CANAL OUTLETS.

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Introduction.

This paper is an attempt to sketch as briefly as possible the history of the canal outlets on the Punjab perennial canals, both old and new. It briefly describes the vicissitudes through which they had to pass and the experiences of their working which have evolved the present day types in use on canals. It is only a historical sketch, laying no claim to originality or research, and there is nothing in it which can be considered new or unknown to the irrigation engineer. The only excuse for writing the paper is to bring out in a connected form what lies scattered here and there, and thus to attract the attention of the profession more pointedly to our requirements and to the defects of the outlets in use, in the hope of securing improvements, and thus lead the way to the adoption of a general type and uniformity of practice for the whole province.

The Punjab perennial canals arrange themselves into two main groups—the old and the new. By the old canals is meant those constructed before 1885, such as the Western Jumna, the Upper Bari Doab and the Sirhind canals, while the second group consists of those opened later, viz. the Sidhnai, the Lower Chenab, the Lower Jhelum, and other canals still more recently opened.

This distinction in point of time is a mere convention, yet a convenience, though the years following 1885 mark a period of general activity in irrigation, for not only were schemes in hand for extending canal irrigation to dry tracts on the Western Jumna and elsewhere, but questions relating to the science of hydraulics, and to securing greater efficiency in the existing channels were engaging the attention of canal engineers.

On the Sirhind Canal, which had started irrigation in 1883-84, about this period (1887-1893) types of outlets and flap valves were being tried and discussed, and attempts were being made to regulate the sizes of permanent outlets, from the experience gained in working temporary ones, so as to ensure an equitable distribution of water in the villages served.

Unlike the new canals, irrigation on the old ones had developed slowly. People did not take to it readily at first and were suspicious, but gradually, as they realized the advantages of irrigation, they became more and more anxious to secure a share of it for themselves.

Definition and Conditions of Working.

An outlet may be defined as the head of a water-course directly serving the fields. It usually consists of a brick culvert or earthenware pipes under the bank of a distributary channel, with face and tail walls of brickwork or concrete. Its size is fixed according to the irrigation required, and is designated according to the equivalent number of standard pipes. The orifice area of any outlet used not to be designed to pass a certain discharge, but used to be arbitrarily fixed to annually irrigate a certain area, and with reference to this the late Sir T. Higham as far back as 1883 wrote as follows : " The conditions, however, that determine the discharge of a water-course head (outlet) will vary in every case and can really only be determined by experience. It is very doubtful whether the best and most painstaking of canal officers could so place and proportion the water-course heads upon a single minor as to ensure from the outset a definite ratio in the distribution without the introduction of tateels " and on these grounds he recommended " as both feasible and expedient, to design the outlets so that their discharging capacity can be varied at pleasure, " the end in view being, "a complete control over the ultimate destination of canal water after it leaves the distributary, without any interference whatever in the details of distribution."

The importance of an outlet will be better realized when it is stated that while the water flowing into a distributary channel is under the complete control of the Department, that passing out is entirely out of its control, and this has led to unceasing efforts on the part of irrigation officers for the last thirty years or more to find out some means of controlling this supply, as until this can be done no claim to equitable distribution of water to all the villages served by a distributary

can be made. The principle involved is a very important one, and so far has been difficult to attain. While each distributary channel—nay, even every reach of it—is designed, constructed, and maintained to carry a certain supply, its outlets and their draw-offs set at nought the whole care bestowed on it. Sometimes it is not possible to reduce outlets where a reduction is required, and thus even legitimate claims for an increased supply, where necessary, cannot be acceded to, and have to be ignored.

It is not the scope of this paper to deal with such troubles, but in so far as they relate to outlets, it will not be out of place to briefly mention them here. Complications result from the way distributaries are worked, from the manner in which the water-courses are maintained by the zemindars, and from the exigencies of the seasons and the rainfall. During periods of slack demand water-courses are not cleared, and the outlets consequently draw off much below their normal capacities, with resultant flooding at the tail, while if the discharge of the distributary is correspondingly reduced, the outlets in the head reach lose their command. When the demand is keen, water-courses are cleared of silt, and the outlets begin to draw off more than their normal share, and the result is a shortage of water in the lower reaches and at the tail.

The diameter adopted for the standard pipe varied on different canals. On the Western Jumna and Upper Bari Doab canals the earthenware pipe or "colaba" was 0·4 of a foot in diameter, giving an area of one-eighth of a square foot, while on the Sirhind Canal it was 0·5 of a foot, with an area of one-fifth of a square foot. On the new canals the smaller section has been adopted.

Location of Temporary Outlets.

The practice followed in the past on old canals, like the Western Jumna, the Sirhind and the Upper Bari Doab, regarding the location of temporary outlets, and the alignment of water-courses, was to leave these things as much as possible to the people themselves. In the first instance temporary outlets, consisting merely of earthenware pipes or sheet iron tubes, were laid in the distributary banks. On the Sirhind Canal their location was decided with the help and advice of the headmen of each village, who were held responsible that the outlets were fairly well distributed throughout the village lands so that all got a fair share of the canal water, but the irrigators had the option

of changing the position of these temporary outlets with the permission of the Executive Engineer.

In 1883 the diameter of the standard pipe colaba for the Sirhind Canal was fixed at six inches, on the recommendation of Major Western, R. E., who was strongly in favour of a single and uniform size being used in all cases. Subsequently, however, it was found necessary to use a smaller sized pipe under certain circumstances, and sanction was obtained in 1888 to use a half pipe size of $4\frac{1}{4}$ inches diameter, with an area of one-tenth of a square foot, and it was assumed that each pipe on a half time minor distributary would irrigate fifty acres, thirty-one in rabi and nineteen in kharif, and on a major distributary, running full time, double the quantity.

About 1885 it was ruled that all irrigation on the Sirhind Canal system was to be effected through the medium of minors taking off from the major distributaries, or in certain cases direct from the canal. The minors were to have outlets and run half time, whereas a major distributary was to run full time, and though it was permitted to place colaba outlets in the major distributary banks, it was enjoined that these should be avoided wherever possible. It was further laid down that, if necessary, two or more colabas might be built together as one outlet.

Temporary outlets were not allowed where the bed of a distributary was above the natural ground surface, but were usually located where the bed was a foot or six inches below the soil. Such trial outlets were intended to work for only one or two years, but they often remained for longer periods, in some cases as much as ten years.

The procedure followed on the still older canals, viz., the Western Jumna and Upper Bari Doab, was much the same, except that on both these canals the size of the standard pipe was 0·4 of a foot in diameter. On the Upper Bari Doab, canal irrigation was not mainly done through minors, but from outlets in the major distributary banks, and to feed all these outlets properly, sectional "tateels" or "bandis" had to be instituted on each distributary. On the Western Jumna Canal, irrigation was done through half time minors, as well as from the outlets in the banks of major distributaries, where sectional "tateels" were enforced.

On the new canals, like the Sidhnai, the Lower Chenab, and those still more recently constructed, detailed contoured plans were prepared, and it was on these contoured plans that the

outlet " chaks " or their commanded zones were first marked out and arranged, and suitable alignments for water-courses to irrigate them, decided upon. The positions of outlets thus fixed were generally correct and changes were seldom needed.

Temporary outlets, consisting of wooden shoots, were first tried at these sites, but such trials did not continue for long. The orifices of these wooden shoots were calculated from the head on each outlet and the supply of water required to irrigate the permissible area in each zone or " chak. " The permissible area was a certain percentage of the commanded culturable land. It varied for each canal, and was often different for different tracts served by the same canal, and was determined according to certain conditions which are, however, outside the scope of this paper. The annual irrigation in acres per cusec of full supply was also fixed for different canals and their branches, and called the " full-discharge factor." Thus if Ap be the permissible area in acres, and F the full-discharge factor for the distributary, the supply of water required for the area Ap, or the discharge required from the outlet, would be equal to $\frac{Ap}{F}$ cusecs.

Alignment of Water-courses

It has been already stated* that on the old canals the location of temporary outlets, and the alignment and construction of water-courses was, to a large extent, left to the people themselves. The chief reason for this was that no detailed surveys of village ands had ever been made, and reliable contoured maps with sufficiently close contours were not available for the use of irri-gation officers.

These water-courses were constructed anyhow by the nindars, and were, generally speaking, defective in alignment, ding and size, and are even up to the present day badly ıtained, causing waste of water. Cases are on record where, g to defective alignment and grading, the major portion of ommanded area remained unirrigated, and elsewhere, owing ective construction, a cross-section of over six square feet was provided for a discharge of one and a quarter cusecs. ions among the zemindars rarely allowed of the best ıt being adopted in the first instance, and usually prevented

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efficient maintenance. The Western Jumna and Upper Bari Doab canals still greatly suffer in this respect, but on the Sirhind Canal, after remodelling the distributaries, and amalgamating and readjusting the outlets, the alignments of many water-courses were set right by the Department after making special surveys, or at the request of the irrigators. This took over two years, and the trouble is not now so acute.

The great importance of a careful and economical alignment of water-courses, and their proper construction, which had not been realized in the early days of canal irrigation was fully recognized, owing to bitter experience, by 1885, and detailed contour maps were prepared of all villages on the Lower Chenab, the Sidhnai and the Lower Jhelum canals. On these contoured maps the "chaks" for each outlet were first arranged, then water-courses to irrigate each portion as economically as possible were aligned on the plan, and, in the case of the Lower Chenab and Lower Jhelum canals, were even constructed by departmental agency both on crown and village lands. This policy is being consistently followed on the new canals more recently opened, and has already resulted in large savings of water for irrigation which would otherwise have been wasted.

The absence of such plans on the old canals was keenly felt at the time of remodelling the distributaries and readjusting the outlet chaks. The zigzag alignment of water-courses along the field boundaries cannot be well avoided, but a systematic and correctly aligned arrangement of water-courses and their branches throughout the chaks would save the waste of water now going on. The "chak-bandis" or "wara-bandis" are also defective, and often water has to run through a long badly kept water-course in order to irrigate a small field at the end of it. High fields are often irrigated from low-lying water-courses in consequence of which the latter silt. Such defects could b easily overcome by branch water-courses suitably aligned ar constructed.

Types of Outlets built prior to 1891.

The oldest canal is the Western Jumna, and next to it cc the Upper Bari Doab ; the former having been opened to ir tion in 1820 and the latter in 1860-61. It is not known permanent outlets were first constructed on these two systen drawings of outlets as old as 1873 have come to hand f Upper Bari Doab Canal, and it is probable that older types lets have disappeared, and have been replaced by more recen

The simplest, and probably the oldest type of outlet, consisted of colabas laid in mortar with a little concrete. This developed into the type shewn in Plate No. 1, also consisting of colabas, but completely bedded in concrete, with face and back walls of plastered concrete. In this type a groove was provided for planks for closing the outlet at both ends, with an iron strap for locking the planks in position in the face wall towards the distributary. These grooves and the planks were necessary in the design, as a regular "tateel" system of minors and outlets was enforced. The outlets were termed one, two or three pipes according to the rows of colabas provided. Examples of both these earlier types were peculiar to the Upper Bari Doab Canal, and were not met with on the Western Jumna. They had disappeared long before the writer joined the department, and were not adopted on the Sirhind Canal When the number of pipes required was more than three, colabas were not used, but an outlet with a brick or masonry barrel, either rectangular or circular in section, was employed, and this type of outlet was known as a "dahana." A specimen with a rectangular orifice is exhibited in Plate No. 2. Such outlets were common on the Western Jumna Canal.

During the five years 1883 to 1888 a type of colaba outlet with masonry face walls came to be adopted. This, as illustrated on Plate No. 3, was meant for minors, but examples of it are rare. A modified pattern was used for major distributaries. Examples of this type existed on distributaries of the Sirsa branch of the Western Jumna Canal till 1903, but have probably disappeared by now, as they were being replaced by that shown on Plate No. 6. Slightly modified examples are found on the Upper Bari Doab Canal, sometimes with and sometimes without flap valves.

On the Sirhind Canal the question of instituting permanent outlets for the temporary ones, though taken up earlier, was not brought to a head till 1893. The types adopted are shown on Plate No. 4, and are similar to the Western Jumna type. They were used for all sizes up to three pipes, with masonry outlets for anything bigger. The chief difference was that the Sirhind type outlets were fitted with cast iron flap valves to admit of their being readily closed when water was not in demand. These flap valves and their seats, both machine planed to ensure a tight fit and no leakage, were adopted after careful trial, and were known as the 'Rupar valves.'

In all the above types of outlets, the boundary road culvert, if needed, was provided by lengthening out the barrel. The colaba outlets were tamper proof, and during slack demand it was possible in some cases to admit less water. Those provided with flap valves readily admitted of being opened or closed from outside.

Remodelling of Distributaries on the Old Canals.

In his note* dated April 1883 Mr. Kennedy had drawn attention to the wasteful methods of irrigation practised by cultivators, and in July 1891 he drew attention to the faulty system for the regulation of supplies in channels by sectional "tateels" or "bandis" in the Third Division of the Upper Bari Doab Canal.

The type of outlet in use was changed, and types with pressure sills, as shown on Plate No. 5, were introduced in the First and Third Divisions. Mr. Kennedy himself wrote somewhat as follows about the experience of their working and failure : "Between 1890 and 1894 strong cemented brick and stone outer sills were built on ordinary outlets over the whole of the Third Division of the Upper Bari Doab Canal, but after some years' struggle to maintain them, they had to be abandoned on account of continuous trouble from dismantling by the cultivators so as to draw off more supply, and ordinary outlets had to be substituted."

Just as very little care had been exercised regarding the location or levels of the temporary outlets, so when permanent ones were substituted, advantage does not appear to have been taken of the lessons learnt from the working of the former, and the result generally was that the outlets were designed with unnecessarily large outlets.

Irrigation "chaks" having been arranged in the unscientific way already described, with high and low land mixed up to suit the convenience of the zemindars instead of with the idea of securing as far as possible a uniform command, it was only natural that the heads on some of the outlets should vary from 0·3 to two or three feet, according as high or low land was being irrigated ; and in course of time, owing to silt deposit on the distributary beds and the consequent rise in their full supply levels,

* Punjab Irrigation Branch Paper No. 10.

the draw off further increased, so that the distributary tateel systems on the Western Jumna and Upper Bari Doab canals were found wasteful and unsatisfactory. A reference to Mr. Kennedy's notes* will show the troubles of the irrigation engineers of that time on the Upper Bari Doab and Western Jumna canals.

The Sirhind Canal was in no better position, as, owing to the extension of the " minor " system of irrigation, the water-courses were necessarily of moderate length, and the dimensions of outlets were restricted to that of the standard pipe already mentioned. The result of all this was that the minors were over-outletted and the canal system over-minored. In other words, the areas at the tails of channels were starved, and those near their heads were being heavily over-irrigated, and a fair distribution of the supply of a channel over the area served by it was considered impossible under the circumstances. The ' tateel ' system was here also proving very wasteful, and the control of supplies let down a distributary was anything but satisfactory, with the result that the important fact that the capacity of the outlets would have to be regulated, so as to minimise the necessity of internal ' tateels ' began to be fully recognized on this canal.

Mr. Kennedy's note of December 1898 on remodelling the distributaries on the Western Jumna Canal, and his theory of silt transport and designs of non-silting sections for channels, had cleared the way for a general remodelling of distributaries on the old canals. The necessity of amalgamating outlets, so as to run bigger discharges, in order to avoid losses by absorption and other waste of water, was fully realized. The evils resulting from over-outletting the minors and assigning colabas for small chaks were accepted as an inefficient method of distributing water, and it was recognized that, by adopting Mr. Kennedy's methods, or at least a modified form to suit local necessities, an efficient method of distribution would result.

Types of Outlets between 1891 and 1906.

This led to the remodelling of distributaries which continued up to 1908-09, and we find colaba outlets gradually discarded, and other types of outlets with rectangular orifices being adopted, but the standard colaba pipe was retained as the

* Punjab Irrigation Branch Paper No. 10.

unit for calculating the orifice sizes for the new type of outlets. For example, on the Western Jumna Canal, where the standard pipe was 0·4 foot in diameter, the equivalent rectangular orifice was fixed at six inches high and three inches wide. The sizes of two pipes, three pipes and other outlets, advancing by half a pipe, were similarly fixed in accordance with the following table both for the Western Jumna and Upper Bari Doab canals ; the only difference being that on the latter earthenware colabas were used for single pipe outlets, and rectangular cast iron orifices for the remaining sizes, whereas on the former rectangular orifices were used for all sizes :—

Number of pipes.	Dimensions.		Area in square feet.
	Height in feet.	Breadth in feet.	
½	0·25	0·25	0·0625
1	0·50	0·25	0·125
1½	0·50	0·375	0·1075
2	0·50	0·50	0·25
2½	0 50	0·625	0·312
3	0·75	0·50	0·375
3½	0·75	0·583	0·437
4	1·00	0·50	0·50
4½	1·0	0·56	0·562
5	1·0	062	0·625
5½	1·0	0·687	0·687
6	1·0	0·75	0·75
6½	1·0	0·80	0·81
7	1 0	0·875	0·875
7½	1·0	0·937	0·937
8	1·0	1·0	1·00

The Sirhind was the only canal where the standard colaba was of six inches diameter, and this unit was retained for that canal, with the result that the sizes for rectangular orifices of

various denominations, advancing by half a pipe, were fixed as follows :—

Number of pipes.	Dimensions.		Area in square feet.
	Height in feet.	Breadth in feet.	
½	0·5	0·2	0·10
1	0·5	0·4	0·20
1½	0·5	0·62	0·31
2	0·75	0·58	0·435
2½	1·0	0·50	0·50
3	1·0	0·62	0·62
3½	1·0	0 687	0·69
4	1·0	0·80	0·80
4½	1·0	0·875	0·88
5	1·0	1·0	1·0

The general type of outlet adopted on the Western Jumna, the Upper Bari Doab, and the Sirhind canals were as shown in Plate No. 6. A similar, but probably better type in several respects was adopted in the Second Division of the Upper Bari Doab Canal, so that the practice throughout the canal was slightly different in different divisions.

One peculiarity of the Western Jumna type No. 6 (*a*) may be mentioned here. For outlets ranging from one to three pipes the orifices were always as shown in the table for a length of about one foot, but the barrel under the bank beyond this point was twelve by six inches, or equivalent to a four pipe section. The orifices were at first made of stone as shown by type No. 6 (*c*) on Plate No. 6, but for outlets built later cast iron orifices were provided. From four pipes upwards the orifice and the barrel were of one and the same uniform section throughout. The bigger section of barrel with the smaller outlets was a source of great temptation, and it was subsequently decided to make all outlets of more than two pipes, with the barrel of the same section as the orifice, while for smaller sections the barrel was made six inches square.

On the Upper Bari Doab Canal, colaba pipes were used for pipe outlets, and rectangular iron orifices for all other sizes.

The two types shown on Plate No. 7 probably belong to the closing years of the nineteenth and the opening years of the present century. Type No. 7 (*b*) is very frequently met with, and appears to have been proposed as an improved modification of No. 7 (*a*). The face of the opening is protected by a cast iron orifice ten inches long, while the size of the barrel for about four feet is of the same section as the orifice. Beyond that the barrel is twelve inches square in section. The advantage of this type is that the orifice area can be altered at a small cost, but the great drawback is that they can be tampered with at the sides. Type No. 7 (*a*), where the central part of the barrel is large and the two ends are of the correct section according to the orifice, is not so much open to the above objection, but it cannot be said that it does not offer temptations to the mind of a zemindar. The cost of carrying out alterations to the size of the orifice in this type of outlet, though greater than the other, could not after all have been much.

Types of Outlets adopted on the New Canals.

The Western Jumna type No. 6 (*a*) was the one adopted on the Lower Chenab Canal where the outlet and boundary road culverts were combined. The standard pipe was 0·4 of a foot in diameter. Half pipe outlets were rare, and even one pipe outlets were not common. The barrel section was the same throughout as that of the orifice, and this, combined with the length of the barrel, made the cost of altering the size high. Separate boundary road culverts were adopted about 1907, but the uniform section of barrel and orifice is still in use. To get over this defect, an outlet as shewn on Plate No. 8 was tried on the Upper Bari Doab, Lower Chenab, Lower Jhelum and Swat River canals. It consisted of a uniform barrel, twelve inches or more square, under the bank, with a cistern two feet square on the downstream or water-course end, and an orifice opening of the correct size in the outer wall of the cistern, the thickness of which was never less than one and a half times, nor more than three times the height of the orifice, which was of cast iron or stone. As far as the cost of alterations to the size of the orifice was concerned, this type gave the cheapest results—in fact there was hardly any expense or trouble in doing so, but unfortunately this facility was equally shared between the Department and the zemindars, and the fact that the latter always could enlarge the orifice, or could remove a brick or from the cistern wall, without being detected for a consi

time, proved its undoing. The Department occasionally exercised their right of reducing sizes, but the irrigators concerned frequently applied the reverse illegal remedy, and this type soon went out of favour. The cisterns were done away with, and the barrels were reduced to the required section of the orifice. In this type, as the orifice was fixed in the cistern wall a foot or a foot and a half thick, the co-efficient C in the formula $D = C A \sqrt{2gh}$ was taken as 0·82. A later type adopted on the Lower Jhelum Canal was the Jhang Division type similar to Type No. 6 (*a*) with a separate boundary road culvert.

Kennedy's Gauge Outlets.

Towards the close of 1906 Mr. Kennedy's device was brought to the notice of irrigation engineers in the Punjab, and orders to carry out elaborate tests were issued in 1907. It is unnecessary to go into the details of these experiments, as they have been suitably recorded in Irrigation Branch Paper No. 12, and every irrigation engineer knows them. Tests were ordered on several canals, but the best record came from the Upper Bari Doab. Certain distributaries on the Chenab Canal were fitted with these outlets in 1912 to test their practical utility, and many suggestions were made to remove defects, such as the heavy silt deposit in the bed of the distributary where the outlets were fixed above the bed level, and tampering with the vent pipe on the part of cultivators, by blocking up the holes and the vent top by means of rags and clay.

Mr. Kennedy wrote several notes about these defects, and proposed modifications in the original design, which is shown as type No. 9 on Plate No. 9. The amended type outlets, shown as No. 9 (*a*), are under trial on the Lower Chenab Canal, but the results of these trials have not yet been made available. The tests already carried out, and the experience gained in working isolated examples of the old type on the Sirhind and Upper Bari Doab canals, lead one to believe that this kind of outlet fulfils most of the conditions which an ideal outlet should possess, to conform with the conditions of working distributaries and questions of supply and demand on canals. The outlet is made of cast iron, and is very simple in construction, while the gauge on the vent tube shows at a glance the discharge that is being drawn off.

If the defects of the older type have been overcome, it is hoped that the amended types will be generally adopted. The only

thing which might stand in the way of its extensive use, would be the life of the sheet iron outfall pipe, but this short-coming would not be difficult to remove in actual practice by making the outfall pipe of specially moulded bricks worked to a template.

Gibb's Module.

In 1908 Gibb's module came under the notice of irrigation engineers, and early in 1909 orders were received to give it a trial on the Shahkot distributary, and it was also tried to a limited extent in other divisions. The trials on the Shahkot distributary, though not quite satisfactory, were very interesting, but as they are fully recorded in the Punjab Irrigation Branch Paper No. 13 it would be waste of time to deal with them here.

The module gives a rigidly fixed discharge between certain limits of head previously fixed at the time of designing, and the discharge is delivered at an unchanging level in the outfall. The module, inasmuch as it delivers a fixed discharge, is an excellent device, but it is not quite suitable to the conditions of demand and supply under which the distributaries on our canals are worked. In short, there is a want of elasticity in permitting no variation of discharge necessitated by changing conditions. As long as a distributary is run with a full supply, *i. e.* the supply required for all its outlets plus the losses due to absorption, these modules will work satisfactorily, but whenever the supply falls, say a quarter of a foot, in the head reach of the distributary, if the modules are working within their range, they will go on drawing off their fixed discharges, and the shortage will be thrown on to the lower reaches, till the depth of the supply falls below the range of the modules, when they start working like ordinary outlets.

The ledge in its design is decidedly a weak point and open to outside interference, while during periods of keen demand in rabi the temptation to break them, combined with the smallness of the risk of detection and punishment, is too great. The escape wall was found to be another weak point, and the cost together with the extreme care required for its construction and subsequent alterations must be put down as other drawbacks to this type of outlet.

Since the Shahkot experiments Mr. Gibb has brought out an improved type of his module, but it is not known if this type is under test anywhere, nor is anything known about its merits and defects. The type tried on Shahkot distributary is shown on Plate No. 10.

The Harvey Stoddard Module Outlet.

In 1915 Messrs. Harvey and Stoddard designed a module outlet, in the working of which the principle of a standing wave is brought into requisition to eliminate varying supplies being drawn off by the outlet due to variations of the supply level in the water-course. The unsilting of water-courses and the consequent lowering of their supply levels cause a great draw off of the supply—sometimes as much as three times their share—and the object of this module outlet is to make the discharge drawn off independent of these variations. The discharge is then only dependent on the depth of submergence of the orifice below the full supply level of the distributary. It is being tried in the Swat River Circle, but no details of its tests are available.

Metal Outlets.

Cast iron pipes have been in use as outlets for some years in other provinces, but they were only introduced into this province in the beginning of 1909, and were probably first tried on the Lower Chenab Canal in that year. Messrs. Stewart and Lloyd's steel pipes came into notice the same year. On the Upper Bari Doab and Sirhind canals they were brought to notice in the years 1911 and 1912 respectively, but were not actually received or used till 1915.

The facility with which alterations can be made at a low cost are greatly in their favour, while they are immune from interference on the part of the cultivators. The initial cost of a steel or iron pipe outlet is also small, and not very much above that of a masonry outlet, while the tubes can be used over and over again. It is at present difficult to say how long the steel pipes will last, but if properly coated with some anti-corrosive solution, they ought to last for quite a long time, since, except for sand and silt, the waters of our canals are not charged to any serious extent with mineral or vegetable matter that would act harmfully on the inside surface of the tubes. Of course rusting is chiefly to be feared, and the uncertainty as to their life does not compare favourably with masonry or colaba barrels which are practically everlasting. Another disadvantage to this type of outlet is the limited range of standard sizes manufactured, which renders it difficult to obtain the exact dimensions required. The sizes to be had range from three to twelve inches, progressing by increments of one inch in diameter except the $3\frac{1}{2}$ inch diameter size, which is also manufactured Another complication arises

owing to the relative friction in masonry or colaba barrels as compared with steel or iron tubes, while it is not always possible to find a suitable size out of those manufactured. If attempts were made to find out the size of an orifice from the required discharge and the pressure head on any outlet, the same difficulty would be experienced. It therefore appears advisable first to fix standard sizes of pipes to be used for the whole province, and then large orders could be placed with the manufacturers for other than their standard pipes, which are now difficult to get.

The Ideal Outlet.

In his note* of the 31st October 1907, Mr. Kennedy has very clearly described the conditions under which our distributaries are worked, and the demand made on the outlets, and has set forth the requirements which a properly designed outlet ought to satisfy. He thus sums up the present defects and the requirements : " During the most important periods, when a full supply discharge is being run, we see that the present arrangements of outlets have two outstanding defects, viz. we do not know, what each outlet is getting, and therefore any equitable distribution is impossible, while, secondly, the cultivators, or some of them rather, have both the power (by water-course clearances) and the incentive to increase their own supply at the cost of others. If we can get over these two difficulties by simple means ensuring a definite and certain discharge to each outlet when the distributary is running with a full supply, we shall have all that is required." During periods when full supply discharge is not run, Mr. Kennedy would like the outlets to draw proportionately less, and this is quite correct, because when there is not enough water in the distributary it would be impossible to give its full share to each outlet, and according to him, proportional distribution was the real desideratum for an outlet. This appears to be a correct view of the case, as it allows the necessary elasticity required in distributing the supply as admitted by most irrigation officers, and Mr. W. B. Gordon, in his note* dated February 1910, considered that a perfect outlet should satisfy the following requirements :—

1. Steady automatic discharge of the volume allotted to the water-course, notwithstanding variations of the head within fixed limits.

* Punjab Irrigation Branch Paper No. 12.

2 Small loss of head.

3. Increase in discharge when the level of the water in the parent channel rises above a certain height.

4. Freedom from derangement by silt or weeds.

5. Absence of complicated mechanism.

6. Absence of any obstruction to the free passage of a reasonable share of silt from the distributary into the water-course.

7. Portability.

8. Provision, so far as is reasonably practicable, against derangement by outside interference.

9. Means of being opened or closed by a cultivator.

10. Cheapness.

11. Durability.

12. Indication of working head or discharge.

In his note, dated 9th October 1911, Sir John Benton was of opinion that an outlet should satisfy the following conditions :—

1. Conformity to a half to one permanent slope of the distributary bank at entrance.

2. Facilities for closure without going into the channel, or using earth dug from the slopes.

3. Work to be of a permanent nature.

4 Initial cost and cost of renewals to be low.

5. Should be simple in form, requiring ordinary materials,

6 Alterations to be cheap and easy.

7. Excess supply easily carried off.

8. Should not be liable to damage or outside interference.

9. To work as a module within certain limits.

Sir John Benton was distinctly in favour of masonry outlets, and though he did not like the present type he thought it could be improved.

Summing up the opinions of these high authorities, the following conditions may safely be laid down as those which a good type of outlet should satisfy :—

1. It should afford ready means of finding out what discharge is passing, and under what head it is working.
2. It should be immune from all outside interference to increase its discharge.
3. It should be able to carry off its share of extra supply, when such is running in the parent channel.
4. It should have a suitable entry from the distributary to avoid loss of head.
5. Its face wall of masonry should conform to a slope of a half to one, which has been accepted as the side slope of a channel in *régime*.
6. It should be durable, and cheap to construct or renew from ordinary materials.
7. It should admit of easy alterations to its size when such are required.
8. It should not be liable to be damaged or tampered with easily.
9. If possible it should have some suitable arrangement to admit of closing by cultivators without going into the channel.

Formulae for calculating Discharges of Outlets.

The formula in general use for calculating the discharges drawn off by outlets is $Q = C\ A\ \sqrt{2\ gh}$ where

Q = Discharge in cubic feet per second.

A = Area of the orifice in square feet.

$\sqrt{2\ g} = 8{\cdot}023$

h = the head

C = the co-efficient of velocity.

As the value of the co-efficient C differs for barrels of different kinds in the following tables :—

C_b will be used to indicate the co-efficient of velocity in masonry barrels of rectangular section.

C_c the co-efficient of velocity for colaba or earthenware pipes.

C_s the co-efficient of velocity for steel or cast iron pipes.

The tables that follow have been prepared from the results of experiments carried out on the Sirhind Canal, and, though not absolutely correct, will be found to be practically so, and will prove useful in designing orifice areas of outlets.

Table I. gives values of C_c obtained on some old colaba outlets six inches diameter with barrel lengths varying between ten and fourteen feet.

Table I.

Head in feet.	Discharge in cusecs.	C_c	REMARKS.
0·25	0·57	0·74	Working submerged.
0·67	1·01	0·80	Do.
1·59	1·66	0·83	Do.
1·65	1·45	0·72	Working free, pipe not quite full.

The next Table shows the change in the value of C_c for colaba pipes $4\frac{1}{4}$ inches and 6 inches in diameter, newly built, with barrels seventeen feet long, for different heads.

TABLE II.

$4\frac{1}{4}$ inches diameter.		6 inches diameter.		REMARKS.
h	C_c	h	C_c	
·92	·63	·67	·69	
1·06	·62	·81	·68	
1·19	·61	1·07	·70	
1·49	·61	1·37	·69	
1·78	·62			
Mean.	·62	Mean.	·69	

TABLE III.

Masonry outlets with a barrel fifteen feet long and in rectangular section.

WORKING SUBMERGED.								WORKING FREE.							
Size of orifice.								*Size of orifice.*							
½ pipe, area ·1 square foot.		1 pipe, area ·2 square foot.		2 pipes, area ·4 square foot.		3 pipes, area ·6 square foot.		½ pipe, area ·1 square foot.		1 pipe, area ·2 square foot.		2 pipes, area ·4 square foot.		3 pipes, area ·6 square foot.	
h	C_b	h	C_b	h	C_b	h	C_b	h	C_b	h	C_b	h	C_b	h	C_b
·38	·58	·34	·65	·34	·68	·45	·74	1·75	·45	1·75	0·58	1·33	0·60	2·0	·63
·66	·57	·76	·64	1·00	·68	1·1	·75	2·25	·48	2·25	0·60	...	...		
1·21	·56	2·50	·66	1·42	·69			2·75	·49	2·75	0·60	1·63	0·62		
1·59	·56			1·84	·69			3·25	·55	3·25	0·60	2·13	0·65		
2·36	·56							3·75	·55	3·75	0·61				
3·5	·58														
0·57		0·65		0·685		0·74		·52		·60		· 62		·63	

Similarly Tables III and IV show the changes in the values of C_b and C_s for different sizes of outlets due to their working under different heads.

TABLE IV.

Showing co-efficient for steel tubes of various diameters under different heads. Length of barrel 16 feet.

Working submerged.												Working free.											
4″		6″		7″		8″		9″		10″		4″		6″		7″		8″		9″		10″	
h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s	h	C_s
·86	·73	·74	·80	·75	·81	·59	·83	·32	·80	·46	·84	2·65	·77	·91	·80	·70	·79	1·06	·79	1·28	0·80	1·08	0·80
·94	·72	·80	·81	1·74	·82	·65	·83	·64	·83	·56	·84			1·75	·81	1·70	·81	1·66	·79				
1·17	·74	1·01	·80	2·70	·82	·67	·83	·95	·83	·69	·82			2·75	·81	2 70	·81	2·66	·79				
1·21	·76	1·05	·82			·88	83			·77	·83			3 75	·81	3·50	·81	…	…				
1·66	·76	1·33	·82			·90	·84			1·02	·84			2·55	·79	…	…	2·42	·825				
		0·85	81			1·18	·84			1·23	·82												
		1·85	·81			1·38	·82			·30	·81												
		2·90	·81			1·9	·82			·90	·83												
						2·60	·82																
Mean values	·75		·81		·82		·83		·83		·84		·77		·79		·81		·82		·82		·82

Table V is prepared from Table IV, for use with other sizes of steel pipes not experimented upon.

TABLE V.

Diameters of steel pipes in inches.	C_s when working submerged.	C_s when working free.
4″	·75	·77
4½″	·77	·77
5″	·78	·77
5½″	·79	·78
6″	·81	·79
6½″	·81	·80
7″	·82	·81
7½″	·82	·81
8″	·83	·82
8½″	·83	·82
9″	·83	·82
9½″	·84	·82
10″	·84	·82

The values of the co-efficients $C_{b.}$, $C_{c.}$ and $C_{s.}$ change according to the length of the barrels of the outlets. Tables VI and VII give the values as found by experiment, with the mean value deduced therefrom.

TABLE VI.

Showing co-efficients for different lengths of barrels for a masonry outlet, 0·5 ft. in height by 0·4 ft. in width, under different heads.

WORKING SUBMERGED.								WORKING FREE.							
15′		18′		21′		24′		15′		18′		21′		24′	
h	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*
2·5	·66	1·82	·55	2·97	·52	3·0	·49	1·75	·58	1·35	·48	1·75	·46	1·75	·46
	·64	1·13	·56	1·87	·53	2·24	·48	2·25	·60	1·75	·51	2·25	·46	2·25	·46
·30	·65	·49	·55	·85	·54	1·22	·48	2·75	·60	2·25	·51	2·75	·50	2·75	·48
		2·2	·56			·62	·47	3·25	·60	2·75	·51	3·25	·50	3·25	·49
								3·75	·61	3·25	·55	3·75	·51	3·75	·49
										3·75	·56				
Mean values. 0·65		0·56		0·53		0·48		0·60		0·53		0·50		·48	

TABLE VII.

Showing co-efficient for different lengths of barrels for a steel tube six inches diameter under different heads.

Working submerged.								Working free.							
15′		17′		21′		24′		15′		17′		21′		24′	
h	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*	*h*	*c*
·85	·82	·74	·80	·84	·74	·9	·70	·91	·80	2·55	·79	1·25	·72	1·25	·70
1·85	·82	·80	·81	1·22	·75	1·93	·71	1·75	·81			1·75	·72	1·76	·70
2·90	·82	1·01	·80	2·96	·76	3·0	·72	2·75	·81			2·75	·73	2·75	·71
		1·05	·82					3·75	·81			3·75	·73		
		1·33	·82												
Mean values ·82			·82		·75		·71		·81		·79		·73		·70

Table VIII has been prepared from the results of experiments carried out by irrigation officers in Egypt, and shows the variations in the value of C_s for cast iron pipes, working under a constant head of 0·82 foot, with different lengths of barrels and sizes of pipes.

TABLE VIII.

Length of pipe	Diameter of pipe.			
	4″	6″	8″	10″
	Value of C_s.			
18 feet ...	·63	·71	·76	·84
36 feet ...	·50	·62	·66	·74

These tables show what values are to be assigned to C_b, C_c or C_s when designing orifices for outlets working submerged or free, under different heads. It also shows how the lengths of barrels affect these values. The figures in Tables Nos. II, III and IV for outlets working submerged, under different heads, are more or less consistent, whereas those for outlets working free are not so. This is due to the exposure of the tail end of the outlet and the barrels not running full. More experiments are, however, required to establish these values with certainty, but the mean values assumed will serve the purpose for the present, as in actual working of such outlets it will not always be possible to avoid defects.

The formula for the discharge from circular pipes, given below, takes into account their diameter as well as their length and has been found to give good results.

$$Q = \cdot 046\, d \sqrt{\frac{hd}{L+d}}$$

where Q = Discharge in cubic feet per second.
d = diameter of pipe in inches.
L = length of pipe in yards.
h = head in feet.

It is no doubt cumbersome, and the only excuse for quoting is its accuracy.

Limit to Size of Outlets.

As already stated, the system formerly was to allow colaba pipes for small areas or chaks of fifty to a hundred acres, while in contrast to this, outlets drawing off three to four cusecs and more have been allowed when remodelling the distributaries, and are frequently met with. Present day practice in such matters is to restrict the capacity of a water-course to two cusecs, and the fact is more or less recognized that, beyond a certain limit, the zemindar is unable to control and utilize economically the supply, yet instances are not wanting where this fact has been overlooked, with a consequent waste of water. Whether by night or day, it rarely happens that more than one of a family comes out to look after the water-course when their turn is on. Usually, one man with a *kassie* (spade) not only attends to watering the fields, but also looks after the water-course which may be a mile or more in length. With such maintenance leakages occur and are not even noticed, while breaches are only noticed after some time, and by the time the cultivator reaches the spot a great deal of water has been wasted.

On the old canals, where holdings are small, much water is wasted in filling the water-courses and branches at the change of turns. On the Sirhind Canal, some old minors were changed into water-courses, and wherever the capacity of these was over three or four cusecs, the irrigators concerned complained of their inability to control the supply, and eventually these had to be again kept up as minors, or split into two or more outlets. Such cases exist on every canal, so that it is desirable to fix the discharge limit of water-courses after considering the size of holdings, the nature of the soil, the rainfall of the tract, and the crops usually grown.

In the Author's opinion the capacity of an outlet should not exceed two cusecs, which may be fixed as the control limit of a zemindar on the old canals. With defective systems, this is bound to result in better maintenance of the water-courses and more economical use of water. On the new canals, where properly aligned and constructed water-courses exist, and where the system of irrigation is from one square to the next, the limit might be kept slightly higher, but not much over three cusecs. This would ensure suitable chaks, fairly large in area, and would be acceptable to all. Objections on the score of absorption going on in two sets of water-courses instead of one would

be counterbalanced by the more efficient control and economical use of the supply on the part of the irrigators concerned, while the objection does not hold so much in practice, as very often irrigators, finding that they cannot control the supply, run it into two branches instead of one. Above all, the proposed arrangement would permit in most cases the separation of the high from the low land in a chak, and thus allow a more uniform range of working heads on the outlets, which would be a great gain in itself. The draw-offs of such outlets would then vary within a small range, and would not upset calculations as much as they do at present.

It is impossible to lay down rigid rules, but it should not be difficult in practice to bear in mind the following when readjusting the outlets on a distributary system on any of the old canals—

(*a*) as far as possible the sizes of the chaks should be so arranged that the discharges of the majority, say sixty per cent. of outlets should vary between 1·2 and 1·9 cusecs ;

(*b*) the number of outlets discharging 0·8 to 1·2 cusecs should not exceed thirty per cent ;

(*c*) outlets required to draw off less than 0·8 cusec, or with capacities between 1·9 and 2·1 cusecs, should be as few as possible, say about five per cent. in each case. ;

(*d*) outlets whose draw offs are less than 0·5 cusec or more than 2·1 cusecs should only be given in special cases and for special reasons.

Relative Values of the Co-efficients of Discharge for Different Materials.

With the introduction of steel pipes as outlets it became necessary to find out the value of C in the formula $Q = C\ A\sqrt{2\ g\ h}$, as some allowance was necessary for the extra smoothness of steel pipes over brick barrels or colabas. On the Lower Chenab Canal an experiment was made by the writer, comparing a cast iron pipe with a masonry barrel of rectangular section, and it was found that seventy per cent. of the sectional area of a masonry barrel would under equal condi-

tions suffice for an iron pipe. The experiment was rough, and as the conclusion was based on the result of only two observations it was not considered reliable. In 1914 another experiment was carried out on the Sirhind Canal for a twenty feet length of masonry barrel of rectangular section (area 0·2 s. ft.) and 19·6 feet length of six inch diameter steel pipe, when the relation between C_b and C_s was found to be 0·72. Having confirmed the first rough experiment, it was decided to carry out elaborate tests on various sizes of steel pipes, and with masonry outlets of one, two, three and four pipe sizes and for various lengths of barrels. This was started in October 1915, but could not be carried through owing to the writer's transfer, but the result of the 1914 experiments had drawn attention to the matter and further experiments were ordered both in the Bhatinda and the Ferozepore Divisions of the Sirhind Canal, and were carried out carefully in 1916 by Messrs. Jesson and Munshi Ram, and the following table has been compiled from the reported results.

In ordinary practice the length of an outlet barrel ranges from twelve to eighteen feet when the boundary road culvert is separate, as it should be, so that the results given in the table cover all cases within the above range of barrel lengths.

TABLE IX.

BHATINDA DIVISION.										FEROZEPORE DIVISION.							
Masonry outlets 15 feet long of rectangular section working submerged under heads ranging from 0·4 to 3·0 feet.					*Steel tubes 15 feet long working submerged under heads ranging from 0·3 to 2·9 feet.*					*Masonry or colaba outlets 17 feet long working submerged under heads ranging from 0·54 to 1·7 feet.*				*Steel tubes 17 feet long working submerged under heads ranging from 0·45 to 1·7 feet.*			
Size.					Diameter.					Colabas.		Rectangular barrel of masonry.		Diameter.			
½ pipe.	1 pipe.	2 pipes	3 pipes	4 pipes	6″	7″	8″	9″	10″	½ pipe.	1 pipe.	2 pipes	3 pipes	4″	6″	8″	10″
Coefficient C_b.					Coefficient C_s.					Coefficient C_c.		Coefficient C_b		Coefficient C_s.			
0·58	0·64	0·68	0·71	0·71	0·82	0·82	0·82	0·83	0·83	0·61	0·68	0·65	0·66	0·76	0·81	0·83	0·83

An extract from experiments by the Egyptian Irrigation Department on the discharges of cast iron pipes is given below, together with the value of C as calculated for each pipe.

TABLE X.

Working head.	0·8202 feet (probably working submerged).						
Diameter of pipe ...	4″	5″	6″	7″	8″	9″	10″
Discharge in cusecs ...	·399	·682	1·01	1·44	1·921	2·543	3·33
Coefficient (C_s) ...	·63	·69	·71	·74	·76	·79	·84

The relative value of the coefficients calculated from these experiments are summarised in the following table :—

TABLE XI.

Size of outlet (Sirhind Canal standard).	Relative value of coefficient.			
	Bhatinda.	Ferozepore.		Egyptian experiments.
	$\frac{C_b}{C_s}$	$\frac{C_c}{C_s}$	$\frac{C_b}{C_s}$	$\frac{C_b}{C_s}$
½ pipe, area 0·098 square foot	...	·8	·763	·899
1 pipe, area 0·196 quare foot	·780	·84	·790	·900
2 pipes, area 0·39 square foot	·824	...	·783	·858
2½ pipes, area 0·49 square foot	·837	...	·789	828

For calculating the relative values of C_b to C_s from the coefficients C_s of the Egyptian experiments, mean values of C_b have been taken from the Sirhind Canal experiments.

From these tabulated results, the relation between C_b and C_s for various sizes of pipes on other canals, where the standard

pipe is only 0·4 of a foot in diameter, can be found from the following table :—

TABLE XII.

Relation of C_b to C_s.	Area and Diameter of Pipes.				Remarks.
	Area 0·0625 to 0·1875 s. ft.	Area ·196 to 0·398 s. ft.	Area ·39 to ·49 s. ft.	Area 0·5 to 1 s. ft.	
Half pipe to one pipe on the Sirhind, or half pipe to $1\frac{1}{2}$ pipes on the Western Jumna Canal.	$\frac{1}{2}$ to 1	$1\frac{1}{2}$ to 2	2 to $2\frac{1}{2}$	3 to 5	Sirhind Canal.
	$\frac{1}{2}$ to $1\frac{1}{2}$	2 to 3	3 to 4	$4\frac{1}{2}$ to 8	Western Jumna Canal.
$\frac{C_b}{C_s}$ or $\frac{A_s}{A_b}$	0·83	0·81	0·80	0·79	Bigger outlets than this are rarely required in practice.

A_s = Area of steel pipes. A_b = Area of masonry barrels.

It should be noted that unless the brick barrels are very carefully constructed with good selected bricks, the coefficient C_b will vary for different barrels of similar dimensions; also that the coefficient C_s for steel tubes is not likely to vary so much if the inside coating of solution is even and smooth. In the Bhatinda Division experiments the steel tubes were scraped clean. Owing to the rush of silt-charged waters at a great velocity through the barrels, the coefficient C_b is likely to improve with the age of the barrel, whereas the reverse will be the effect on the value of the coefficient C_s owing to rusting and the action of acids in the water on the steel, but both these actions will be very slow, and will take years to produce any appreciable change in the value of the coefficients, and have consequently not been taken into account. According to Table III or IV it would be correct to substitute steel tubes for masonry outlets if the latter are doing very nearly what they were designed for, but if not, the diameter of the steel tubes should be designed for the required discharge, after finding out the range of the head from the coefficients given in Table I.

Better Control.

Putting aside any consideration of modules or semi-modules, it is worth considering whether the present type of outlet can be made to conform more closely to our requirements. The case against the outlets is briefly that they are merely culverts in the banks of channels, with orifices discharging under varying heads whose coefficients of discharge are not only unknown, but variable. On one and the same outlet the range of head may be anything between 0·3 and 2·0 feet, and some of these heads may be working as free fall outlets while others are quite submerged. Thus there are several unknown factors to be eliminated in designing an outlet. It has also been shown that the value of coefficients of discharge for colabas, rectangular brickwork sections, and steel or cast iron tube barrels, vary a good deal, and, therefore, by adopting different kinds of barrels for outlets on one and the same distributary we are evidently adding to our difficulties, so that first of all it appears advisable to adopt either the brickwork or the steel tube barrel outlet on all channels.

The conditions that a good outlet should satisfy have been stated *, and applying them to brickwork or steel outlets we find :—

(*a*) That conditions, Nos. 3, 5, 6 and 8 are generally satisfied by the brickwork and Nos. 3, 5, 6, 7 and 8 by the steel pipe outlets.

* Page 118.

(*b*) That condition 9 does not apply to all cases of outlets ; for example, on canals irrigating dry tracts, where the demand is continuous, such an arrangement would be considered superfluous. If the conditions on other canals be analysed the necessity for a rigorous enforcement of this condition will probably not be proved.

(*c*) That our outlets do not satisfy conditions 1, 2 and 4, and our aim should be to improve or amend them in these respects as much as possible. A brief description of the conditions under which outlets have to work has already been given, * and the range of conflicting conditions is such that even a carefully thought out design is bound to fail at some point or other. It is hopeless to try to satisfy all conditions, and we can only try to satisfy those which will ensure a proper share of the supply to all the outlets on a channel during keen demand periods, because water is then most valuable and no one is willing to lose his share.

Uncertainty about variations in head, according as high or low land is commanded, could best be removed if the tracts under irrigation on old canals were surveyed, as has been done on the newer canals, and the chaks of the various outlets so arranged that there would be no excessive variations of head due to difference in level of the land to be irrigated. For example, the command might vary between 0·3 and 0·7, or 1·0 and 1·3, or 1·5 and 1·9, etc., etc., This would not be difficult in the case of seventy to eighty per cent. of outlets on a channel. Where the range of head lay between wider limits, each case could be treated on its merits, and the outlet designed for commanding the major portion of the area, the very high and very low lands being left out of account from the orifice calculations. Internal distribution could be arranged by allowing longer and shorter turns to very high and very low lands, respectively, in the *wara-bandi* lists.

It may be noted in this connection that the amalgamation of chaks at the time of remodelling, and the readjustments subsequently carried out by transferring high or poorly commanded lands to other suitable sources of irrigation, have to a large extent removed any excessive range of variations in the head on most outlets. Attempts made to find out the difference between the highest and lowest supply levels on some water-courses in Bhatinda Division convinced the writer of this fact, and it is probable that outlets where the working head varies between unmanagably wide limits are few, and put together would not amount to more than ten per cent. of the total discharge of a distributary.

* Pages 102 & 103.

Another thing to be noted is that the raising of distributary beds and full supply levels has made it possible to rearrange some of the old outlets with high heads as free fall outlets, and thus make them independent of the lowering in the supply levels of the water-courses owing to silt clearance. This should be done wherever possible, even if it is necessary to raise the orifice six or nine inches above the bed level of the distributary, so as not to prevent such outlets from drawing off their proper share of silt.

As it would be difficult and costly to prepare complete contoured plans for the old canals on lines similar to the new ones, an attempt should be made to obtain the variations of head on each outlet by direct measurement. This will not be an easy matter, as the present outlets are of various types, with high and low parapets at any level. If measuring points at suitable heights above, or just at full supply level, were fixed when taking the longitudinal sections of distributaries, measurements of heads would be quite possible. Nails, if carefully fixed at suitable places, but at one and the same level in both the front and back parapets of an outlet, would last for a long time, and afford good enough bench marks for measuring heads. Half a dozen such records taken at different times during keen demand periods, when collected and entered in the outlet register (in a column specially ruled for this purpose) would not only afford good data for orifice calculations, but would give facilities for readjusting sizes of outlets, and would be of use even if it were subsequently decided to fix modules or gauge outlets.

In the case of outlets where it was impossible to reduce the variations, it would be necessary to go into greater detail to find out the areas of the very low, very high, and the average land. The variation for the average land would be noted along with the extreme variations, and the design based on this average, while the internal "waris" would be increased for the high lands and decreased for the low lands.

This proposal would suit the chaks of those outlets where things have got more or less settled, and where it would not be advisable to remove very high areas and keep only low lands, or *vice versa*. As already stated, such cases would be few, and some of them could be managed by the construction of suitable branch water-courses for their irrigation. Variations in discharge due to 0·4 or 0·5 of a foot variation in the working heads on outlets, would cancel one another on the whole distributary system, as when some outlets were drawing slightly less, others would be drawing off slightly more, as all would not draw more or less at one and the same time,

The following Table shows the discharges that would be drawn off by a two pipe masonry outlet of the Sirhind Canal standard under various heads, using the coefficients obtained from the Sirhind Canal experiments :—

Head h in feet.	$\sqrt{h}$	Discharge in cusecs.	Remarks.
0·3	0 55	1·21	Formula used $Q = C_b A \sqrt{2 g h}$
0·4	0·63	1 38	
0·5	0·77	1·55	Length of barrel about sixteen feet.
0·6	0·77	1·69	Coefficient C_b = 0·685 —*vide* Table
0·7	0·83	1·83	III *
0·8	0·89	1·96	If the range of head is 0·3 to 0·7 the
0·9	0 95	2·09	mean head and discharge would be
1·0	1·0	2·20	0·5 and 1·55 cusecs.
1·2	1·1	2·42	Range of discharge ±·3 cusecs on
1·4	1·18	2·59	either side of the mean.
1·5	1·22	2·68	For heads ranging from 1·0 to 1·3,
1·6	1 26	2·71	the range of discharge is ±·15 on
1·8	1·34	2·95	either side of the mean and for heads
2·0	1·41	3·10	ranging from 1·5 to 1·9 the range
2·2	1·48	3·25	is ±0·16 on either side of the mean.

Thus, knowing the variations of head on the outlets and the coefficients of discharge, their sizes could be readjusted with more certainty.

On the new canals, where detailed surveys of village lands have been made and where accurate chak plans exist, but where irrigation is still in its infancy, (that is, the chak boundaries have not finally been fixed), and wooden shoots are serving as temporary outlets, the chaks should as far as possible be now arranged or readjusted so as not to allow great variations in head, while low and high lands are being watered. This should not be difficult to arrange, as levels exist at the corner of every square. The water-courses already designed for irrigating those chaks should be carefully scrutinized, branches re-aligned if necessary, and orifices of the permanent outlets designed to draw off their correct discharges on the mean head obtained.

Types 6*a*, *b* and *c* contemplated that the front and back parapet tops of an outlet should be exactly at the full supply level of the distributary, thereby affording a chance to the inspecting officer to see how the distributary was working and to ascertain quickly, if necessary, the working head

* Page 120.

of the outlet. The existing outlets afford no such facilities, nor are both their parapets at one level. In some cases the back parapet, if built up to the full supply level of the distributary, would look unsightly, even if the cost of building a wall higher than necessary were ignored. In such cases only the front wall would have its top at the full supply level of the distributary, but the top of the back wall could be fixed an even number of feet below the front wall, and the level noted on the longitudinal section.

Conclusion.

As the efficiency of a canal, and the contentment and good will of the irrigators concerned, largely depend on the satisfactory working of its outlet system, no attention paid to their design should be considered too much, nor would the care bestowed on their readjustments be in vain. The first step in this direction would be to fix a uniform standard pipe for all canals, and to adopt a suitable type of outlet for the whole province, but this should not be delayed because it may not be possible to satisfy all conditions at present. Improvements in respect to the remaining conditions can follow. The adoption of a uniform type would do away with various kinds of barrels, and remove some unknown factors, while engineers all over the province would settle down to the one type, and thus be able to devote their undivided attention to its shortcomings better than heretofore. The uniformity of practice thus secured would result in an all-round improvement, not only in the design of orifices, but in the working of outlets as well.

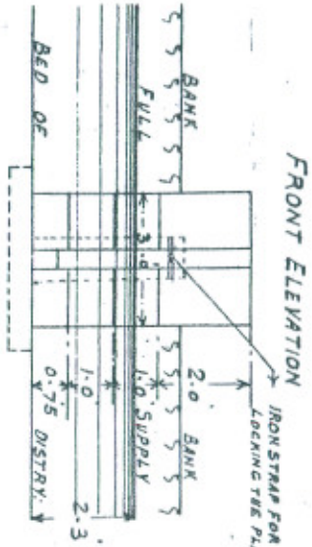
In conclusion the writer takes this opportunity of expressing his grateful thanks to Messrs. Foy, Carne, Hindley and Cook who helped him with drawings and other materials for preparing this paper.

PLATE No. I.

TYPE No. I

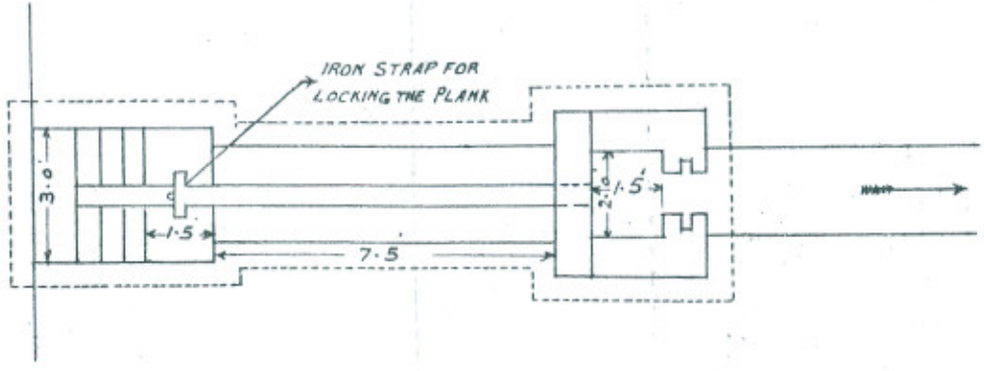
COLABA OUTLET CONCRETE

SCALE 1/50

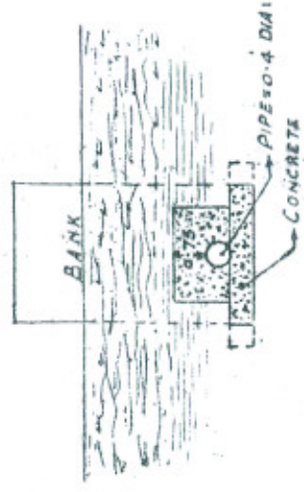


FRONT ELEVATION

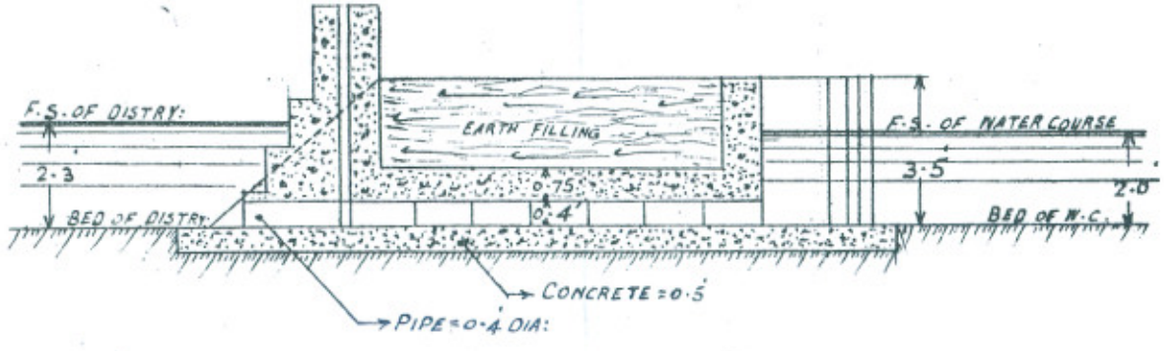
PLAN



CROSS SECTION



LONGITUDINAL SECTION



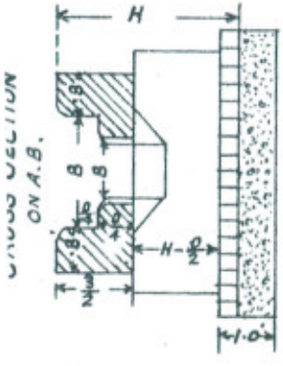
Nº 5

OUTLET

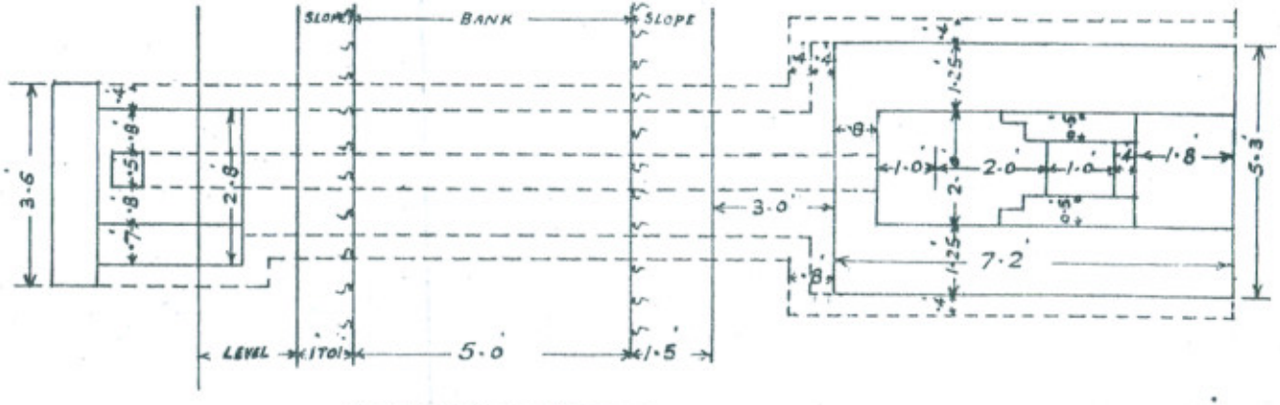
SSURE SILLS

LE: 1/50

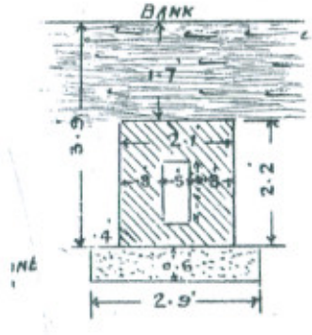
PLATE Nº 5.



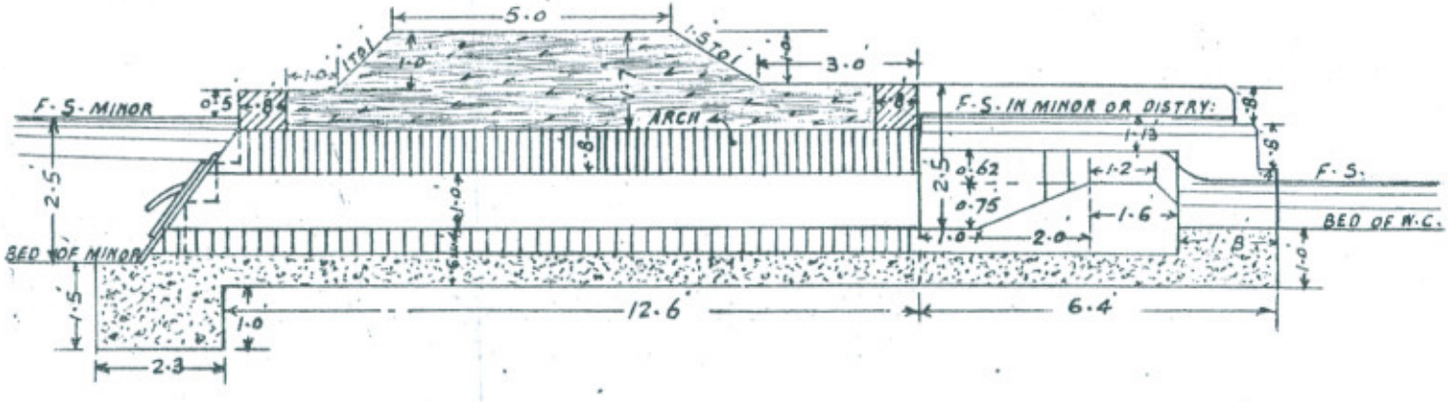
PLAN



CROSS SECTION



LONGITUDINAL SECTION

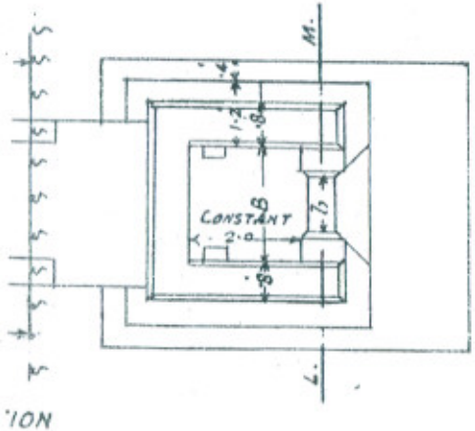


TYPE

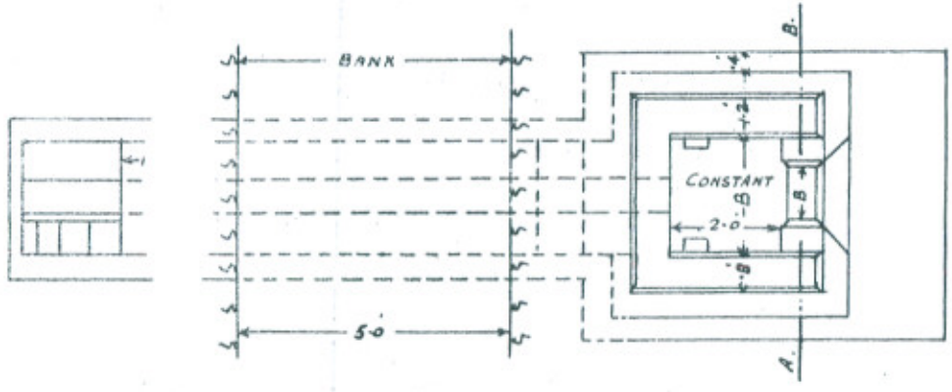
4 PIPE (

WITH PRE

SCA

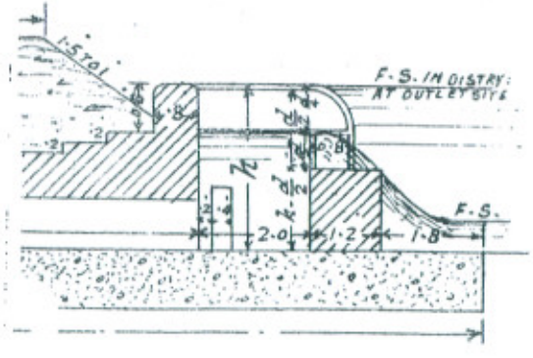


PLAN



ION

HEAD



LONGITUDINAL SECTION

AS NEAR DISTRY: HEAD

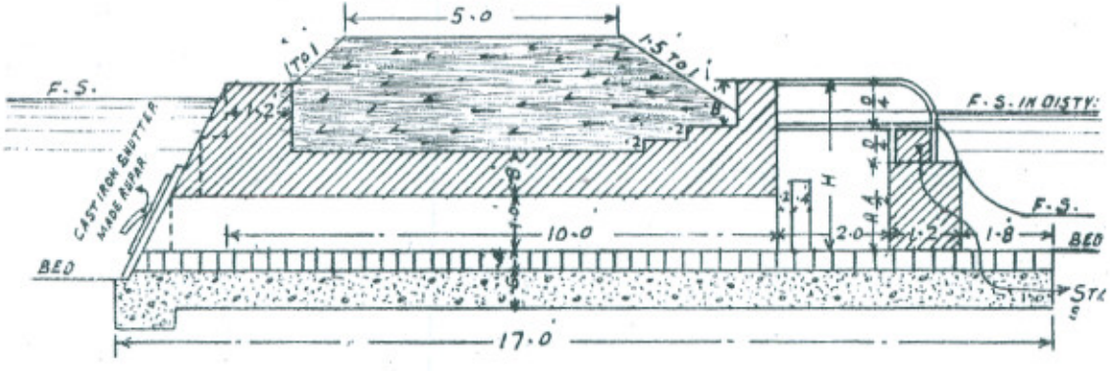
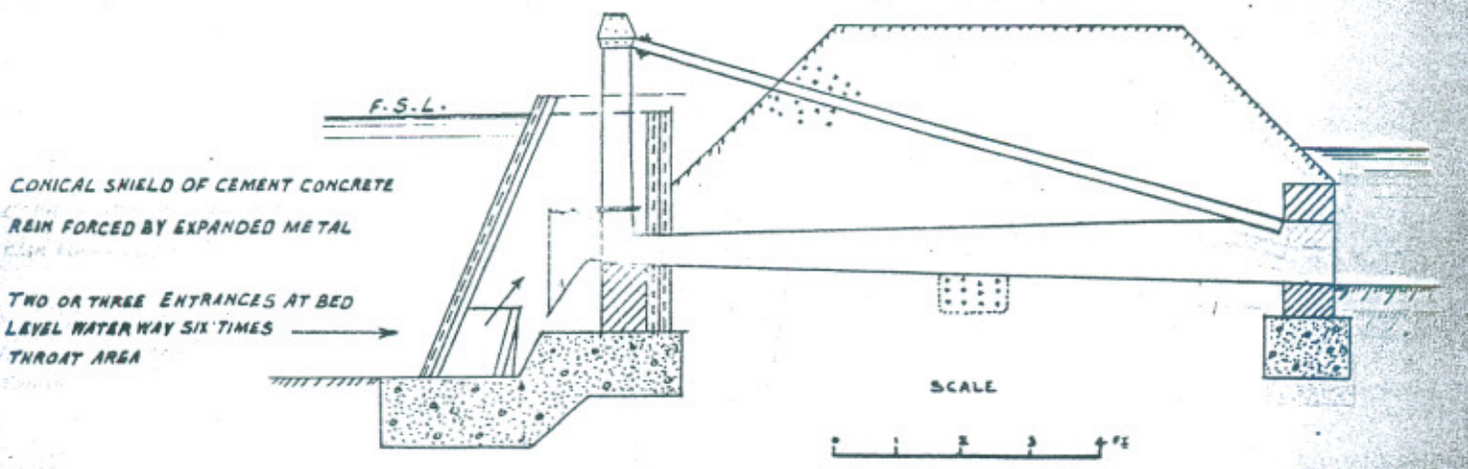
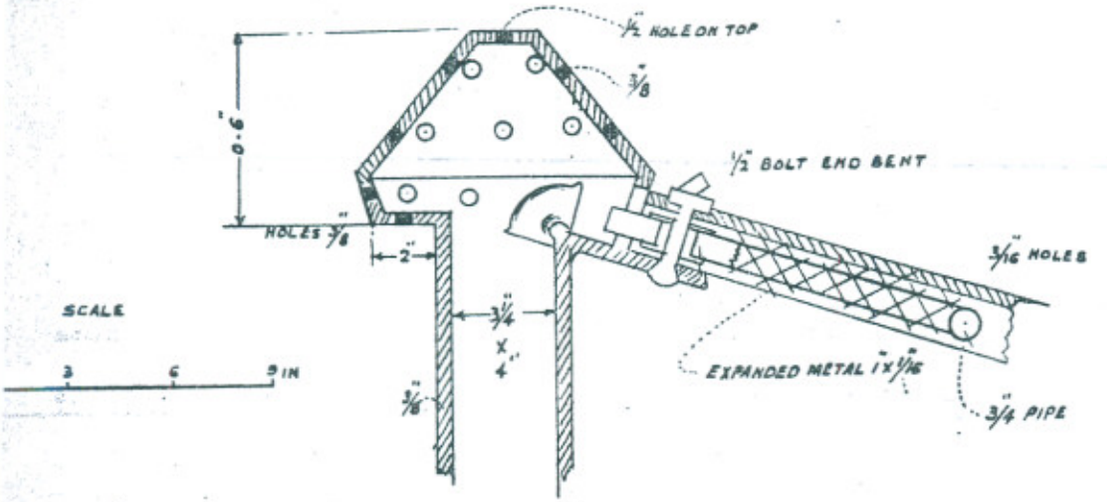


PLATE No. 9.

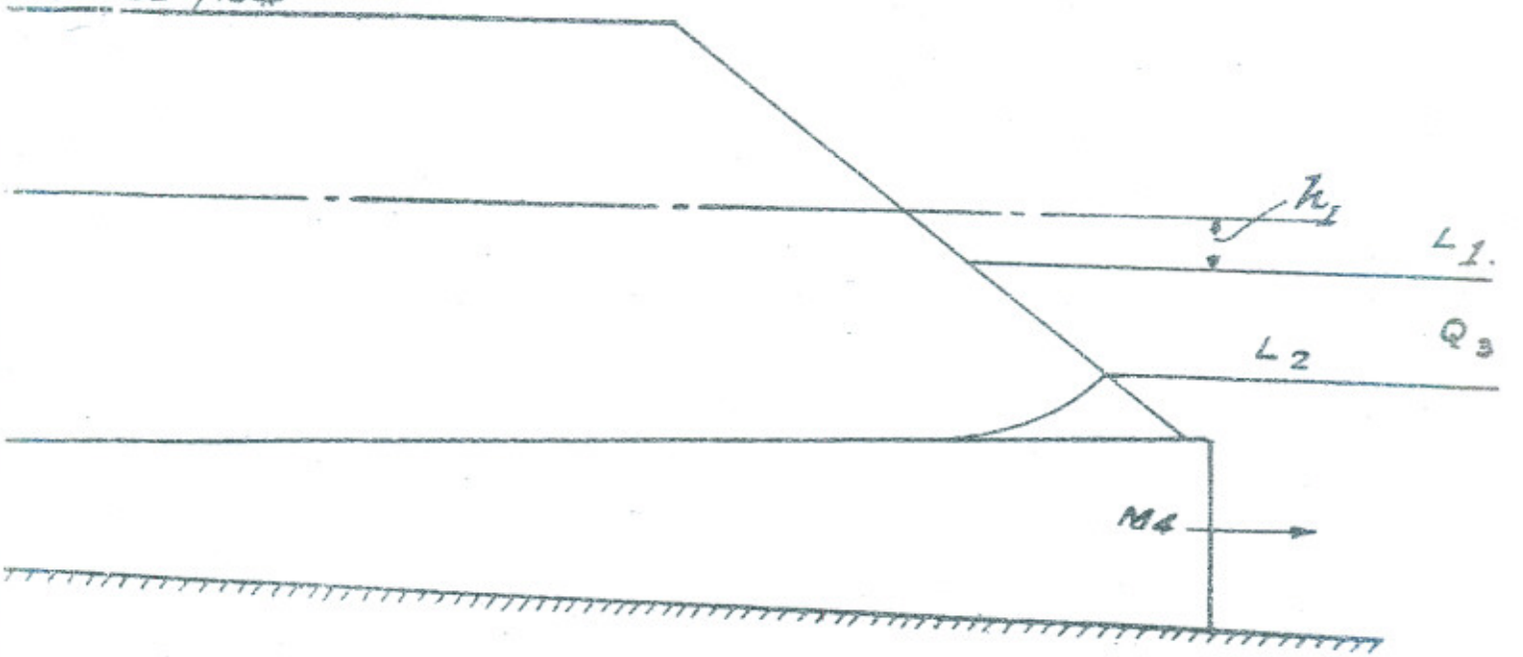
TYPE 9 (a) — SPECIAL CASE OF DEEP CHANNEL HEAVY BED SILT AND POOR COMMAND



DETAIL OF VENT PIPE

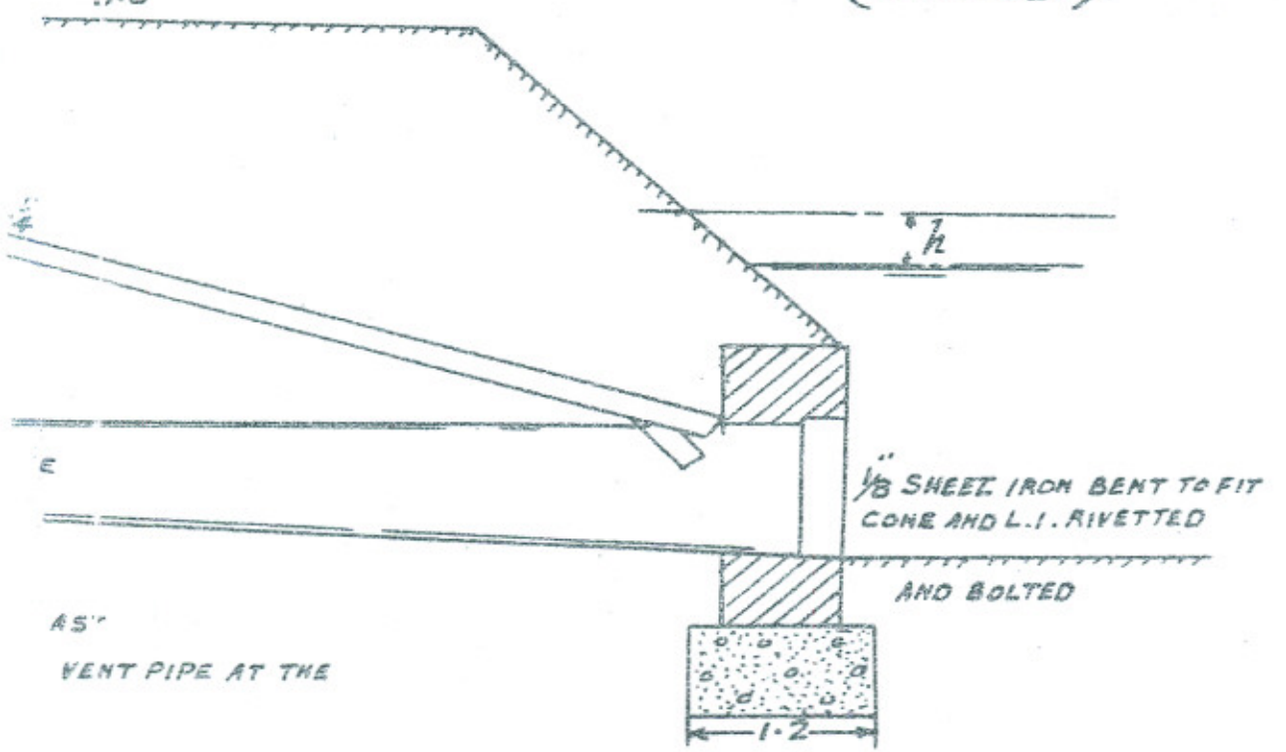


UG : OUTLET
CTING AS A
BLE SEMI-MODULE
SCALE - 1/16"



"LET TYPE 14(a)

PIPE & SCALES
O SHUTTER
(AMENDED)



DISCUSSION.

MR. GIBB said that the author had written a most interesting history of the introduction and development of pipe and culvert outlets on the Punjab canals. He would rather, however, that it had taken the form of an obituary notice of these old types of outlet, instead of the author endeavouring to stimulate fresh interest in what was almost universally recognised to be fundamentally an inadequate and unsatisfactory type of apparatus.

It must ultimately be admitted that the simple pipe or culvert outlet was not and could not be the embryo from which the perfect or ideal outlet was to develop. On this subject of the ideal outlet he noticed an important discrepancy in the paper. The author quoted Mr. Gordon and Sir J. Benton.* The former's first requirement was a "steady automatic discharge... notwithstanding variations of head within fixed limits" while the latter said the outlet was "to work as a module within certain limits." These two statements meant practically the same thing. Both authorities demanded a constant discharge between certain limits of head. That is, the ideal outlet according to both Mr. Gordon and Sir J. Benton was a module. The author, however, in amalgamating their ideals, had taken no account of these two requirements, and consequently arrived at an outlet which was not a module at all, and, therefore, was quite different from the ideals of the authorities quoted. Nothing was said about the way in which an outlet should be regulated to control the supply. The author was apparently content with being able to see what was happening without being able to control it.

With regard to the remarks about the Gibb module and the illustration on Plate No. 10, he wished to point out that the design mentioned had been obsolete for some time and he himself had been the first to condemn it. The old type of masonry module, built on the Shahkot distributary, was superseded about six years ago by a quite different and much simplified steel apparatus, which was so great an improvement on the old type as virtually to constitute a new module.

The new module completely fulfilled all Mr. Gordon's requirements, and all Sir J. Benton's except his item No. 6. The discharge of this module could not be altered either cheaply or easily, and he noticed that the author did not believe in cheap and easy alteration, recognising that such facilities were equally shared between the department and the zemindars.

* Pages 116-117.

The chief improvements which differentiated the new Gibb module from the old Shahkot distributary masonry type were as follows :—

(*a*) Complete control of the silt charge drawn off was now afforded, because the mouth of the pipe in the distributary could be placed at any desired level above, at, or below the bed.

(*b*) Portability.

(*c*) The structure was much simplified, and there was no recess or backwater anywhere in which silt or other obstructions could be deposited or lodged.

(*d*) The masonry ledge and downstream delivery channel of the old Shahkot type, to which the author rightly objected, had altogether disappeared.

(*e*) The discharge was much more accurate and the range of head much greater in the new type.

The old Shahkot modules were now in process of being replaced by the new type, but the literature on the subject had not been printed up to date, so it was probably not available to the author when he was writing his paper. Had he written to him, however, he would gladly have supplied any information or plans he might have wanted.

The bogy of rigidity seemed to frighten many people away from the idea of a module. There were two possible methods of regulating supplies in distributaries to meet alterations of demand. Either the distributary could be kept continuously running and the discharge adjusted, or the discharge could be kept constant, and the time during which it ran adjusted by rotational turns. In practice a mixture of these two methods was employed.

The objections to the first method were that any alteration of the discharge altered the water-level, and therefore the command at the outlets, and so upset the whole of the outlet system, while fluctuating supplies in a distributary prevented a stable silt *regime* from becoming established. The advantage that was supposed to be derived was a greater refinement in making the supply meet the demand, but this was an illusion. Were the demand altered so as to require a certain definite alteration in the quantity of water given, this could be more accurately met by lengthening or shortening the full supply time, than by any regulation of the supply entering the distributary head, because in the one case it was a matter of days and hours, while in the other, of tenths and

hundredths of a foot. When the available supply was limited, and rotational, full-supply working was in force, there was bound to be a balance which would not exactly fit the full supply of any distributary. This, however, was also true if the other method of regulation were adopted. After adjusting the discharges of all the open distributaries to suit these demands, there was bound to be a balance that would not fit the demand on any of the remaining distributaries, so that in either case there was bound to be a ragged end, but it was no more ragged in the one case than in the other. The inconvenient balance was the same in both cases, but there could be no question that adjustment of the time factor of moduled distributaries provided a much more delicate and accurate system of regulation than it was possible to obtain by altering the discharges let into the distributaries.

In discussing the problem of outlets, there was a tendency to forget that there were two classes of variation of supply level in distributaries. In the one class there were variations which were the result of regulation, and which were completely under control. The other class resulted from changes in the silt bed of the channel, periodic or otherwise, and from changes in efficiency due to various causes, such as growth of weeds on the berm, falling in of the berm, etc. With the simple exception of the constant discharge module, there was no outlet with a discharge independent of these uncontrolled variations, and this was one of the chief advantages of module outlets. Were it not for these uncontrolled variations which occurred in both distributaries and watercourses there would be no outlet problem worth writing a paper about.

MR. CARNE remarked that reference had been made to the Harvey Stoddard module outlet, and it was noted that details of the tests were not available, but these would probably be available before the next Congress. Mr. Harvey had so far only had a brief period in which to make his tests, and until these had been completed it was not likely that others would be prepared to make exhaustive tests and trials.

The author had quoted the opinions* of three eminent Punjab engineers as to the conditions to be satisfied in an outlet, and he now proposed to deal with the condition requisite to give the steady automatic discharge desired by Messrs. Kennedy and Gordon. Sir John Benton seemed to prefer a module within certain limits. There seemed to be no possibility of obtaining an outlet to give a discharge variation relatively the

*Pages 116-118.

same as the discharge in the parent channel. Plotting the logarithmic values of discharge against the logarithmic values of the depth for any channel selected from Kennedy's diagrams, would be found, from the straight line logarithmic equations, to give as nearly as possible a discharge of $C\,D^{\frac{5}{3}}$. By employing a Kennedy gauge outlet or a free fall outlet a formula was obtained for the discharge of $C\,D^{\frac{1}{2}}$, while if the usual close opening were discarded for one without any top, but with its bottom at the bed level of the channel, a discharge was obtained that varied as $D^{\frac{3}{2}}$; in fact the offtake had become a notch. This type of outlet resulted in a condition of variation of discharge nearly in agreement with the variation in discharge of the parent channel, and the difference between $D^{1\cdot67}$ and $D^{1\cdot5}$ was not very great, but the backing up of the supply in the watercourse to an unknown level interfered with the working of this form of outlet, and it would be essential to provide weirs with high crests across the watercourses near the outlets, though there would be difficulty in deciding on the necessary height of weir to prevent drowning by the watercourse supply. The crest of the weir should be at least as high as the full supply level of the watercourse. If the watercourse were allowed to silt up, the supply level would rise and choke the supply; if the supply were lowered by silt clearance there would be no gain in discharge.

This idea for an outlet was, however, not likely to become popular among canal engineers, as it necessitated separate calculations for each outlet unless tables were prepared catering for every possible condition. It would also be unpopular among the cultivators, but this should be no deterrent to its adoption, since every improvement in outlets was more particularly for the prevention of excess supplies being drawn through excessive silt clearance.

MR. LINDLEY said that one of the questions discussed in the paper was that of the relative merits of the module and the gauge outlet. The author appeared to favour reversion to some form of the ordinary outlet, though this was contrary to the general opinion. Mr. Gibb had put the case for the module, and as no inventors of gauge outlets were present, nor any of the gentlemen who had had to report on them, he would put forward such points of their comparative merits as he could marshal without preparation.

The most common objection to the module was its absolute rigidity, or lack of elasticity of distribution. As each module

gave a fixed discharge as long as the working head remained within working limits, any error of regulation, either excess or defect, affected only the tail, which was therefore subjected to relatively large fluctuations. If one or more outlets were closed by the zemindars for silt clearance or other reason, the tail was flooded out till the closure was discovered and the supply reduced. On the other hand, if the lack of demand on some outlets necessitated a reduction of supply in the channel, those outlets still wanting water would get their fixed supply.

With the gauge-outlet on the other hand, the supply passing into a watercourse varied with the supply level in the distributary. With normal submergence it was considerably less than proportional to the discharge, but was still sufficient to damp considerably variations on their way down to the tail. On the other hand, a reduction of the supply through lack of demand on some outlets also in some degree reduced the supply to those outlets that still wanted water, but the actual reduction was, with normal submergence, in most cases, a probably suitable allowance for simultaneous drop of demand on these outlets. The point was not one that could be settled by theoretical discussion, but distributaries fitted completely with one or the other type of device must be compared in actual working. To both modules and gauge outlets the objections had been raised that they drew either too much or too little silt, and though silt regulation had not yet been reduced to a precise formula, enough was known to enable designers (or the engineers building the module) to make it draw more or less silt.

In other points such as simplicity, safety from interference, etc., the best forms of the two kinds of device at present available seemed to be on an equality, and the most important question was to decide whether rigid or elastic distribution of supply was more suitable.

MR. VARMA in reply said that he was aware of Mr. Gibb's new type of module, but did not know how it had worked in practice ; even in this discussion Mr. Gibb had failed to tell them of its good points and superiority over the type tried on the Shahkot distributary. He had nothing more to say beyond expressing his pleasure at being given the opportunity of hearing what had been said on the general subject of canal outlets.

CORRESPONDENCE.

MR. PADDAY considered that the extent to which the discharge of an outlet could be made to vary with that of the parent channel, which had been referred to in the paper and discussion, was an interesting and important point, since under ideal conditions the percentage of its full supply taken by an outlet should equal the percentage of full supply running in the parent channel at the same time.

The discharge of an outlet was represented by the equation

$$q = ax^{\frac{1}{2}} \text{ cusecs}$$

a being a constant and x the working head. Also the discharge of the usual canal channel within working limits could be represented by the equation

$$Q = mh^{\frac{5}{3}} \text{ cusecs}$$

m being a constant and h the depth of the main channel.

Taking these two equations

$$q = ax^{\frac{1}{2}} \qquad Q = mh^{\frac{5}{3}}$$

Differentiating

$$dq = \frac{a\,dx}{2x^{\frac{1}{2}}} \quad dQ = m\tfrac{5}{3}h^{\frac{2}{3}}dh$$

Dividing

$$\frac{dq}{q} = \frac{dx}{2x} \quad \frac{dQ}{Q} = \frac{5\,dh}{3h}.$$

For the ideal outlet

$$\frac{dq}{q} = \frac{dQ}{Q}$$

so that

$$\frac{dx}{2x} = \frac{5\,dh.}{3h}$$

Again, if for x the level in the watercourse were naturally practically constant owing to cultivators having to head up to the same level to get water on to their fields, or the watercourse level did not affect the case as with a free fall or a Kennedy outlet, then dx would equal dh

so that

$$\frac{1}{2x} = \frac{5}{3h}.$$

that is for the proportionate variation required

$$x = \frac{3h}{10}$$

Under ordinary conditions the relative change of level in the watercourse would be small for small changes in the parent channel, and the effect of such change would be to slightly increase x, so that practically the working head of the outlet should if possible be one-third the depth of flow in the parent channel.

This relation opened up interesting questions as to the design of channels with either ordinary or Kennedy outlets arranged so as to vary their discharge proportionately with that of the parent channel. It also probably explained why ordinary outlets were not always so unsatisfactory as they appeared to be at first sight.