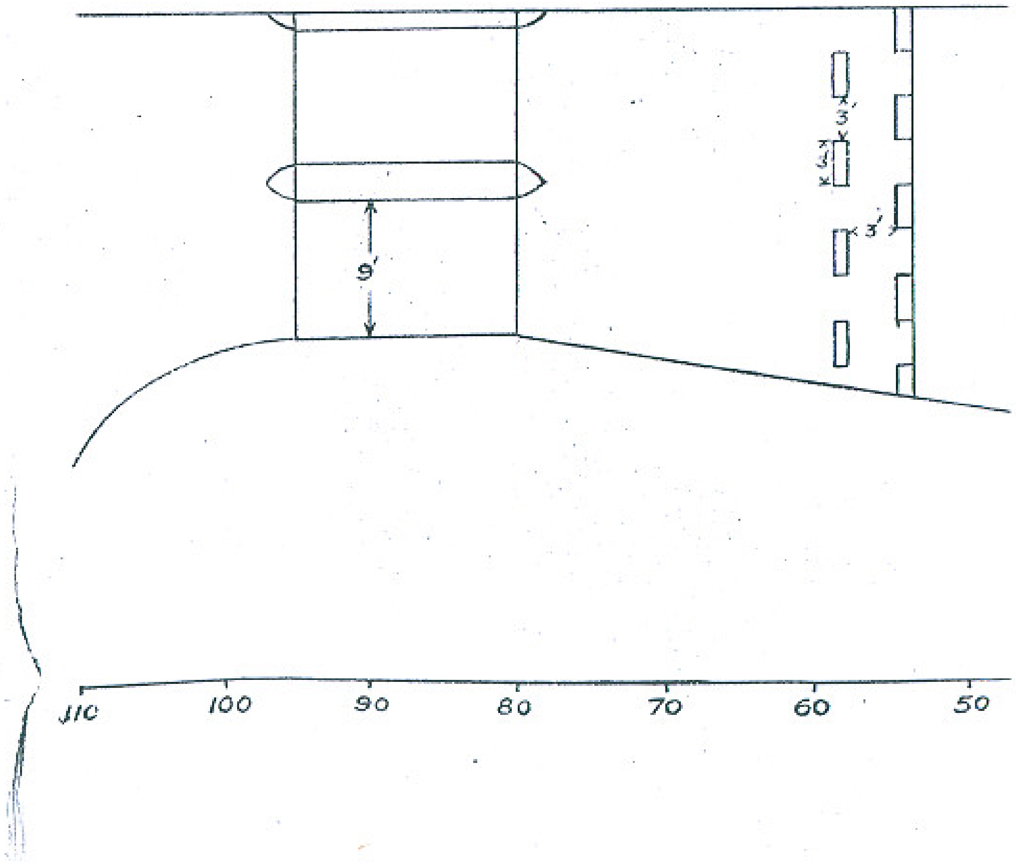


115
110
105
100
U.S.L. 112·6
R.L. 114·6
R.L. 106·72
R.L. 105·2
R.L. 101·6
R.L. 103
2'



9'
3'
3'
3'
100
90
80
70
60
50

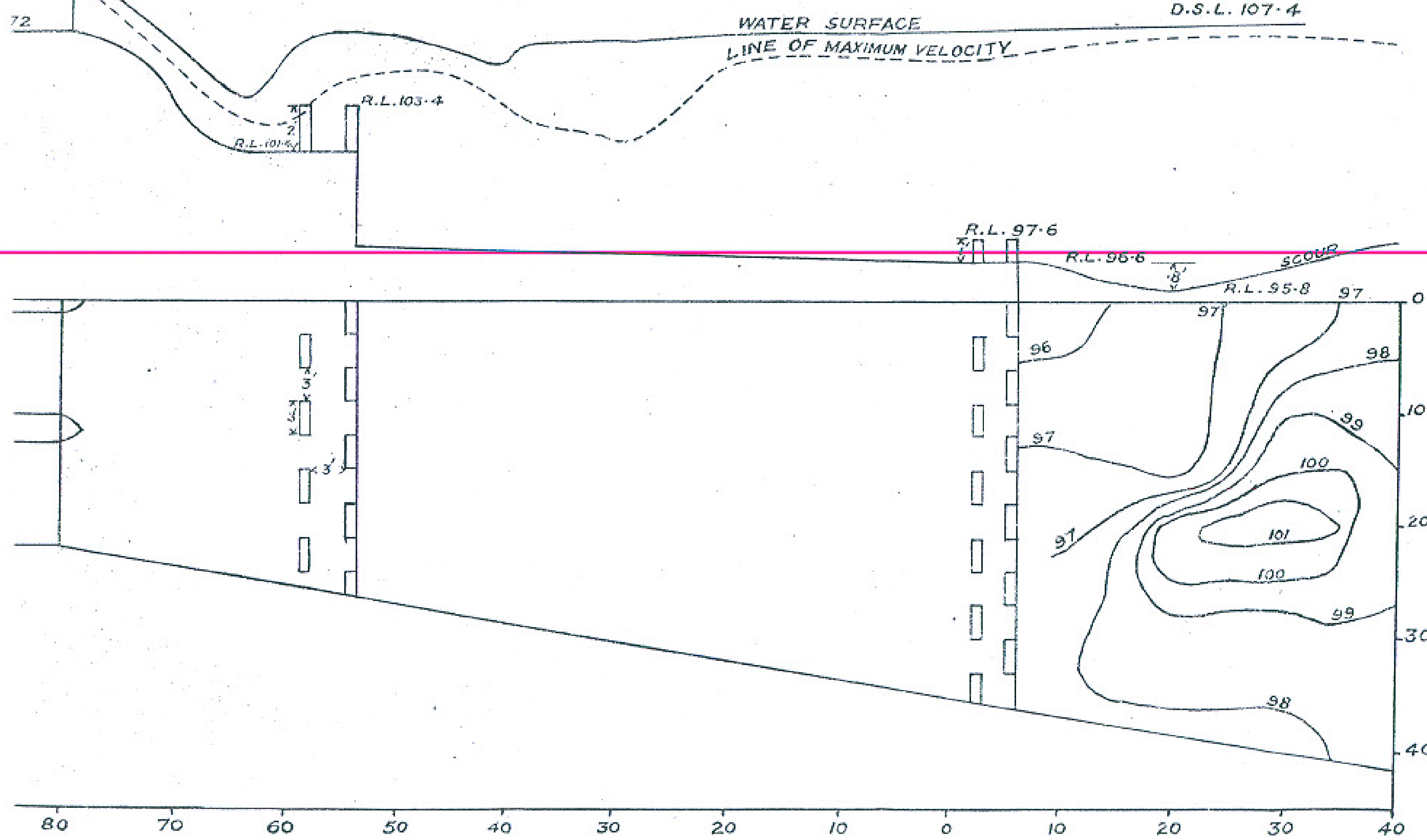
PLATE VII
PAPER NO. 214

HAVELI RROJECT

PROPOSED FALL AT R.D.18000

DESIGN NO. 4 (INGLIS)

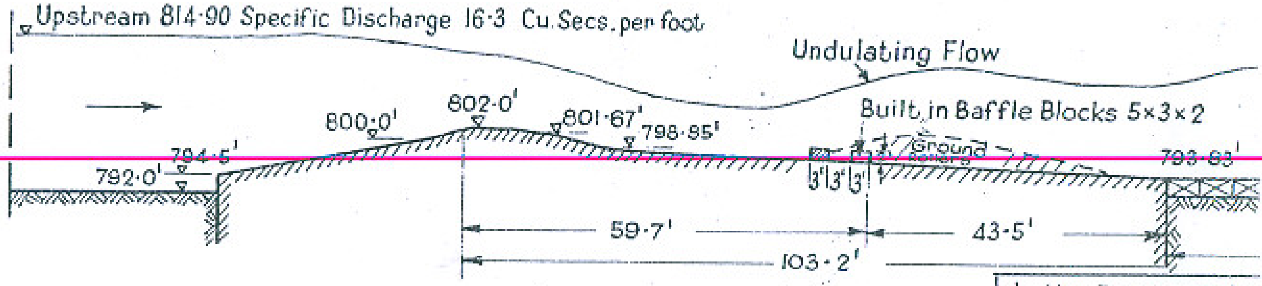
DISCHARGE 1930 CUSECS



TESTS ON BED FORMATI

on a Weir with a Downs

SECTION 1 ARRANGEMENT OF A LOOSE BLOCK APRO
ROWS OF BAFFLE BLOCKS ON THE SLOP
(LATER PROPOSAL OF THE CENTR



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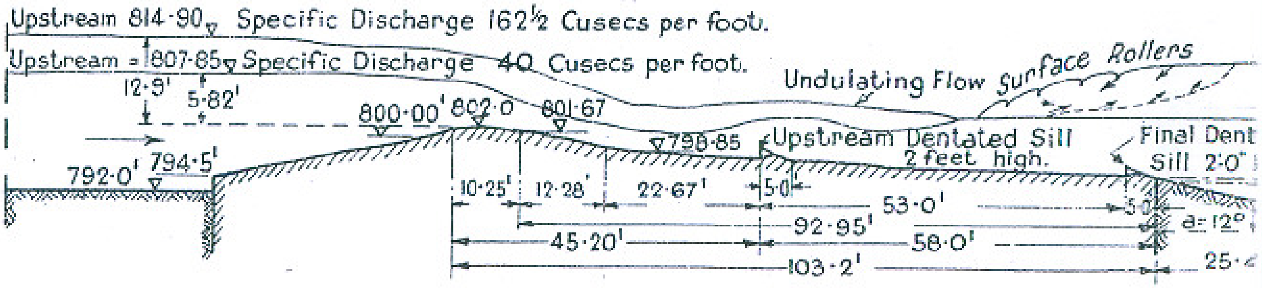
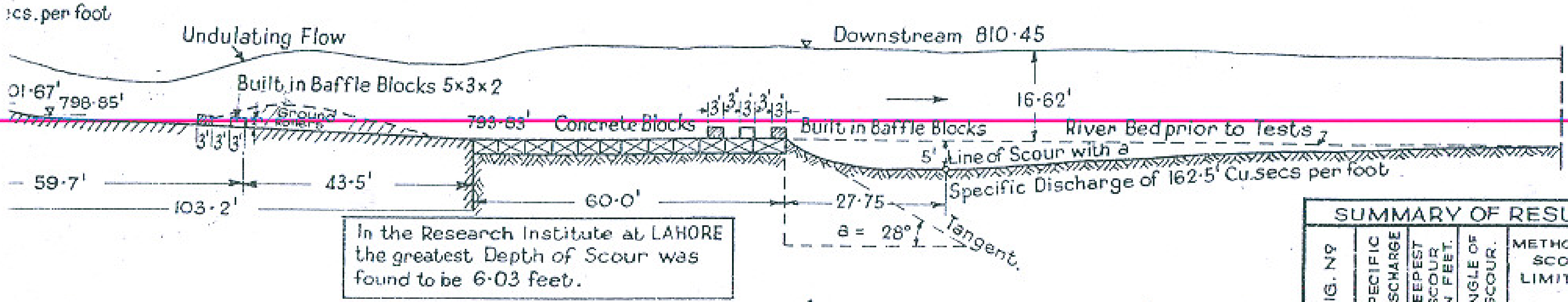
SECTION 2 ARRANGEMENT OF TWO DENTATED SILLS



STS ON BED FORMATION AND SCOUR LIMITATION.

on a Weir with a Downstream Apron with 1:15 Slope.

NGEMENT OF A LOOSE BLOCK APRON 60'-0" WIDE DOWNSTREAM OF THE WEIR & SEVERAL OF BAFFLE BLOCKS ON THE SLOPE & AT THE END OF THE LOOSE BLOCK APRON. (LATER PROPOSAL OF THE CENTRAL BOARD OF IRRIGATION AT LAHORE, STAGGERED BLOCKS.)



ANGEMENT OF TWO DENTATED SILLS 53 FEET APART (REHBOCK'S PROPOSAL.)

SUMMARY OF RESULTS				
FIG. Nº	SPECIFIC DISCHARGE	DEEPEST SCOUR IN FEET	ANGLE OF SCOUR	METHOD OF SCOUR LIMITATION
1.	162·5	5·0	28°	LOOSE BLACK APRON & 5 ROWS OF CONCRETE BAFFLE BLOCKS
2.	162·5	4·4	12°	REHBOCK'S PROPOSAL WITH 2 DENTATED SILLS.