PAPER No. 237

IMPROVED ADJUSTABLE PROPORTIONAL MODULES AND OPEN FLUME OUTLETS

By

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Part I.

Adjustable Proportional Modules.

In the remodelling of channels in the Lower Jhelum Canal Circle in 1928 and 1929 adjustable proportional modules (A.P.M.), as described by Mr. Crump in Irrigation Branch Paper No. 26. Class A, were constructed with their setting at $0{\cdot}6d$ (d=designed full supply depth in the channel). Actual experience of the working of these channels showed that

(*i*) The channels had a tendency to silt, because the A.P.M.s, as constructed, did not take their due share of silt.

(*ii*) The co-efficient of discharge "C" in the discharge formula of the A. P. M. ($q = C\,by\,\sqrt{h}$) was not found to be constant, but showed considerable variation.

(*iii*) The minimum Modular Head (M.M.H.) required for the A. P. M. was found to be considerably more than that given in the above mentioned Paper, when the outlets were narrower than ·5 ft., and the depths on crest were more than 2·0 ft.

Quantitative silt experiments were carried out by the Author on A.P.M.s and some other outlets, as described in Paper No. 168 of the Punjab Engineering Congress, 1933. These tests showed that A. P. M. outlets, constructed according to the design recommended by Mr. Crump in I. B. Paper No. 26 with a $0{\cdot}6d$ setting, did take a little less silt than their proportional share, and that the silt conducting power of the A. P. M. outlet could be considerably improved by modifying the design of its upstream

approaches, and by setting the outlet lower than 0·6*d*. It was further shown in these tests that the modified A. P. M., set at 0·6*d*, was not only a proportional distributor of supply, but also took proportionate share of silt, when its upstream approaches were designed as per type A described in the Author's Paper No. 168, and that for further improvement in the silt conducting power, the setting of the outlet needed to be lowered.

Detailed experiments were carried out by the Author to obtain the discharge co-efficients and M. M. H. of A. P. M. outlets, and were described in Paper No. 176 of the Punjab Engineering Congress, 1934. The piezometric tests as described therein, showed that the main cause of the considerable variation of co-efficients was the instability of the jet leaving the A.P.M. Block. The jet was non-adherent, and liable to pressure inflation. The actual control section formed on the glacis beyond the level portion "*H*" downstream of the A.P.M. Block. The minimum modular heads also were, therefore, considerably more than those given in Mr. Crump's Paper No. 26 mentioned above.

In May 1934 the Author's Papers Nos. 168 and 176, mentioned above, formed the subject matter of a discussion between Messrs. Crump, Jesson and the Author. The unanimous conclusions of these discussions are described in Appendix I.

It was considered advisable to adopt the upstream approaches of the A.P.M. and open flume outlets, as shown in Plate Nos. 2, 6 and 7 and mentioned in paragraph 8 of Appendix I. It was, however, considered advisable to try a continuous slope of 1 in 15 in the outfall of an A. P. M., accompanied by a tilt in the roof block to remedy the hydraulic shortcomings mentioned in paragraph 11 of Appendix I.

In this Paper an attempt is made to describe briefly the final experiments, carried out by the Author, to determine the discharge co-efficients and M. M. H. of A. P. M. outlets and to perfect them as submerged semimodules. The experiments described in this Paper were carried out under the guidance of Mr. E. S. Crump.

Experimental Station.

The experimental site was selected near Shadiwal at the Bhimber Weir, where there is a fall of about 10 ft. in the Main Line, Upper Jhelum Canal. The arrangement of the experiments is shown in Plate No. 1.

A very important feature of this arrangement was the instaliation of an adjustable spillway syphon to insure a steady water level in the tank *A*, where the depth on the crest of the outlet was measured during the course of the observations.

In chamber *C* piezometric pressures were recorded. A special arrangement in the form of a funnel at the end of the pressure recording tube was arranged to deaden the pulsations in all pressure readings. A special form of spillway syphon with instantaneous and automatic make and break arrangement was installed at *H* just before the calibrating tank. This ensured elimination of any possible error in calibration of the standard weir *F* due to the varying water levels in the portion of the watercourses from *F* to *M*.

All gauge readings and pressure observations were made by means of Hook Gauges, capable of reading accurately up to 0·001 ft.

The standard weir *F* was very accurately calibrated by means of measurements in the tank *L*. This weir was used for all subsequent measurements of discharges of the experimental outlets.

The measurements of minimum modular heads were very accurately done as the slightest variation of discharge was registered by these special hook gauges.

Design of the Experimental A. P. M.

A drawing of the A. P. M. tested is given in Plate No. 2. The design is described in detail in paragraph Nos. 10 to 14 of Appendix I by Mr. Crump, and the structural details are shown in Plate No. 2.

A slight modification in the design of the roof block was subsequently found necessary. A tilt of 1 in 10 in the lemniscate curve, as specified in paragraph 12 of

Appendix I, was found to be insufficient. It resulted in starvation of the jet in the vertical plane, as the jet left the A. P. M. block. '*Y*' depth of water at the end of the A. P. M. block did not exert '*Y*' pressure but something less. Generally the A.P.M. did not run full bore, A.P.M. block was then modified and a tilt of 1 in $7\frac{1}{2}$ was given to the lemniscate curve.

When all these defects had been removed the pressure observations in the subsequent work showed that pressure at the floor level at the end of A.P.M. block was in no case less than '*Y*'. In some cases it was more than '*Y*' by 5 to 10 %. It was observed that the pressure at this point did not change when the hydraulic jump was brought up the glacis to observe M.M.H. This ensured that there was no starvation of the jet in the vertical plane, and that the jet leaving the A.P.M. block with '*Y*' depth was perfectly adherent, and not liable to pressure inflations. It was, therefore, concluded that the section of the jet with '*Y*' depth at the end of the roof block was a perfect control section. It was not affected by the position of the jump, or the downstream water level in the water-course, until the buffer of the jump actually fell against it, and fouled it.

Results of the Experiments.

The results of these experiments on A.P.M.s are tabulated in Appendix II. The pressure observations are omitted to save space. The necessary pressure conditions for a perfectly adherent jet at the end of the roof block were actually observed, and ensured in every observation.

Discussion of the Results.

The variation in the co-efficient of discharge in the final improved design has been very much reduced in comparison with that in the design of A.P.M.s given in I.B. Paper No. 26 by Mr. Crump, and the one adopted by the Author in Paper No. 176 Punjab Engineering Congress. The curve of the variation of "*C*" for the proposed design is plotted in Plate No. 3. The co-efficient "*C*" varies with the ratio of the width "*B*" of an A.P.M. and '*Y*', the height of the opening. The

variation of "C" with "H" has been made negligibly small by improving the design of the roof block.

Minimum Modular Head (M.M.H.)

M. M. H. results have been produced in the form of curves in Plate No. 4 for easy reference, and use in practice. The M.M.H. results for an A.P.M. are capable of mathematical treatment, but it is too cumbersome to be of any practical utility. The M.M.H. curves drawn in Plate No. 4 show the variation with "B/Y" and "h".

It is evident from the curves in Plate No. 4 that the M. M. H. in some cases is very high, being of the order of 90 % of "h". It was considered advisable to try some cheap device to reduce the working head required in practice.

Recommendation for Existing Outlets Built as per Mr. Crump's Original Design.

The A.P.M. design as per Irrigation Branch Paper No. 26 is likely to remain in use for a long time, as a large number of outlets have been constructed according to this design. It will take a long time before they are replaced. The curves of M. M. H. given in Plate No. 4 are equally applicable to that design, erring on the safe side, because the glacis in these observations is flat, and the M. M. H. results cannot be materially different from those on a level floor, though the wave on a level floor is somewhat unstable.

Mr. Crump's A. P. M. as per Irrigation Branch Paper No. 26 is no doubt a submerged orifice with a hydraulic jump, provided the jump remians on the level floor within the length "H" downstream of the roof block. The formula $q = cBY\sqrt{h}$ is correctly applicable. The design now proposed has a much reduced variation of the discharge co-efficient on account of a perfectly adherent jet leaving the A. P. M. block, and due to the improvements in the lemniscate curve of the roof block.

On channels fitted with A. P. M.s constructed according to the original design of Mr. Crump given in Paper No. 26, when the jump does not take place on the level

floor downstream of the roof block, immediate relief to the starving tails can be given by lengthening the level floor. Wherever this structural change is not possible, the roof block should be adjusted after determining the actual co-efficient of discharge in the formula $q = cBY\sqrt{h}$ by means of calibrated portable iron flumes. These portable flumes were devised by the Author in 1931, and their calibration curves were obtained by tank measurements. In the case of outlets suffering from lack of command, the outlets should be redesigned adopting M. M. H. according to Plate No. 4. To facilitate the design of an A. P. M. for varying values of the co-efficient of discharge in the formula $q = cBY\sqrt{h}$, a monogram was published by the Author in Plate No. 7 of Paper No. 176, Punjab Engineering Congress, 1934.

General Remarks on the Proposed Design.

The remarks concerning proportionality, flexibility, adjustibility, and immunity from being tampered with as described in Irrigation Branch Paper No. 26, Class A, equally apply to the A. P. M. described in this Paper.

The base and cheek plates of the existing A. P. M. outlets can be re-used, while adopting the design described herein. Only the roof block has to be recast.

The depth on crest in this design is to be measured at the end of the roof block on the downstream side. There is no level crest. Checking of "Y" and "H" in practice will be a little difficult. In order to overcome this difficulty a special type of "Y" rod has been devised.

The discharge gauge of the proposed A. P. M. design will be of the same type as adopted in Irrigation Branch Paper No. 26, Class A. A gauge designed for an average co-efficient of 7·4 will do. In no case will the variation of the correct discharge be more than 5 % from that read by the gauge. It would just suffice for field inspection to read from the gauge that the discharge was about correct.

A Special Type of A. P. M. for low M. M. H.

The design of the A. P. M block was kept the same as described before in this Paper, and, therefore, the co-efficients of discharge were found to be unaltered in the formula $q = c B Y \sqrt{h}$.

A space of 1·0 ft. was left open downstream of the A.P.M. block, and a portion of the outfall was covered to prevent the buffer of the jump fouling the control section. This arrangement formed a sort of surge chamber. Various forms and lengths were tried. The cheapest, the simplest, and the most efficient device was found to be as sketched in dotted lines in Plate No. 2.

The outfall is covered for 4 feet length horizontally, keeping the bottom level of the cover 0·05 ft. above the "Y" of the A. P. M. The upstream edge is rounded, forming a quadrant of 0·1 ft. radius. Wooden planks were used for this arrangement in the experiments, but a cement concrete slab should be used in practice, and would be quite cheap. It was found that closing the open space between the A. P. M. and the cover did not affect the discharge of the improved A. P. M. as described in this Paper, because the jet leaving the A. P. M. block has been designed to be specially immune from pressure inflations. The closing of the open space between the A. P. M. block and the device for low M. M. H. would affect the discharge of the outlets in the case of designs as per Mr. Crump's Paper No. 26, but it was actually checked at the experimental site by Mr. Nand Gopal, I. S. E., and S. B. Bakshi Singh Sidhu, I. S. E., that there was no increase in the discharge of the improved type of A. P. M. advocated in this Paper, even when the open space on the downstream side of the roof block was closed.

Results of Special A. P. M.

The M. M. H. results are given in col. 9 of Appendix II. The results are plotted in the form of curves given in Plate No. 5 for use in practice. The results clearly show that the M. M. H. for the A. P. M. is reduced by this device by 30 to 40 per cent.

The device tried in these experiments is very simple and inexpensive. By adopting a curved and longer surface for the surge chamber, considerably better results could be arrived at than those obtained in these experiments, but the cost would be prohibitive. The results obtained are quite satisfactory as special A. P. M.s could be worked modularly with 1 ft. to 1·25 ft. working head for as high depths on crest as 3·5 ft.

Final Conclusions about A. P. M. Outlets.

The conclusions outlined in this Paper are based on Mr. Crump's life long experience of these outlets, and the very detailed, and exhaustive experimental work (extending over eight years) carried out by the Author.

This Paper was written in July 1936, and formed the subject matter of an exhaustive discussion in August 1936 between Messrs. Crump, Nand Gopal and the Author.

The conclusions arrived at represent the unanimous views of those present at the discussion. The publication remained pending so far because Mr. Crump intended to add an introduction, which could not, however, be done on account of his illness, and sudden departure from India.

1. An A. P. M. designed as per I. B. Paper 26, Class A, has proved to be an imperfect submerged orifice. Formation of the standing wave was not a sufficient guarantee of a constant discharge under all conditions of the water level in the watercourse. The control section was imperfect, and liable to pressure inflations.

The co-efficient variation was observed to range from 6·2 to 8·4, and the minimum modular heads were generally more than those given in the said Paper.

2. The improvements in the design of the upstream approaches, advocated by the Author in his Paper No. 168 to improve the silt-conductive power of outlets, were very suitable, and were accepted by Mr. Crump, as stated in paragraph 8 of Appendix I. They have been incorporated in the designs proposed in this Paper.

The setting of the A. P. M. crest for proportional share of silt and discharge is at $0{\cdot}6d$, but proportional silt conduction by the outlets is not enough to prevent the channel silting because 10 to 12 % of the channel discharge is lost in absorption.

The experiments described in Paper No. 168 showed that a setting of $0{\cdot}8d$ was required to make an A. P. M. take its due share of silt, that is 112 %. This would make the outlet slightly subproportional, which is advantageous for the tails.

3. Hydraulic shortcomings of A. P. M. outlets, as found in the experiments described in Paper No. 176, were correct. The structural changes required to remove the defects as described in paragraph 12 of Appendix I by Mr. Crump and adopted in this Paper, were better than those described in the Author's Paper No. 176.

4. The improved A. P. M. is a perfect submerged orifice, and an ideal semimodule. Formation of the standing wave becomes a sure guarantee of a constant discharge, which is now made definitely independent of the water level in the watercourse under all conditions.

The minimum modular limits have been reduced by providing suitable designs for the roof block, and the outfall.

5. The device of providing a surge Chamber in the outfall of an A.P.M. was very effective in reducing the M.M.H.

6. Proportionality in an A.P.M. is a great scientific achievement, and is an asset of incalculable value in outlets on regime channels.

It is the considered opinion of Mr. Crump, who invented this outlet, and the Author, who developed it that proportionality should not be sacrificed on regime channels, which could be run nonsilting by suitable grading and silt selection at distributary head regulators (Paper No. 189, Punjab Engineering Congress, 1936).

If a channel cannot run in regime, proportionality in its outlets becomes a disadvantage. Once it is discarded there is no limit to the lowering of the setting and to make outlets subproportional, *i.e.*, rigid. A.P.M. outlets may even be set below bed level, if the available working head permits.

The use of an A.P.M. approaching a rigid module is far superior to the known devices of rigid modules with moving parts such as Kent's.

PART II.

Open Flume Outlets.

Open flumes are constructed as per the design described in Appendix D of Irrigation Branch Paper No. 26 by Mr. E. S. Crump. Experience of these outlets showed that the narrow outlets had very low co-efficients of discharge, and were difficult to construct with a uniform width for a long length of $2H$ for the throat. They also required a high M.M.H. A distinction is, therefore, introduced in the open flume outlets as below:—

1. Open flume outlets for widths 0·3 ft. to 1·0 ft.
2. Narrow open flume outlets for widths 0·05 ft. to 0·30 ft.

Design of Open Flume Outlets.

A design of the open flume outlet is given in Plate No. 6. It is just the same as given in Appendix D of Irrigation Branch Paper No. 26 Class A, except that the upstream approaches have been added as per type A described in the Author's Paper No. 168 of the Punjab Engineering Congress, 1933. Its length of crest is equal to $2H$, according to the conclusions described in paragraphs Nos. 2 to 4 of Appendix I. The standard outfall design has been provided as described in paragraph 7 of Appendix I.

Silt Conduction by Open Flume Outlets.

The silt experiments in the Author's Paper No. 168 show that an open flume takes about its due share of silt for its proportional setting at $0{\cdot}9d$.

Minimum Modular Head of Open Flume Outlets.

The tests have shown that the minimum modular head is generally 10 to 15 % of the depth on the crest.

The co-efficient of discharge is steady at about 3·0 in the formula $q = CBH^{3/2}$ for all values of H and widths so long as the length of the crest is $2H$.

Narrow Open Flume Outlets.

Narrow open flume outlets of various widths from 0·05 ft. to 0·3 ft. were tested in these experiments. The design adopted is described in paragraphs 5 to 8 of Appendix I.

The length of the crest in all cases was 0·5 ft.

The structural details of the design are shown in Plate No. 7.

The results of observations for various widths and depths on the crest are given in tabular form in Appendix III.

The variation of the co-efficient " C " in the formula $q=CBH^{\frac{3}{2}}$ is plotted in Plate No. 8 for different widths and depths on the crest.

The minimum modular head required is given in the same plate. Minimum Modular heads were taken when the discharge variation was recorded within $\frac{1}{2}$ %, although the jump continued to form a long time afterwards, generally to a drowning ratio of 80 to 85 % in all cases.

Discussion of Results of Narrow Open Flume Outlets.

Narrow open flume outlets require fairly high working heads, as shown in Plate No. 8. Probably an A. P. M. with a low M. M. H. could be designed for the same working head.

The co-efficient variation is rather unusual. The control section does not remain within the length of the crest, but shifts further into the wider section beyond, as the depth on the crest increases. The co-efficient of discharge, therefore, increases even beyond 3·09.

The control section in a narrow flume outlet is fouled by the buffer of the jump long before the jump dies out. The presence of a standing wave is not a correct indication of modularity. However narrow open flume outlets can be designed with the co-efficients and the working heads given in this Paper.

Narrow open flume outlets are easily choked with jungle, and the zemindars have to clean them frequently. It is, therefore, recommended that outlets narrower than 0·1 ft. should not be constructed.

Lastly it is remarked that, even though a narrow open flume outlet could be designed in some cases with a relatively low working head, yet it should always be borne in mind that it is not a perfect outlet, as the control section of the discharge does not remain within the protected length of the crest for high depths on crest.

APPENDIX I.

Hydraulics of Open Flume and A. P. M. Outlets.

1. Messrs. Jesson, Crump and Sharma met at Sargodha on 11th, 12th and 13th May, 1934. Experimental sites and many examples of recent remodelling works on the L. J. C. system were inspected and Mr. Sharma's latest proposals in connection with Open Flume and A. M. P. outlets were discussed. The following notes present facts, data and conclusions which purport to represent the unanimous views of those present.

Open Flume Outlets.

2. Some misunderstanding has arisen regarding the length of crest or throat advocated by Mr. Crump in I.B. Paper No. 26. In Plate IV of Mr. Sharma's Congress Paper No. 168 is shown a Flume Outlet taken from the former Paper. The upstream edge of the shorter parallel side-wall has a 1 : 2 batter. The surface being H feet above crest, the effective length of throat at surface level is $2H$ and at crest level $2{\cdot}5\ H$ as shown in the drawing. This model, therefore, conforms to Mr. Crump's general stipulation for a throat length of $2H$ for all weirs and flumes. To avoid confusion, in what follows, throat length will be understood to be the length at an elevation H above crest and not that at bed level.

3. In 1922 Mr. Crump, assisted by L. Munishwar Chand, carried out co-efficient and submergence tests on numerous medels of weirs and flumes at Renala. It was found that provided the length of crest or throat was not less than $2H$ the co-efficient of any one model was sensibly constant and had the same value whether the model was truncated or was provided with an expending outfall, either by means of a sloping glacis or of splayed side walls. In truncated models the modular limit was round about 66% and the only effect of adding an expansion was to increase the modular limit above this figure. In models having a throat length of less than $2H$, the co-efficient was not constant but increased with H. It was also greater than for models otherwise similar but having a throat length of $2H$ or more. There was thus an essen-

tial difference of behaviour in long and short throated models as distinguished by a length of throat greater or less than $2H$. Short throated models if truncated had a very low modular limit but were rendered modular by the addition of an expanding outfall.

4. Two examples of tests made by Mr. Crump may be quoted to illustrate the above principles. The large model weir constructed at Sulki near Sargodha in 1918 had no parallel throat at all. The approach section consisted of a meticulously shaped bell-mouth, both bed and side walls having curves similar to that of an A.P.M. roof block. The essential feature of these curves is a continuously changing curvature becoming infinite at the downstream end of the approach, where the tangent to the curve is parallel to the axis of flow. A 1 in 15 glacis started immediately from the end of the approach. It had parallel side-walls and a width of 10 feet. In this example, modularity was clearly dependent on the provision of a glacis. The modular limit was as high as 93% which has rarely, if ever, been exceeded.

One of the Renala Flume-models tested in 1922 gave a modular limit of nearly 80%. In this model the floor was horizontal throughout. This model, also, had no parallel throat. The approach and outfall both had straight vertical side-walls: the former had a splay of 1 in 5, and the latter a splay of 1 in 15. The throat width was 0·5 feet. Being short-throated, the co-efficient of this model was not constant: it increased with H and was given by

$$C=2{\cdot}74+0{\cdot}33H$$

Test results were as follows:—

H	C	Modular limit.
1·39	3·20	79 %
2·11	3·44	70 %

The above examples show that a high modular limit with a short-throat is not a recent discovery. What led, Mr. Crump to adopt as standard length of throat of $2H$ was the fact that this was the shortest length which conferred the interdependent advantages of a constant co-efficient unaffected by truncation, and a modular limit rang-

ing from 66 % upwards. It is considered that these advantages are substantial and ought not to be abandoned without good reason.

5. Mr. Sharma's latest proposals for Open Flume Outlets contemplate the use of a short throat as defined above. The model he proposes is similar to his modified design shown in Plate IV of his Congress Paper No. 168, but with a length of throat of $1{\cdot}25H$. Except at the tails of small channels where the depth is small, open flume outlets tend to have small values of B relative to those of H. This disproportionality is further increased by deep bed-level setting adopted with a view to improve silt-induction. Retention of the standard $2H$ length of throat thus leads to the practical difficulty of constructing, with any, degree of precision a deep long and narrow parallel-sided throat. **It is with a view to reduce this difficulty that Mr. Sharma advocates the adoption of a short-throat. It is felt that his proposals in this direction might with advantage be carried further.** From what has been said in paras 3 and 4 above, it is clear that once the standard $2H$ length of throat is abandoned, the length may be reduced, even to zero, without entailing a serious reduction in the modular limit. This being the case, the adoption of a much shorter throat length than $1{\cdot}25H$ is recommended. To ensure accuracy of construction the throat should be formed from standard cast-iron bed and cheek plates with a distance piece inserted above water-level. A standard length of six inches would be suitable, and all cases would then be met by keeping a stock of parts comprising a range of standard bed-plates and distance pieces, and an independent range of cheek plates of various heights.

6. The chief disadvantage of adopting standard short-throated flumes lies in the fact that the value of the co-efficient (within the range of modular action) depends upon the values of the three dimensions : H, B and throat length L. This disadvantage must definitely be overcome by carrying out tests covering the whole range of probable values of the above dimensions. Both co-efficient and submergence tests would be necessary, and

the number of tests would have to be enough to yield well confirmed values of the co-efficient C and the modular range over the whole field of practical design. Such co-efficient could be represented graphically by curves of constant B plotted against values of H as abscissa and values of C as ordinates. These curves would be found to be rising curves. Such curves have already been determined, but with doubtful accuracy by a number of model tests made by Mr. Sharma on $L=1{\cdot}25$ H models. The above relation may be written as $H=0{\cdot}8\ L$; so that in any one model the fixed value of L fixed the value of H, and each observed result plotted on the graph represented a different model. Thus to obtain three points on each of the three curves $B=0{\cdot}10$. $B=0{\cdot}20$ and $B=0{\cdot}30$ meant setting up nine different models. This unnecessary multiplication of models is largely avoided by making $L=0{\cdot}5$ a standard for all models. With this arrangement, experimental models would differ only in regard to the value of B, and experimental results for any one value of B would be obtainable from a single model by varying H, instead of building a different model for each test as Mr. Sharma had do.

Shape of Outfall.

7. In the case of long-throated flumes, the shaping of the outfall is a matter of minor importance ; variations in design affect only the modular limit and this only to a small extent. In short-throated flumes, on the other hand, both the co-efficient and the modular limit depend very greatly upon this shaping. It is, therefore, most important that it should be standardised. In Plate IV of Congress Paper No. 168 two examples are shown : in both models the radius of splay is variable and only in the Sharma model is the glacis slope fixed. For the new short-throated flume proposed above, the following specification is recommended :—

Floor : to have a 5 ft. length of 1 in 10 glacis starting from the throat : beyond this, to be horizontal.

Sides : to have a fixed curvature of 25 ft. radius, the curve starting tangentially from the throat.

Shape of Approach.

8. As the experiments described in Congress Paper No. 168 clearly show, the shape of the approach has an

important influence on the silt drawing properties of an outlet. The bed curve is dependent upon the setting of the crest, both for Open Flumes, and A.P.M.s and it would appear from Mr. Sharma's results that the setting is the chief factor in determining the silt induction. For convenience of reference Mr. Sharma's results are re-capitulated below :—

Serial No.	Description of model.	Setting.	Plate.	Percentage induction.
1.	Crump's Open Flume	10/10ths	IV. C.P. 168	107·20
2.	Sharma's ,, No. 3	,,	,,	115·80
3.	Crump's A. P. M.	6/10ths	I.C.P. 176	92·4
4.	Sharma's A. P.M. Type A	,,	VI.C.P. 168	99·5
5.	,,	8/10ths	II. C.P. 176	109·7
6.	,, No. 2	,,	I.C.P. 168	110·4
7.	,, Type A	10/10ths	,,	121·9
8.	,, Type B	,,	V.C.P. 168	113·7
9.	,, ,,	12/10ths	,,	128·9

Comparison of the behaviour of Nos. 1 and 2 and of Nos. 3 and 4 above indicate that the **modifications adopted by Mr. Sharma in regard to the shaping of the two side-walls give an improved silt induction compared with Crump models of the same setting. These modifications are therefore recommended for adoption, both for Open Flumes and A. P. M. Outlets.** The high induction of No. 9 may be attributed rather to the abnormally deep setting adopted than to the projection into the parent bed of the down-stream wing. The effect of the setting on silt induction is very apparent, and it would seem that to ensure good silt induction we are forced to abandon the 6/10ths setting of A. P. M. outlet in favour of deeper setting, and thereby lose the advantages which the former setting offers of proportional distribution and smaller minimum modular Heads. Before this view is finally accepted, it is considered that further experiments should be carried out, and the possibilities investigated of improving the 6/10ths A. P. M. by modifying the bed curve, setting back the A. P. M. orifice and introducing a fixed roof block at the upstream and of the approach.

Stability of the Jet.

9. In regard to the modular behaviour of weirs, flumes and outlets, it is evident that under certain conditions the high velocity jet is remarkably stable. When these conditions prevail, the depth of the jet and the pressures and velocities of all its filaments are unaltered by the proximity of the standing wave. At such a section the jet resists pressure inflation, and screens all sections upstream of it from the effect of drowning by rise of the tail-water. These conditions are essential to perfect modularity. It is evident that they are fulfilled at some section in the throat of a weir or flume, provided the parallel length is not less than $2H$. In short-throated models having a glacis, these conditions do not obtain at any section of the throat, but are established at a section some distance down from the upper end of the glacis and result in modular action which persists until all such stable sections of the jet are actually smothered by retrogression of the standing wave.

10. If a long-throated model is examined when in action about H upstream of the end of the throat the following conditions obtain :—

(*i*) The depth has the critical value of $2/3H$ (or allowing for frictional losses in the approach $2/3K$).

(*ii*) The filaments are rectilinear and convergent, there being no curvature apparent in the surface filament.

(*iii*) The jet adheres to the bed.

In the case of a glacis, the piezometric tests made by Mr. Sharma on A. P. M. models described in Congress Paper No. 176 clearly show the existence, near the head of the glacis, of a low pressure pocket. The jet, in leaving the horizontal floor, evidently springs clear of the bed of the glacis and, describing a parabolic arc, again impinges on the glacis. Below this point of impact, conditions similar to the above obtain (except that the depth is less than critical) and result in modular behaviour.

In view of the above it is suggested that to ensure modularity the following conditions must be fulfilled at some section above the wave :—

(*i*) depth not more than $2/3\ K$, *i.e.*, 2/3rds of the total energy ;

(*ii*) filaments convergent and either rectilinear or of concave curvature ;
(*iii*) jet in contact with the bed.

A. P. M. Design.

11. In his original A. P. M. design, Mr. Crump hoped to produce a stable jet on the horizontal floor downstream of the orifice. To effect this object the roof block was specially shaped to a curve having a horizontal tangent and infinite radius of curvature at the exit, and provision was made for a parallel throat of length H below the orifice. **Mr. Sharma's tests and pressure observations clearly show that this object has not been perfectly realised. The jet at the exit of the orifice is liable to pressure inflation,** and true modularity depends not upon the stability of the horizontal jet, but upon the stable section formed on the glacis.

Non-stability of the horizontal jet may now be attributed to the fact that in traversing a parallel horizontal throat, the jet thickens as it loses energy in friction. Condition (*ii*) above is, therefore, not fulfilled. The filaments are divergent and the jet liable to pressure inflation.

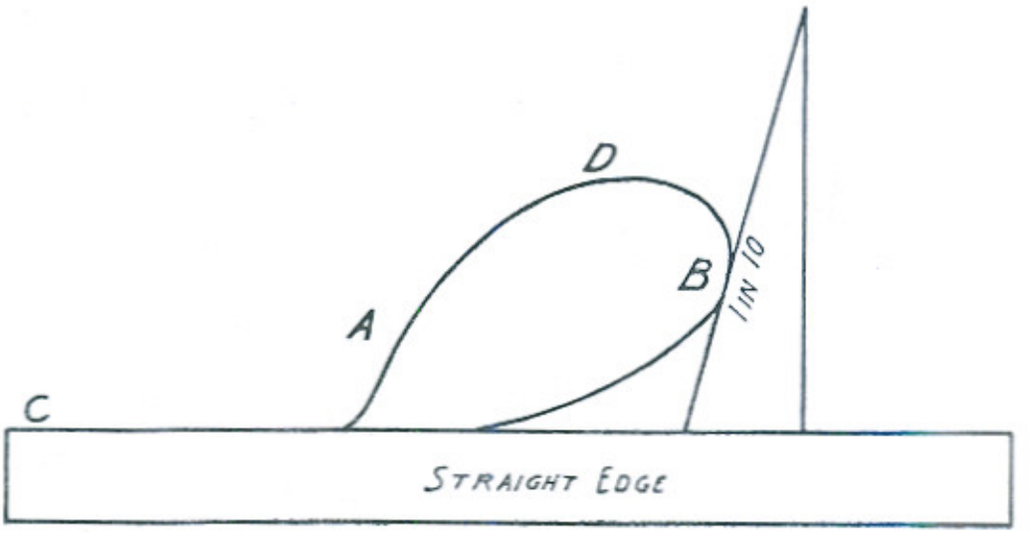
12. It is now felt that further experiments are most desirable with a view to remedy the lack of perfection which Mr. Sharma's experiments have revealed. It is suggested that the defect explained above might be removed by giving the A. P. M. orifice and floor beyond it a tilt somewhat greater than the hydraulic or energy gradient of flow in the throat. A slope of 1 in 15 would probably be found sufficient for all practical purposes.

Roof Block Curve.

13. In conjunction with the above expedient it is considered that in order to ensure convergence of the filaments when issuing from the orifice the roof block curve might be tilted somewhat more than the bed. The degree of tilting suggested is that to give a 1 in 10 inclination of the tangent at exit.

As regards shaping of the roof block: in the original A. P. M. the curve was obtained by bending a flexible saw-blade to the required shape. To give a formula for this curve is attended with mathematical difficulties. Bernoulli's lemniscate ($r^2 = a^2 \cos 2$) has the desired properties, but it is thought better to specify a curve which can readily be produced by any intelligent draftsman. The

curve recommended is that formed by bending a uniform flexible strip of some suitable homogeneous material (such as steel or celluloid) in the manner indicated below :—



The portion *CA* of the strip is unstrained and therefore straight, and rests against the straight edge which is tangential to the curve at the point *A*. The only constraint imposed on the strip is that of a freely hinged attachment at *A*. A light thread attached to the end of the upper limb and passed through a small hole in the lower limb, would give this. The loop produced is of fixed shape in the sense that a large loop is an exact magnification of a smaller loop. By adjusting the length of *CA* a loop of the required size can be obtained from a strip of sufficient length. For the roof block suggested above, the requisite curve would be *AB*, *A* being tangential to the straight edge, and *B* to *A* 1 in 10 set square.

14. The approach and outfall of an A. P. M. should be designed to the same standards as already recommended for Open Flume Outlets.

15. Having regard to the need of further experimental work it is thought that unless this work could be undertaken by the Hydraulic Section of the Research Institute it would be well worth while to place Mr. Sharma on special duty for this purpose. If thought desirable, the work could be carried out under Mr. Crump's direction at some suitable site on the Upper Jhelum Canal system.

E. S. CRUMP,
Superintending Engineer,
UPPER JHELUM CANAL CIRCLE.

17-5-34

APPENDIX II

SET No. I
Width = ·3

Statement showing value of Co-efficient and Minimum Modular Head.

$B = ·2$ $y = ·4$ $B/y = ·5$

Serial No.	H on Crest.	h	Gauge Standard Weir.	Discharges	Value of C in $q = CBY\sqrt{h}$	hm.	A. P. M. $\frac{hm}{\cdot}$.	Special A. P. M. hm.	Special A. P. M. $\frac{hm}{h}$.	REMARKS.
1	2	3	4	5	6	7	8	9	10	11
1	1·6	1·2	·2375	·66	7·50	·84	·7	·70	·59	
2	1·8	1·4	·2475	·71	7·50	1·00	·71	·77	·55	
3	2·0	1·6	·2575	·76	7·50	1·18	·738	·87	·54	
4	2·2	1·8	·2675	·80	7·455	1·30	·73	·98	·54	
5	2·4	2·0	·2775	·85	7·51	1·51	·755	1·03	·51	
6	2·6	2·2	·286	·89	7·50	1·66	·760	1·13	·51	
7	2·8	2·4	·293	·92	7.425	1·90	·79	1·24	·52	
8	3·0	2·6	·3025	·97	7·52	2·10	·807	1·38	·53	
					7·49		Average		·53	
			$B = ·2$		$y = ·6$		$B/y = ·33$			
1	1·6	1·0	·2825	·89	7·42	·68	·68	·53	·53	
2	1·8	1·2	·3025	·97	7·35	·86	·71	·70	·58	
3	2·0	1·4	·3175	1·04	7·32	1·08	·77	·84	·60	
4	2·2	1·6	·33	1·11	7·31	1·25	·78	·94	·587	
5	2·4	1·8	·343	1·18	7·33	1·44	·80	1·03	·572	
6	2·6	2·0	·356	1·25	7·37	1·64	·82	1·16	·57	
7	2·8	2·2	·366	1·30	7·30	1·84	·836	1·26	·51	
8	3·0	2·4	·378	1·37	7·37	2·00	·833	1·37	·565	
					7·36		Average		·57	

$B = \cdot 2$ $y = \cdot 6$ $B/y = \cdot 33$

1	1·8	1·0	·34	1·16	7·25	·75	·75	·60	·60
2	2·0	1·2	·358	1·26	7·16	·91	·76	·72	·60
3	2·2	1·5	·373	1·34	7·08	1·08	·77	·88	·61
4	2·4	1·6	·3925	1·45	7·16	1·30	·81	·96	·60
5	2·6	1·8	·405	1·53	7·13	·48	·82	1·14	·63
6	2·8	2·0	·42	1·615	7·14	1·70	·85	1·27	·635
7	3·0	2·2	·432	1·69	7·12	1·90	·865	1·40	·61
					7·17		Average		·61

$B = \cdot 2$ $y = 1 \cdot 0$ $B/y = \cdot 2$

1	2·0	1·0	·385	1·40	7·0	·92	·92	·64	·64
2	2·2	1·2	·41	1·55	7·03	·97	·81	·78	·65
3	2·4	1·4	·423	1·64	6·98	1·22	·18	·88	·63
4	2·6	1·6	·444	1·77	7·01	1·44	·90	1·02	·64
5	2·8	1·8	·46	1·87	7·0	1·59	·89	1·17	·65
6	3·0	2·0	·473	1·96	6·93	1·74	·87	1·360	·68
					7·00		Average		·65

$B = \cdot 2$ $y = 1 \cdot 2$ $B/y = \cdot 166$

1	2·4	1·2	·4525	1·82	6·91	1·13	·94	·80	·66
2	2·6	1·4	·474	1·96	6·90	1·24	·9	·97	·69
3	2·8	1·6	·491	2·08	6·88	1·52	·9	1·16	·72
4	3·0	1·8	·5125	2·23	6·92	1·64	·95	1·34	·73
					6·90		Average		·70

APPENDIX II. SET No. II.

Statement showing values of Co-efficient and Minimum Modular Head.

Serial No.	*H.* on Crest.	*h.*	Gauge Standard Weir.	Discharge.	Value of C in $q = CBY\sqrt{h}$	*m.*	A. P. M. $\frac{hm}{h}$.	Special A. P. M. *hm.*	Special A. P. M. $\frac{hm}{h}$.	REMARKS.
1	2	3	4	5	6	7	8	9	10	11
				$B = ·32$	$Y = ·4$		$B/Y = ·8$			
1	1·2	·8	·21	·87	7·58	·39	·5	·28	·36	
2	1·4	1·0	·302	·97	7·57	·56	·56	·38	·38	
3	1·6	1·2	·32	1·06	7·56	·74	·61	·49	·40	
4	1·8	1·4	·336	1·14	7·57	·88	·61	·59	·42	
5	2·0	1·6	·351	1·22	7·58	1·03	·64	·65	·407	
6	2·2	1·8	·367	1·30	7·555	1·22	·68	·71	·395	
7	2·4	2·0	·377	1·36	7·56	1·46	·73	·78	·39	
8	2·6	2·2	·389	1·43	7·55	1·59	·723	1·06	·48	
9	2·8	2·4	·4	1·49	7·56	1·74	·721	1·20	·50	
					7·56				·43	
				$B = ·32$	$Y = ·6$		$B/Y = ·53$			
1	1·20	·6	·33	1·11	7·46	·25	·42	·20	·33	
2	1·4	·8	·364	1·29	7·48	·40	·50	·30	·375	
3	1·6	1·0	·391	1·44	7·50	·58	·58	·42	·42	
4	1·8	1·2	·415	1·58	7·48	·77	·64	·49	·41	
5	2·0	1·4	·4325	1·69	7·44	·95	·68	·60	·43	
6	2·2	1·6	·449	1·80	7·45	1·12	·70	·74	·47	
7	2·4	1·8	·465	1·90	7·38	1·28	·71	·77	·43	
8	2·6	2·0	·481	2·02	7·44	1·50	·75	·90	·45	
9	2·8	2·2	·4975	2·12	7·44	1·68	·758	1·10	·50	
					7·45				·445	

					$B = ·32$	$Y = ·8$		$B/Y = 2·4$	
1	1·60	·8	·4325	1·69	7·32	·52	·65	·36	·45
2	1·8	1·0	·4625	1·88	7·33	·62	·62	·48	·48
3	2·0	1·2	·49	2·06	7·32	·78	·73	·57	·475
4	2·2	1·4	·5125	2·22	7·34	·98	·7	·71	·507
5	2·4	1·6	·5325	2·38	7·36	1·16	·72	·78	·49
6	2·6	1·8	·553	2·51	7·30	1·26	·7	·84	·47
7	2·8	2·0	·5725	2·64	7·28	1·52	·76	1·02	·51
8	3·0	2·2	·588	2·76	7·32	1·78	·8	1·10	·50
					7·31				·50
					$B = ·32$	$Y = 1·0$		$B/Y = 2·3$	
1	2·0	1·0	·5175	2·265	7·08	·72	·72	·48	·48
2	2·2	1·2	·5525	2·50	7·10	·88	·73	·60	·50
3	2·4	1·4	·577	2·68	7·09	1·04	·74	·76	·54
4	2·6	1·6	·603	2·87	7·10	1·24	·7	·83	·52
5	2·8	1·8	·628	3·06	7·14	1·42	·746	·93	·52
6	2·99	1·99	·65	3·23	7·15	1·57	·78	1·04	·52
					7·11				·52
					$B = ·32$	$Y = 1·20$		$B/Y = ·266$	
1	2·4	1·2	·618	2·98	7·05	1·0	·83	·72	·6
2	2·6	1·4	·65	3·21	7·06	1·20	·85	·83	·59
3	2·9	1·6	·675	3·42	7·04	1·34	·84	·90	·57
					7·05				·586

APPENDIX II. SET III.

Statement showing values of Co-efficients and Minimum Modular Head

Serial No.	*H.* on Crest.		Gauge Standard Weir.	Discharge.	Value of C in $q = CBY\sqrt{h}$.	*hm.*	A. P. M. $\frac{hm}{h}$.	Special A. P. M. *hm.*	Special A. P. M. $\frac{hm}{h}$.	REMARKS.
		$B = \cdot5$				$y = \cdot4$		$B/y = 1\cdot25$		
1	2	3	4	5	6	7	8	9	10	11
1	1·2	·6	·343	1·18	7·61	·22	·4	·18	·3	
2	1·2	·8	·379	1·37	7·61	·37	·46	·30	·375	
3	1·4	1·0	·403	1·52	7·60	·52	·52	·4	·41	
4	1·6	1·2	·429	1·67	7·61	·67	·56	·56	·47	
5	1·8	1·0	·450	1·80	7·62	·84	·60	·64	·47	
6	2·0		·47	1·93	7·63	1·11	·63	·72	·45	
7	2·2		·486	2·04	7·62	1·17	·68	·82	·46	
8	2·4		·503	2·16	7·63	1·33	·73	·90	·45	
9	2·6		·5175	2·26	7·63	1·51	·755	1·08	·49	
10	2·8		·5325	2·36	7·62	1·70	·77	1·18	·49	
					7·62				·461	
		$B = \cdot5$				$y = \cdot6$		$B/y = \cdot83$		
1	1·2	·6	·443	1·75	7·52	·22	·4	·15	·25	
2	1·4		·481	2·02	7·49	·38	·48	·31	·39	
3	1·6		·5175	2·26	7·53	·52	·52	·41	·41	
4	1·8		·549	2·48	7·52	·63	·525	·48	·4	
5	2·0	1·4	·576	2·665	7·51	·82	·587	·62	·44	
6	2·2		·604	2·88	7·52	·98	·61	·74	·47	
7	2·4		·623	3·02	7·50	1·16	·644	·82	·48	
8	2·6	2·0	·647	3·20	7·54	1·32	·66	·90	·45	
9	2·8		·663	3·33	7·49	1·62	·775	·98	·45	
10	3·0		·685	3·50	7·50	1·78	·742	1·08	·45	
					7·51				·44	

$B = \cdot 5$ $y = \cdot 8$ $B/y = \cdot 625$

1	1·6		·576	2·66		·42		·52		·32	
2	1·8	1·0	·616	2·97	7·43	·62		·62		·41	·4
3	2·0	1·2	·653	3·25	7·42	·75		·63		·48	·41
4	2·2	1·4	·685	3·50	7·40	·93		·664		·62	·40
5	2·4	1·6	·717	3·76	7·41	1·10		·69		·70	·44
6	2·6	1·8	·743	3·98	7·43	1·27		·701		·82	·44
7	2·8	2·0	·768	4·19	7·42	1·40		·7		·95	·455
					7·41						·47
					7·42						·43

$B = \cdot 5$ $y = 1 \cdot 0$ $B/y = \cdot 5$

1	2·0		·703	3·64	7·28	·60		·6		·42	
2	2·2		·746	4·0	7·27	·74		·62		·58	·42
3	2·4		·779	4·29	7·26	·94		·67		·67	·48
4	2·6		·8125	4·60	7·27	1·02		·64		·80	·48
5	2·8		·8423	4·88	7·28	1·30		·72		·90	·50
6	3·0		·87	5·14	7·27	1·48		·74		·98	·50
					7·27						·49
											·48

$B = \cdot 5$ $y = 1 \cdot 2$ $B/y = \cdot 417$

1	2·4		·83	4·75	7·20	·88		·73		·66	
2	2·6		·869	5·12	7·21	·97		·7		·75	·55
3	2·8		·9025	5·46	7·19	1·25		·78		·88	·536
4	3·0		·9325	5·78	7·18	1·32		·73		·95	·55
					7·20						·53
											·54

APPENDIX III SET No. IV

Statement showing values of Co-efficient and Minimum Modular Head.

$B = \cdot 8$ $y = \cdot 2$ $B/y = 4 \cdot 0$

Serial No.	H. on Crest.	h.	Gauge Standard Weir.	Discharge.	Value of C in $q = CBY\sqrt{h}$.	hm.	A. P. M. $\frac{hm}{h}$	Special A. P. M. hm	Special A. P. M. $\frac{hm}{h}$	REMARKS.
1	2	3	4	5	6	7	8	9	10	11
1	1·2	1·0	·359	1·26	7·84	·56	·56	·38	·38	
2	1·4	1 2	·38	1·38	7·85	·68	·57	·53	·44	
3	1·6	1·4	·40	1·49	7·87	·82	·587	·62	·44	
4	1·8	1·6	·416	1·59	7·84	·93	·581	·74	·66	
5	2·0	1.8	·431	1·69	7·86	1·05	·593	·78	·43	
6	2·2	2·0	·4475	1·78	7·87	1·20	·600	·91	·455	
7	2·4	2·2	·459	1·86	7·85	1·34	·61	1·0	·454	
8	2·6	2·4	·47	1·94	7·83	1·50	·624	1·12	·467	
9	2·8	2·6	·484	2.03	7·85	1·65	·635	1·18	·453	
10	3·0	2·8	·495	2·10	7·84	1·85	·66	1·36	·485	
					7·86				·44	

		$B=\cdot8$			$y=\cdot4$			$B/y=2\cdot0$	
1	1·4	1·0	·553	2·51	7·84	·52	·52	·39	·39
2	1·6	1·2	·583	2·72	7·73	·65	·54	·45	·375
3	1·8	1·4	·613	2·94	7·77	·77	·55	·54	·386
4	2·0	1·6	·639	3·14	7·75	·90	·562	·59	·37
5	2·2	1·8	·666	3·35	7·80	1·04	·577	·70	·38
6	2·4	2·0	·686	3·51	7·76	1·17	·585	·79	·395
7	2·6	2·2	·7075	3·68	7·76	1·34	·609	·84	·382
8	2·8	2·4	·729	3·86	7·78	1·50	·625	·94	·391
9	3·0	2·6	·745	4·0	7·75	1·66	·637	1·05	·404
					7·77				·385
		$B=\cdot8$			$y=\cdot6$			$B/y=1\cdot33$	
1	1·6	1·0	·705	3·66	7·62	·53	·53	·45	·45
2	1·8	1·2	.75	4·03	7·63	·64	·533	·47	·39
3	2·0	1·4	·785	4·36	7·66	·77	·55	·55	·39
4	2·2	1·6	·815	4·62	7·70	·92	·575	·63	·395
5	2·4	1·8	·8475	4·92	7·68	1·07	·59	·69	·384
6	2·6	2·0	·875	5·18	7·64	1·20	·600	·78	·39
7	2·8	2·2	·90	5·45	7·68	1·37	·620	·87	·40
					7·65				0·40
		$B=\cdot8$			$y=\cdot8$			$B/y=1\cdot0$	
1	1·8	1·0	·836	4·81	7·58	·57	·57	·54	·45
2	2·0	1·2	·885	5·29	7·59	·72	·6	·57	·41
3	2·2	1·4	·925	5·70	7·58	·85	·61	·62	·39
					7·583				·42

APPENDIX III.

Observations on Narrow Open Flume Outlets.

SET No. I Width = ·3

Statement showing values of Co-efficient of Discharges of an Open Flume Outlet.

Serial No.	*H* on Crest.	Gauge Standard Weir.	Discharges.	Value of *C* 3/2 $q = CBH$.	*h m.*
1	2	3	4	5	6
1	1·2	·34	1·16	2·93	·17
2	1·4	·394	1·46	2·93	·23
3	1·6	·448	1·79	2·94	·30
4	1·80	·498	2·13	2·90	·40
5	2·0	·55	2·49	2·93	·53
6	2·2	·604	2·88	2·94	·62
7	2·4	·669	3·29	2·95	·68
8	2·6	·71	3·71	2·95	·73
9	2·8	·766	4·17	2·97	·77
10	3·0	·816	4·63	2·97	·81
11	3·2	·869	5·12	2·98	·84
12	3·4	·919	5·62	2·99	·86

APPENDIX III.

Observations on Narrow Open Flume Outlets.

SET No. II Width = ·2

Statement showing values of Co-efficient of Discharges of an Open Flume Outlet.

Serial No.	*H* on Crest.	Gauge Standard Weir.	Discharge.	Value of *C* 3/2 $q = CBH$	*hm.*
1	2	3	4	5	6
1	1·0	·213	·56	2·80	·26
2	1·2	·254	·74	2·82	·30
3	1·4	·298	·935	2·825	·34
4	1·6	·3375	1·15	2·836	·42
5	1·8	·38	1·38	2·85	·54
6	2·0	·419	1·61	2·845	·63
7	2·2	·46	1·87	2·86	·72
8	2·4	·498	2·13	2·87	·80
9	2·6	·521	2·42	2·89	·87
10	2·8	·586	2·74	2·92	·97
11	3·0	·626	3·04	2·93	1·05
12	3·2	·680	3·47	3·03	1·13

APPENDIX III

Observations on Narrow Open Flume Outlets

SET No. III Width = ·1

Statement showing values of Co-efficient of Discharges of an Open Flume Outlet.

Serial No.	*H* on Crest.	Gauge Standard Weir.	Discharge.	Value of C where $q = CBH^{3/2}$	*hm*
1	2	3	4	5	6
1	1·22	·163	·36	2·67	·43
2	1·25	·1675	·38	2·72	·45
3	1·40	·186	·452	2·73	·50
4	1·60	·21	·55	2·725	·57
5	1·80	·236	·66	2·73	·67
6	2·0	·26	·77	2·72	·76
7	2·2	·288	·90	2·76	·85
8	2·4	·3175	1·04	2·79	·97
9	2·6	·346	1·19	2·84	1·10
10	2·8	·378	1·36	2·90	1·22
11	3·0	·41	1·55	2·98	1·34
12	3·2	·4425	1·75	3·97	1·45
13	3·4	·476	1·97	3·14	1·55

APPENDIX III

Observations on Narrow Flume Outlets

SET No. IV Width = ·05

Statement showing value of Co-efficient of Discharges of an Open Flume Outlet.

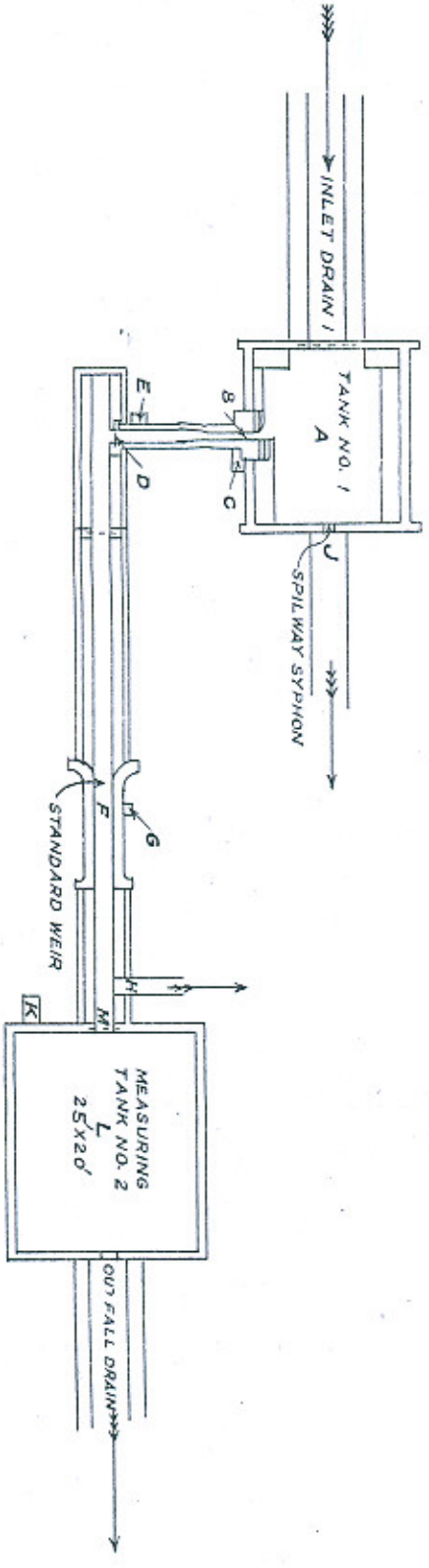
Serial No.	*H* on Crest.	Gauge Standard Weir.	Discharge.	Value of C where $q = CBH^{3\,2}$	*hm.*
1	2	3	4	5	6
1	1·60	·133	·26	2·668	·65
2	1·80	·15	·32	2·68	·75
3	2·0	·1675	·38	2·687	·84
4	2·2	·184	·44	2·697	·96
5	2·4	·201	·50	2·689	1·07
6	2·6	·22	·59	2·81	1·20
7	2·8	·2425	0·69	2·945	1·36
8	3·0	·2625	·79	3·04	1·40
9	3·2	·286	·89	3·11	1·61
10	3·4	·308	1·02	3·21	1·73

SITE PLAN OF EXPERIMENTAL STATION

SCALE = 1/200

PLATE I

PAPER NO. 237



TYPE DESIGN OF AN A.P.M.

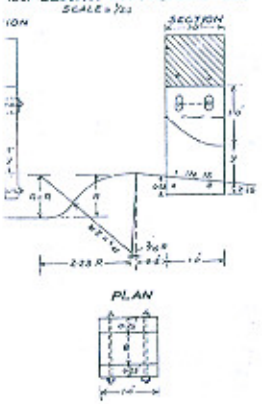
SCALE = 1/50

PLATE 2

PAPER NO. 237

ROOF BLOCK AND APPROACH IN BED

SCALE = 1/25



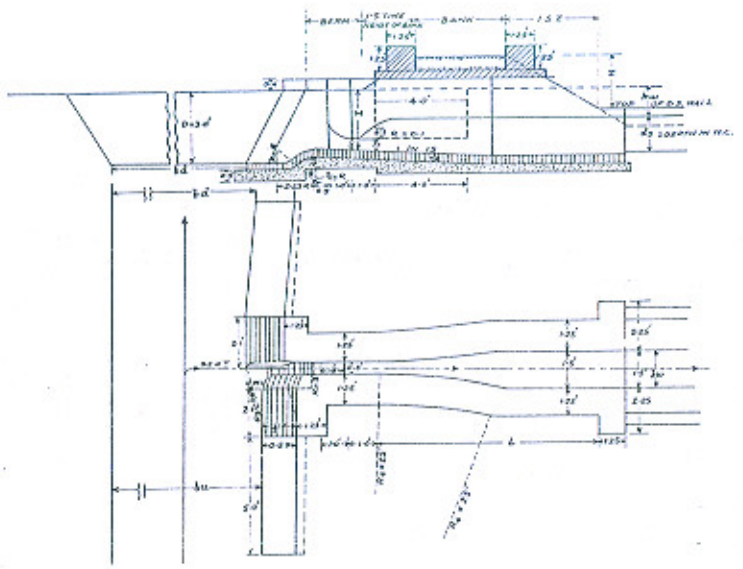
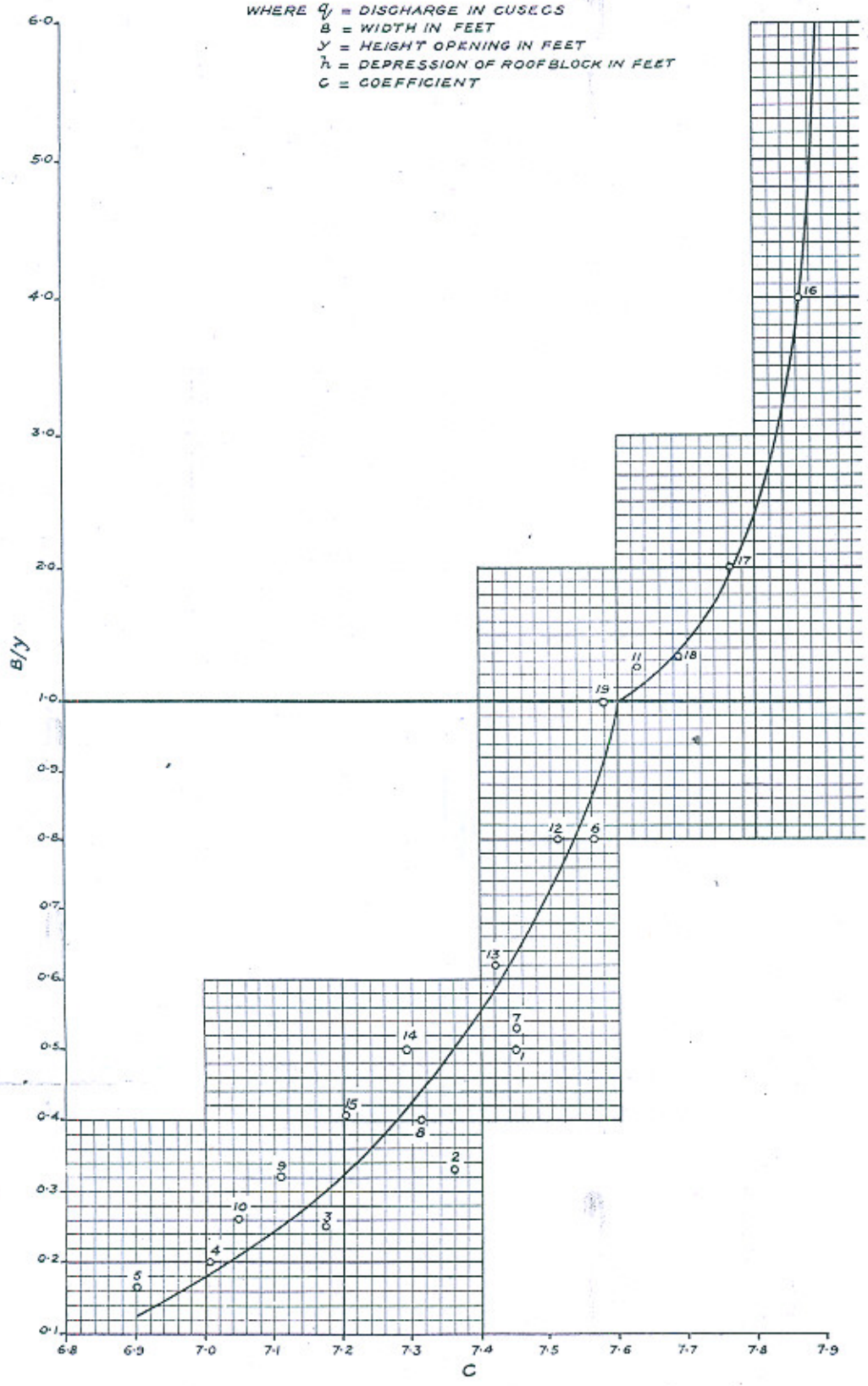

BERM
1.5 TIMES THE DEPTH OF BED
BANK
1.5 :1
4'-0"
0.3d
0.2d
0.1d
0.2d
0.1d
0.2d
0.1

PLATE 3
PAPER NO. 237

VARIATION OF COEFFICIENT 'C' IN FORMULA $q = C.B.y.\sqrt{h}$ OF A.P.M.

WHERE q = DISCHARGE IN CUSECS
B = WIDTH IN FEET
y = HEIGHT OPENING IN FEET
h = DEPRESSION OF ROOF BLOCK IN FEET
C = COEFFICIENT



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PLATE 4

PAPER NO 237

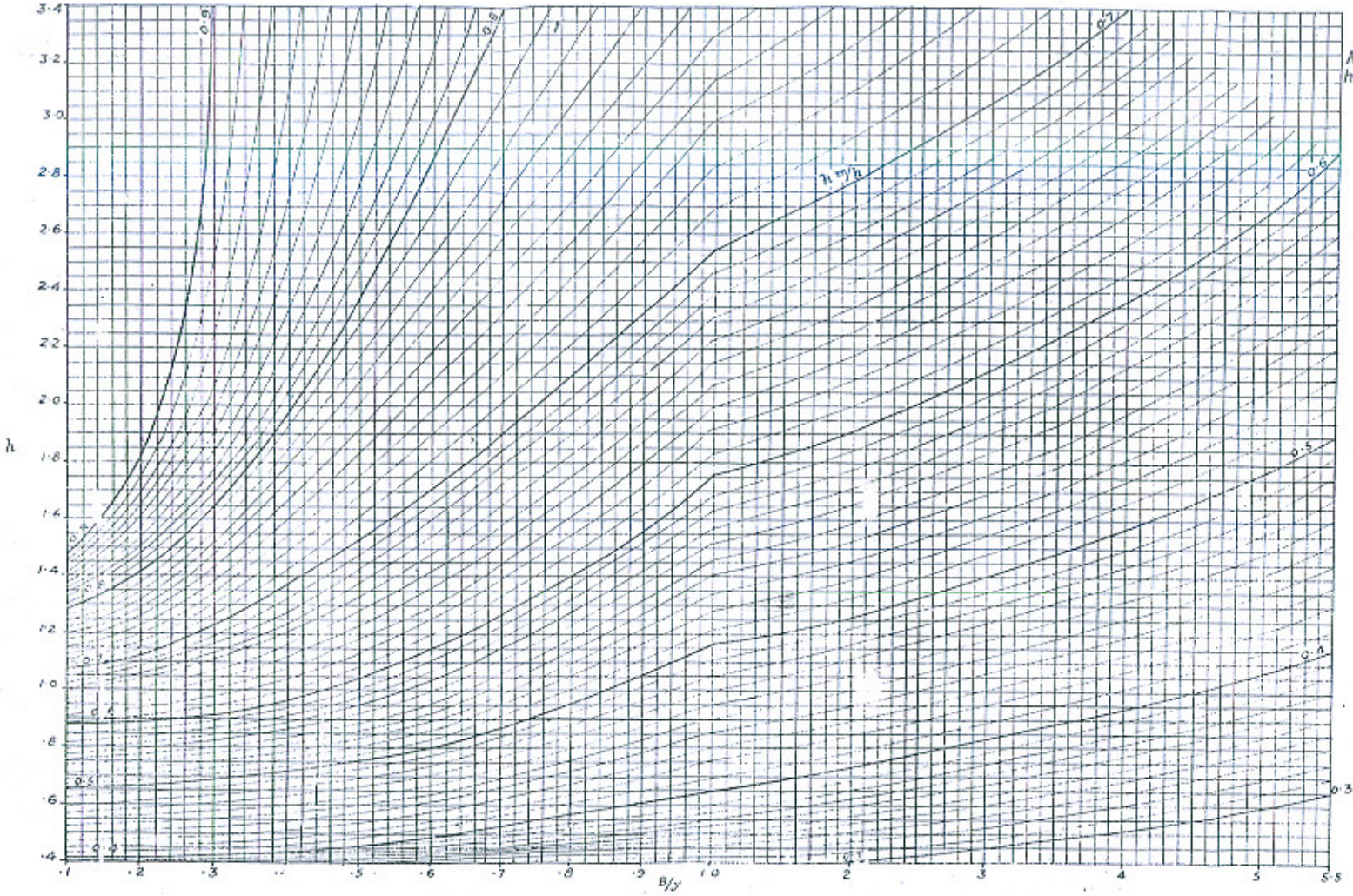
MINIMUM MODULAR HEAD FOR AN A.P.M.

h_m/h IS PLOTTED AGAINST h & B/y, WHERE h_m = M.M.H.

h = DEPRESSION OF ROOF BLOCK

y = HEIGHT OF THE OPENING

B = WIDTH OF THE A.P.M.



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PLATE 5

PAPER NO. 237

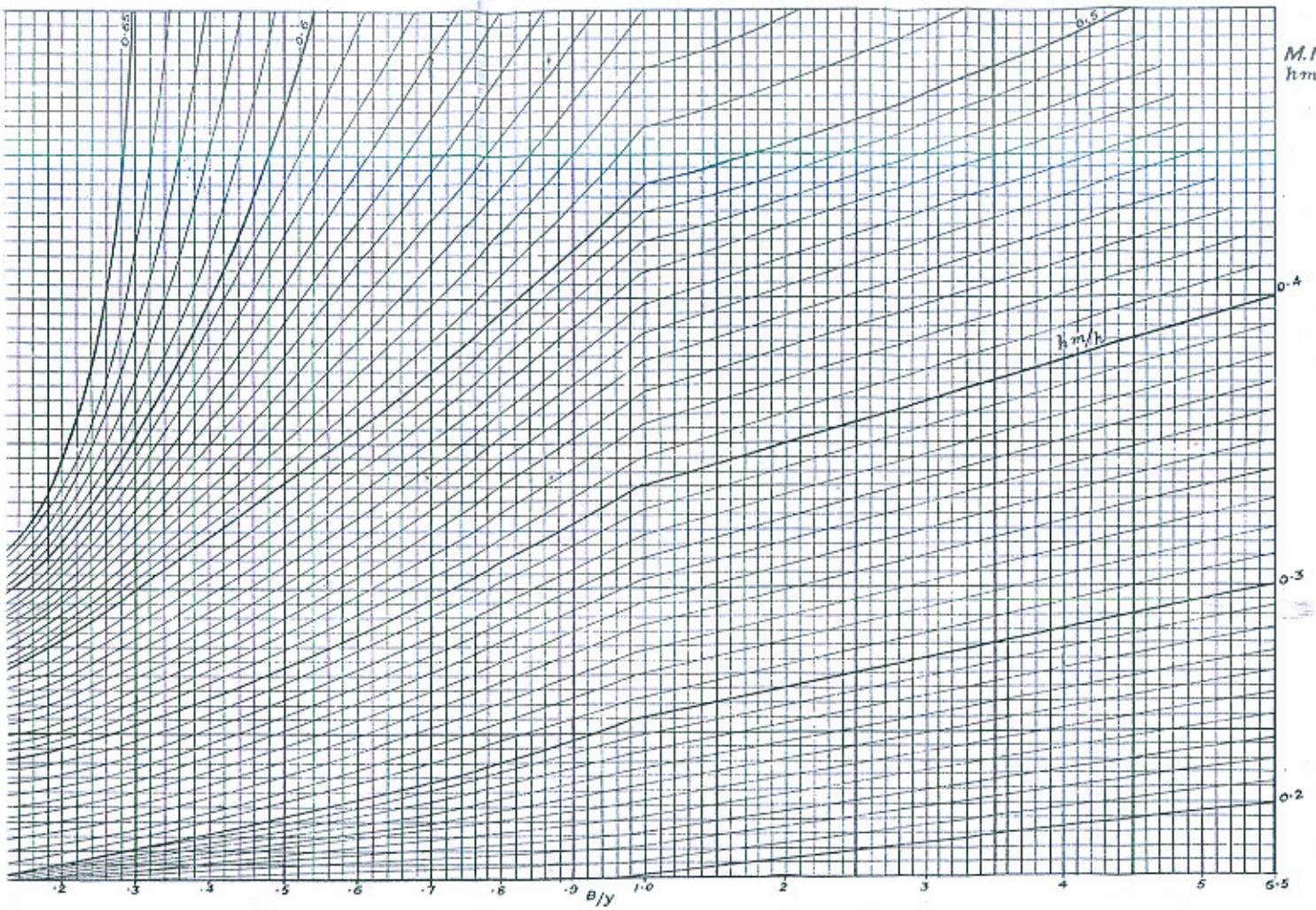
M.M.H. DIAGRAM OF SPECIAL A.P.M. FOR LOW M.M.H.

h_m/h IS PLOTTED AGAINST h & B/y, WHERE h_m = M.M.H.

h = DEPRESSION OF ROOF BLOCK

y = HEIGHT OF THE OPENING

B = WIDTH OF THE A.P.M.

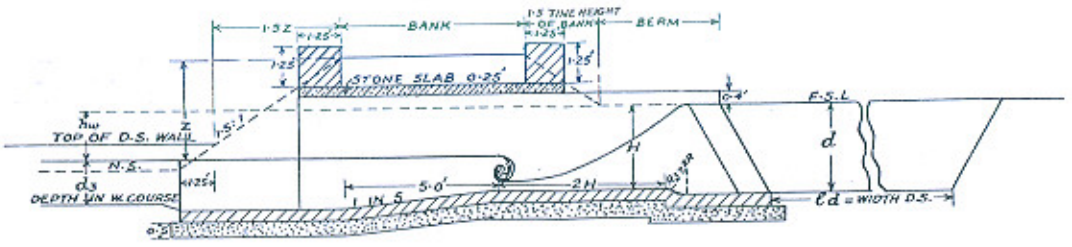


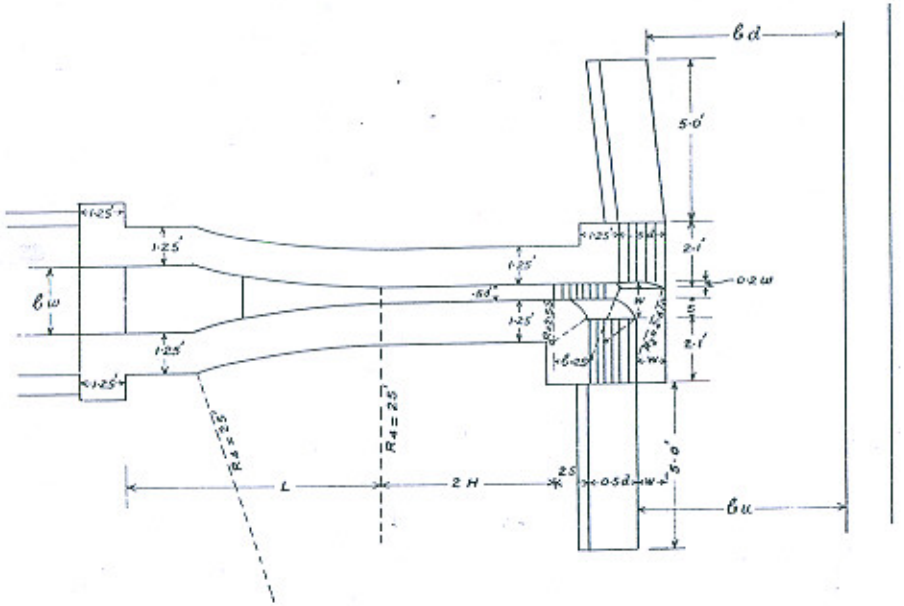
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TYPE DESIGN FOR A WEIR FLUME OUTLET

SCALE = 1/50

PLATE 6
PAPER NO. 237





WIDTH IN CHANNEL U.S. OF OUTLET	$= b_u$
DEPTH " " "	$= d$
DISCHARGE " " "	$= Q$
BED WIDTH IN CHANNEL D.S. OF OUTLET	$= b_d$
DISCHARGE OF THE OUTLET	$= Q$
SETTING OF THE OUTLET	$= \delta$
DEPTH ON CREST	$H = A d$
WIDTH OF THE OUTLET	$B = \frac{Q}{3H^{3/2}}$
LENGTH OF CREST	$= 2H$
MINIMUM MODULAR HEAD	$h_m = \cdot 15\, H$
ACTUAL WORKING HEAD	$= h_w$
SET BACK OF U.S. WING WIDTH OF APPROCH	$W = K \cdot \frac{Q}{Q} \left(b_w + \frac{d}{2}\right)$
SPLAY OF U.S. SIDE WALL	$S = W - B$
RADIUS OF SPLAY ON SIDE	$R_1 = 2{\cdot}5\, S$
LENGTH OF APPROACH CURVE ON SIDE	$= 2\,S$
RADIUS OF CURVATURE OF D.S. PROJECTED WING	$R_2 = 2{\cdot}6\, w$
RISE OF CREST ABOVE DISTY: BED U.S.	$= R$
RADIUS OF CURVATURE OF APPROACH CURVE IN BED	$R_3 = 4\,R$
LENGTH OF OUTFALL	$= L$
RADIUS OF CURVATURE OF OUTFALL	$R_4 = 25$ FEET.
DISTANCE OF BEGINNING OF CREST FROM C. LINE OF DISTY: U.S.	$= \frac{b_u}{2} + \frac{d_u}{2} + 2{\cdot}5$

WIDTH OF WATER COURSE $b_w =$
- 0 TO 1 CUSEC = 1·5 FEET
- 1 TO 2 CUSECS = 2·0 FEET
- ABOVE 2 CUSECS = 2·5 FEET

K = AVERAGE VELOCITY IN CHANNEL U.S. / VELOCITY NEAR THE SIDE

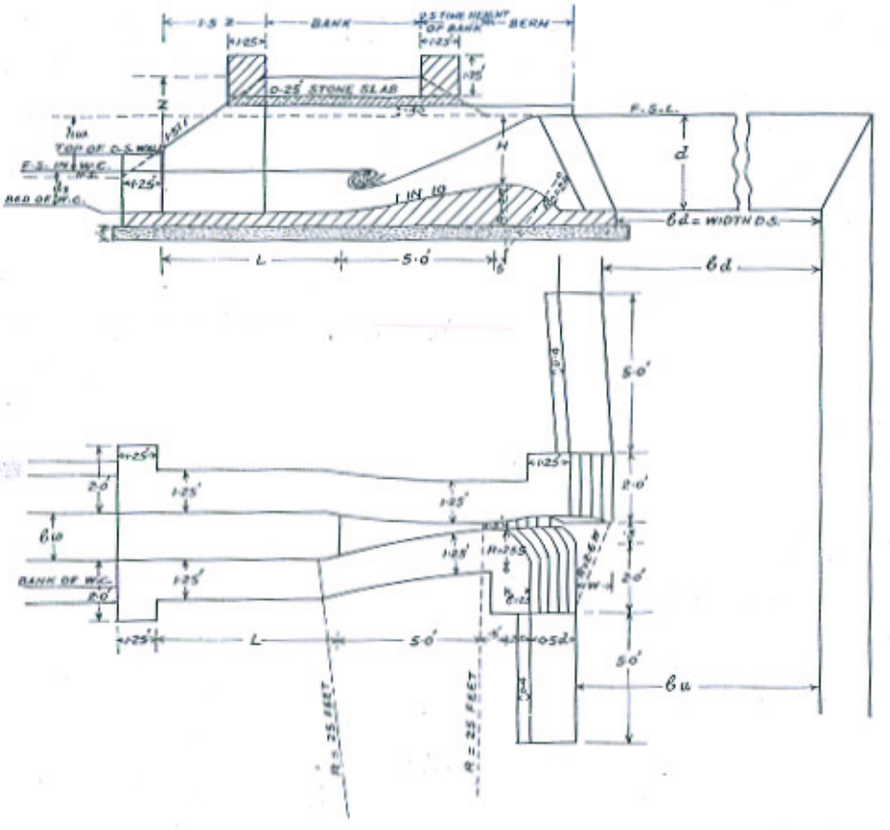
K
- = 2 FOR HEAD REACHES IN MAJOR DISTYS:
- = 1·5 FOR MIDDLE REACH "
- = 1·25 FOR TAIL REACH "
- = 1·0 FOR CHANNELS BELOW 10 CUSECS DISCHARGE.

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TYPE DESIGN OF NARROW OPEN FLUME OUTLET

SCALE = 1/50

PLATE 7
PAPER NO. 237



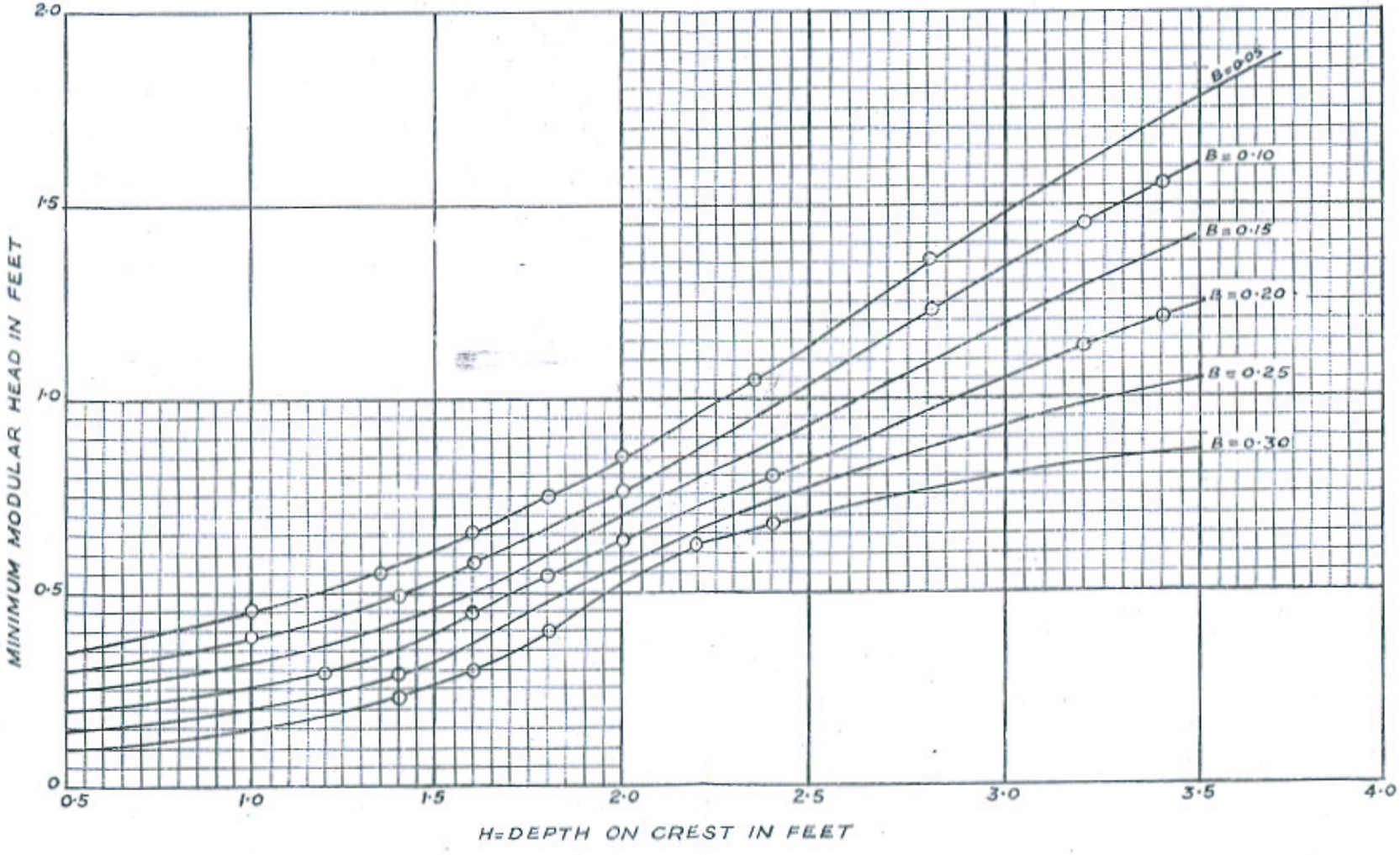
BED WIDTH IN CHANNEL U. S. OF OUTLET ____ = bu
DEPTH " " " ____ = d
DISCHARGE " " " ____ = Q
BED WIDTH IN CHANNEL D.S. OF OUTLET ____ = bd
DISCHARGE OF THE OUTLET ____ = q
SETTING OF THE OUTLET ____ = δ
DEPTH ON CREST ____ = δd
WIDTH OF OUTLET ____ = $B = \frac{q}{C H^{3/2}}$
COEFFICIENT OF DISCHARGE (FROM DIAGRAM) ____ = C
LENGTH OF CREST ____ = 0·5 FEET
MINIMUM WORKING HEAD (FROM DIAGRAM) ____ = hm
ACTUAL WORKING HEAD ____ = hw
SET BACK OF U.S WING / WIDTH OF APPROACH $W = K \frac{q}{Q} (bu + d/2)$
SPLAY OF U.S. SIDE WALL ____ = $S = W - B$
RADIUS OF SPLAY ON SIDE ____ = $R_1 = 2{\cdot}5\ S$
LENGTH OF APPROACH CURVE ON SIDE ____ = $2\ S$
RADIUS OF CURVATURE IN D.S. PROJECTED WING = $R_2 = 2{\cdot}6\ W$
RISE OF CREST ABOVE DISTY: BED U.S. ____ = R
DISTANCE OF BEGINING OF CREST FROM CENTRE LINE OF DISTY: W.S. = $\frac{bu}{2} + \frac{d\ u}{2} + 2S$
RADIUS OF CURVATURE OF APPROACH CURVE IN BED = $R_3 = 4R$
WIDTH OF WATER COURSE = bw
- 0 TO 1 CUSEC = 1·5 FEET
- 1 TO 2 CUSECS = 2·0 FEET
- ABOVE 2 CUSECS = 2·5 FEET

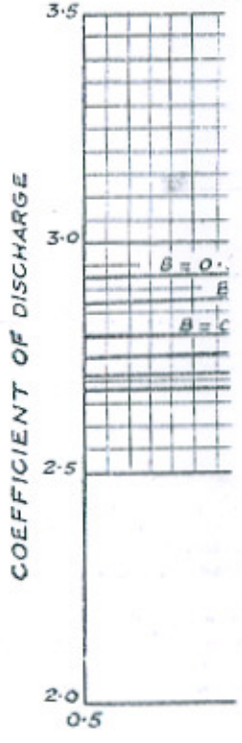
K = AVERAGE VELOCITY IN CHANNEL U.S. / VELOCITY NEAR THE SIDE
K
- = 2·0 FOR HEAD REACHES IN MAJOR DISTRIBUTARIES
- = 1·0 FOR MIDDLE REACH " "
- = 1·25 FOR TAIL " " "
- = 1·0 FOR CHANNELS BELOW 10 CUSECS DISCHARGE

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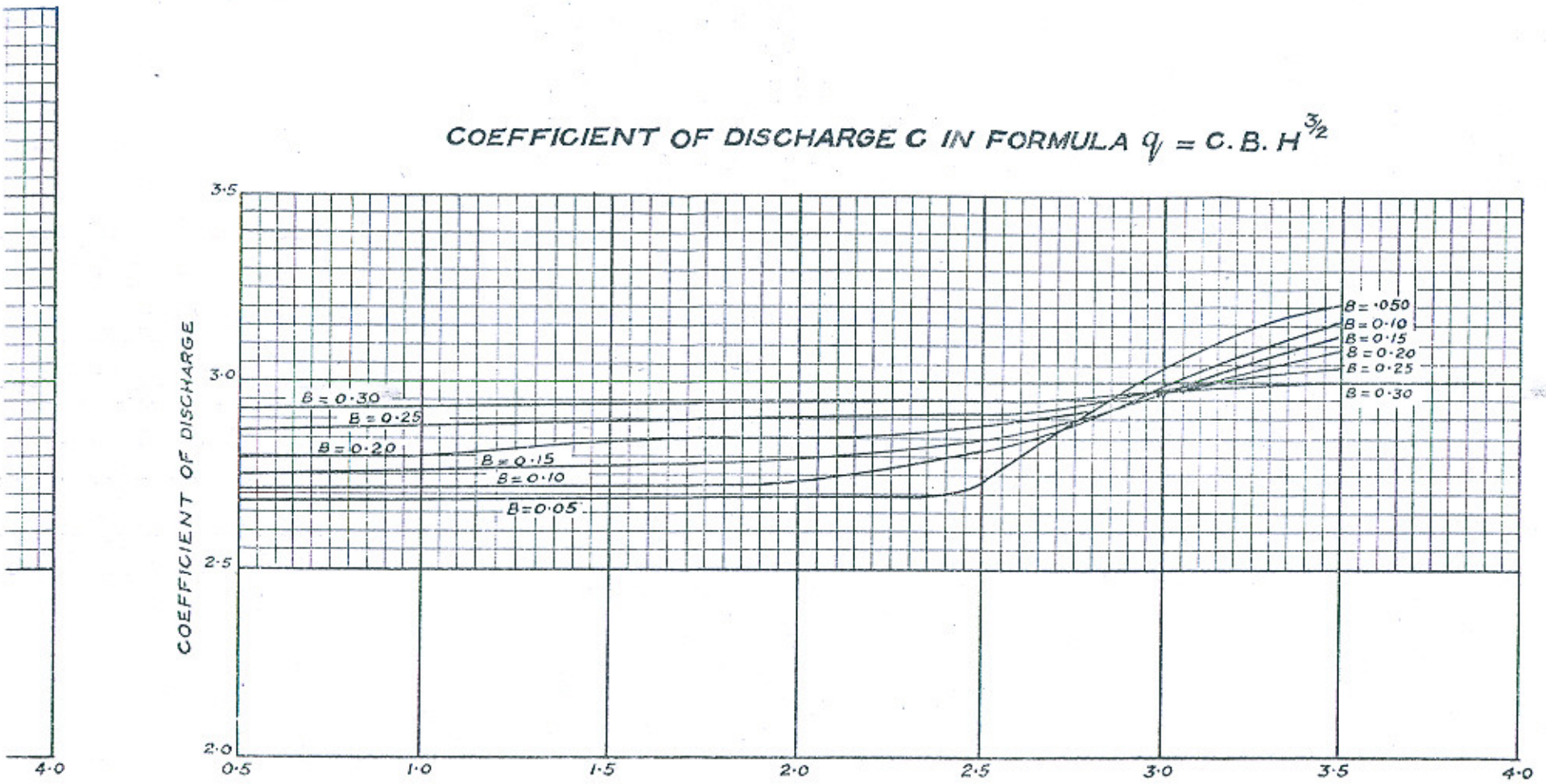
NARROW OPEN FLUME OUTLE

MINIMUM MODULAR HEAD DIAGRAM





COEFFICIENT OF DISCHARGE C IN FORMULA $q = C.B.H^{3/2}$



In introducing the Paper, the Author said that the history of development of the A. P. M. design was given in this Paper starting from the experimental work of R. S. Munishwar Chand and Mr. Crump at Balloki who had aimed at making the A. P. M. a submerged orifice.

The aim had not at all been attained by the outlets introduced in the Department. The pressure observations as described in the Author's Paper No. 176 proved this beyond doubt (as accepted by Mr. Crump in Paragraph 11 of Appendix I).

The Author tried to develop this outlet to remove these defects as stated in Paper No. 176 but the final form of the A. P. M. based on the latest researches was described in this Paper. The A. P. M. as finally developed was now definitely a submerged orifice under all conditions of its working.

The main object of this Paper was to impress that the A. P. M. design was not so simple. It was not enough to know that in an A. P. M. $q = 7{\cdot}3\ B\ y\sqrt{h}$. The constancy of discharge depended on the behaviour of the control section as defined by the following two factors :—

(1) The outlet should run full bore. There should be no starvation of jet both in its height and width.

(2) The jet leaving the orifice should be immune from pressure inflamations, that is, y depth of water should exert y pressure on the orifice floor.

In this Paper, the observations for the M. M. H. were plotted in plates No. 4 and 5 and the curves were drawn through them for use in practice. For the detailed theory of M. M. H. he referred the readers to the January Issue of the *Punjab Engineer*, Lahore (57, Mall).

Similarly calibration curves for the portable tin flume for water-course discharges might be had from the February Issue of the *Punjab Engineer*, Lahore, wherein the design of tin flumes with the necessary precautions was described in detail.

Mr. Jesson sounded a note of warning regarding the setting of A. P. M.'s. He said that when the Mithalak Distributary was remodelled in October, 1928, the outlets were constructed with their crests at $0.6d$.

The distributary silted, and this silting was attributed

to the high sitting of the crests of the A. P. M. outlets, so the outlets were again remodelled at the end of 1930, and the crests of those in the reach R. D. O. to 67,000 were set at 0.8*d*., and of those in the reach R. D. 67,000 to the tail at designed bed level. Since 1930 the distributary had worked extremely well. This instance showed that the crests of A. P. M. outlets should be set as low as the available working head permitted. He also drew attention to the special type of A. P. M., described on page 199 of the Paper, and pointed out that a similar device had been tried on the Lower Chenab Canal, and it had been found that closing the space between the outlet and the special device, had resulted in an increase in the discharge of the outlet.

Referring to the co-efficient "C" in the formula $q = C\, b\, y\sqrt{h}$ he pointed out that experiments carried out on the Lower Chenab Canal showed that for $b = 0{\cdot}2'$ and $0{\cdot}25'$ the average co-efficient worked out to 7·6, when "H" exceeded 2'. When "H" was less than 2' the co-efficient increased rapidly, but for low values of "H" the experiments carried out were insufficient to arrive at any definite conclusions.

The Lower Chenab experiments were carried out with the design of A. P. M. described in the Author's previous Paper No. 176.

Concluding Mr. Jesson regretted that Mr. Crump was not present to comment on the Paper, but he understood that the experiments had been carried out very carefully under Mr. Crump's direction, and suggested that the new type of A. P. M. should be tried out in Practice.

Mr. M. L. Aggarwal said that the Author had advocated some very intricate curves for the approaches of A. P. M's which looked quite ingenious on Paper but were perhaps hardly ever achieved in actual practice except perhaps in his experimental outlets.

On the Lower Jhelum Canal where his type had been adopted as the standard type the double upstream approach curve of glacis was nothing more than an abrupt rise rendered still worse by the dropping of mortar during the construction of the outlet. By virtue of this curve in the downstream projecting wing it was impossible in certain cases to get anywhere near the crest for purposes of checking. Correct measurements of crest levels were impossible as the working staff could not be put anywhere near the

crest. Further, by virtue of the curve in the downstream wing wall it was a problem in certain cases even to check the B and Y of the outlet for it was difficult to get any calipers or an L rod into the outlet.

Some clever subordinates were not slow in taking advantage of this difficulty and they had started in even increasing the B of the standard A. P. M. outlets which was otherwise fixed.

Mr. M. D. Mithal said that one of the changes desired by the Author in the A. P. M. outlet was the provision of curvature in the downstream wing wall ostensibly with a view to arrest the heavy silt particles and then to direct them into the outlet.

This device in miniature was similar to the curved extensions of downstream wing walls of head regulators of distributaries and minors provided with the express (and proved successful) purpose of excluding heavy silt from the heads and thus from the channels. Obviously the same device could not be claimed to serve diametrically opposite purposes by changing the names of the off-takes, as it were.

He further added that the curved portion was expensive In design, difficult to construct and was seldom found intact after construction. It was therefore useless to adopt this feature.

Replying to the remarks of Mr. Jesson, the Author said that his comments about the co-efficients and special A. P. M. related to the A. P. M. outlets described by the Author in Paper No. 176 where the Author discarded the submergence of the jet and gave it a parabolic outfall. Mr. Jesson had to revise the Author's co-efficients beyond the range of the Author's experiments and the Author had no hesitation in accepting his comments.

The A. P. M. described in this Paper was essentially a perfect submerged orifice and the control section was not liable to pressure inflations under any conditions. It was for this reason that Mr. Jesson's remarks about the increase of discharge did not apply to the present proposed design of the A. P. M.

Replying to the remarks of Mr. Aggarwal, the Author said that the open space left downstream of the roof block was meant for checking the size of outlets. The check

should be carried out by using differential *y*-rods mentioned in this Paper which were already in use in some Circles.

Replying to the remarks of Mr. Mithal, the Author said that the downstream approach curve was not similar to the design of the Gibb's groyne walls which were meant to exclude silt. The curve provided in this outlet deflected silt towards the orifice but a Gibb's groyne was designed on the simple principle that the supply of the parent channel was distributed before any disturbance of the off-take head could exercise its effect.

The Author never had any complaints of any damage done to these curves for 6 years when he was in charge of channels fitted with his A. P. M. outlets.