REMODELLING INUNDATION CANALS IN THE MUZAFFARGARH DISTRICT

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Brief history of the canals—Control of supplies—The open cut system—The introduction of masonry outlets and pipes—Consequent necessity of remodelling—Chakbandi—Supply required from each outlet—Longitudinal section—Size of outlets - Typical examples—Necessity of making remodelling effective—Semi-module masonry outlets—Large watercourses—A peculiar case—General results.

Brief History of the Canals.

The inundation canals of the Muzaffargarh District were originally dug, before the British occupation of the country, either by the zemindars themselves, or by the former rulers, and after the British occupation, they were for many years managed by the civil district officers, the work being done by forced labour, which was exacted from the irrigators in proportion to the area irrigated, any necessary cash expenditure being met from a special fund.

The result of this management proved very unsatisfactory, and Mr. Garbett, Superintending Engineer, who was deputed to report on the question of the Irrigation Department taking the canals over, stated that failures were frequent and that the water could seldom be got to the tail of a channel. Much of the land, now fully commanded and irrigated by flow, could then, on account of the excessive silt clearance that was carried out annually, only be irrigated by lift, and it is still a common saying in the district, that it is better to be a small cultivator at the head of a channel than a large landlord at the tail. There appear to have been at that time some seventy separate canals, each with a separate head, and it would have been impossible even for a trained staff to have given adequate attention each year to each of these ; and it appears that heads were cleared year after year in the same site, although they had regularly silted up in previous years. The civil officers and their subordinates, with little knowledge of hydraulics, or, in many cases, of even the most elementary irrigation principles, could hardly be expected to produce satisfactory results ; and it was decided to make the canals over to the Irrigation Department

The department at once set about amalgamating the small canals, with their separate heads, into large systems, each with a single head, which could be given proper individual attention each year; and eventually the seventy canals mentioned by Mr. Garbett were collected into nine such systems. At the same time silt was only removed from the distributary channels where necessary, and to previously designed levels, and the banks being raised where required, most channels gradually attained a permanent régime, which has rendered future silt clearance on them unnecessary.

Control of Supplies.

The supplies now obtained for each canal are usually ample and seldom fail, but under present conditions sufficient control over them cannot be exercised. As a rule, the supply channel takes out of a creek and has no regulator in the first five miles of its course. If there is an escape at this point, it is almost always inadequate, so that when the river comes down in flood, the supply reaching the head regulator is often many times the total full supply of the canal and the capacity of the escape; and in order to avoid heading up, which would be dangerous to both bunds and regulators, the canal has often to carry two or three times its designed full supply. The problem of disposing of this additional supply, especially when floods occur as they often do just after heavy rain has fallen and no water is required for crops, is a very difficult one; and it is often impossible to avoid flooding large areas of crops. The only methods of control at present available are to cut the bunds erected to prevent water running to waste down side channels, and to breach the banks of the supply channels above the head regulators, but these methods are only partially successful, and jeopardize the later supplies after the flood has fallen, especially those of September and October, on which the rabi crop very largely depends.

It has now been decided that the problem of bringing these canals under control must be solved, and various schemes to effect this are being prepared. The expense will be heavy, but in view of the large profit the accounts for working these canals show; the benefit to the district, both in health and fertility, which will follow a reduction of the annual flooding which now occurs; and the improvement to the canal revenues which will result from fewer remissions of revenue on account of flooding, and from the additional areas which will be brought under cultivation; the author has no doubt of its being justified.

Such schemes must inevitably involve building some expensive works in positions where it is possible they may be destroyed by the river, but the author is of opinion that the chance of erosion occurring at any particular point is small, and that the probable life of each work will be at least twenty years, within which time it will have paid for itself many times over, but the risk must be taken if the object aimed at is to be achieved.

The question of the control of supplies must be solved before many channels can be remodelled, since, in order to enable them to work satisfactorily, they must first be regraded ; and the cost of this, as long as they must be able to take three or four times their normal full supplies, would be prohibitive.

The Open Cut System.

When the Irrigation Department took over these canals, and for many years afterwards, all irrigation was done from open cuts in the banks of the channels, and much of the time of the officers in charge was occupied in endeavouring to so control the distribution of water under this system as to ensure that each man got his fair share. For this purpose the number of cuts allowed was as far as possible reduced, and the channels were divided into lengths, the cuts in which were periodically closed to enable the cultivators lower down to get their fair share of water. On channels, with bad command, stop dams were introduced, at each of which the water could be headed up in turn so as to enable the cuts in the reach above to get water. The system, however, has many very serious drawbacks. Owing to the difficulty of regulating the discharge from an open cut, when it is running, the control exercised can only be very rough. It is practically impossible for an officer, with three hundred miles of channel in his charge either to personally collect, or to effectively check, the information on which these turns have to be worked out, or to control them. He has to rely, both for his information and for the carrying out of his orders, on subordinates and low paid officials, which results in far too much power being in the hands of these men, while the system involves an enormous amount of recurring work for all concerned.

Introduction of Masonry Outlets and Pipes.

In consequence of the defects of this system, masonry outlets have from time to time been built in the worst cases,

which were generally those of the larger cuts where the supply was most difficult to control, and for the past few years the policy of replacing open cuts everywhere by iron pipe outlets has been definitely adopted.

Consequent Necessity of Remodelling.

Under the old system, as long as a channel would bring down water it was good enough, for if it did not give sufficient command, either a higher supply could be run or stop dams could be introduced. On the other hand, if the object of piping, which is to cause an automatic distribution of the supply among the various outlets, is to be achieved, every channel must be regraded so that all the land to be irrigated from it by flow is commanded by the depth of water which gives only the required supply at various points in the channel, without any temporary heading up. It is especially necessary that no heading up by means of temporary or permanent stop dams should be needed, as this is open to much the same objections as the old open cut system, and because the determination of the sizes of the pipes, when the full supply level in the channel is subject to variations caused by heading up in turn at various stop dams, involves a very uncertain and complicated calculation. It will, therefore, be readily understood that considerable remodelling and regrading is often necessary before a channel can be piped.

The author has found that such channels may usually be divided into one of the following classes. First, channels on which the command was very poor, but on which, under the open cut system, the land could still be irrigated, owing to the negligible loss of head beween the channel and the water course, and the extra volume of supply which could be obtained by increasing the width of the cut; secondly, channels on which bad command had previously been compensated for by a series of temporary or permanent stop dams where water was headed up in turn; and thirdly, channels on which bad command had previously been compensated by running higher supplies than were necessary and thus flooding out the tail. The treatment of each class of channel is similar, but it is necessary, before deciding to replace open cuts by pipes, to consider if the channel belongs to any of these classes and whether regrading is consequently necessary. It is with the methods of deciding the sizes of the pipes and the new grading of the channels, and causing channels to conform to the grading so decided, that this paper deals.

Chakbandi.

Before remodelling a channel it is advisable to carefully revise the boundaries of the land to be irrigated from each outlet, which is conveniently denoted by the vernacular word *chakbandi* ; the tract assigned to each outlet being known as a *chak*. In the past the whole aim has been merely to reduce the number of cuts as far as possible, but in many cases this system had been carried too far, and it is now necessary to again increase their number while reducing the area irrigated by each. The cultivators should also be freely consulted, both with a view to preventing subsequent genuine complaints, and because, by a few concessions to their wishes in respect to these areas, it is often possible to minimise the opposition that the introduction of a new system is certain to raise. The area of culturable land in each *chak* having been determined, the proposed area for annual irrigation must next be decided ; the general principle adopted being that this area should not be less in any well (a well being a sub-division of a village of which there are often two or three in one *chak*) than sixty per cent. of the total culturable area, or than the area shown as irrigated annually at the last settlement. The result thus arrived at is usually greater, for the whole *chak*, either than sixty per cent. of the culturable area or than the settlement area.

Supply required from each Outlet.

Having determined the area proposed to be irrigated in each *chak*, the next problem is to determine the discharge required to irrigate it. In this calculation the time fraction of the channel is an important factor. Were the whole system to be remodelled at once, it would be easy to determine this fraction (i. e., the proportion of the whole time the canal is in flow that this channel is likely to be running) from the average supply entering the canal and the sum of the full supply discharges of all the channels fed from it ; and even when a large part of the system has not been remodelled, and the discharges of other channels are variable, a consideration of the number of days, during the four months, 15th May to 15th September, that the channel has in the past been open, will give a fairly correct approximation. It is assumed that on a channel, such as a main line, where the time fraction is unity, a cusec will irrigate ninety acres, i. e., the duty on a full-time channel is ninety acres per cusec, and on other channels it is ninety multiplied by the time fraction. The area to be irrigated, divided by the duty, will give the discharge, and this in turn will give the draw off, at each point of the remodelled channel.

Longitudinal Section.

The next step is to design the longitudinal section for the channel, and the two points to be considered are the critical velocity ratio to be allowed in the various reaches in the channel, and the grading of both bed and water surface.

It has already been stated that most channels have been allowed to assume their natural gradient and have thus come to a permanent régime ; banks having been raised and strengthened where necessary instead of silt clearance being carried out annually. Where the gradient so assumed gives proper command at all points in the channel without such extra supplies being run which would swamp the tail, this gradient can be adopted. Where regrading is found necessary, the hydraulic conditions, which can be deduced from the self-assumed gradient of the channel and its general full supply level as shown by the berms, are extremely useful in showing the lower limit of the critical velocity ratio which can be safely adopted without danger of silting. Where stop-dams and other devices have been necessary in the past, it has of course been impossible for the channel to attain a permanent régime, and no deductions can be made from the present conditions. In these cases the limiting critical velocity ratios must be deduced from experience with other channels similarly situated.

It has been found on these canals, probably owing to a very large proportion of the silt in the water being dropped in the creeks and supply channels, that the limiting critical velocity ratios required are extremely low and vary from 0·75 at the head of the system to 0·55, and in some cases even 0·50 and 0·45 at the tails of the minors, and this enables very low gradients to be adopted, so that slopes of 1 in 10,000 are usual for the tail minors. When the limiting critical velocity ratio has been fixed, it is easy, by experiment, to arrive at bed and surface slopes that will give proper command and at the same time a suitable channel. When fixing the longitudinal section it is neeessary to know and carefully consider all fixed points, such as the masonry floors of bridges, since, if the grading is such as to bring the bed below these points, it will be necessary to lower them, whereas another grading, which did not involve this additional expense, might be more economical.

Size of Outlets.

A cast iron pipe is in some respects an unsatisfactory form of outlet, since it is seldom possible to give it a free fall, and in consequence its working head and discharge will be largely dependent on the level of the particular field being irrigated at the

ime. Two methods are in use for determining the size. The irst is to deduce the probable mean level of the water in the vater course from the levels of the fields to be irrigated and heir respective distances from the outlet. The second is to make a series of direct observations of the actual level of the water in the water course when irrigating through an open cut, the observations being taken at least a hundred feet from the outlet, but this method is impossible in the case of a very large water course drawing more than about ten cusecs.

The author is inclined to prefer the second method when the observations are available, but, although both methods give fairly satisfactory results, these results will require to be carefully watched and the sizes of the outlets adjusted by the irrigation experience of the next few years. For this reason it is usual to fix the pipes in brushwood for the first few years, and not build them permanently till experience has shown that their size is correct.

Examples.

To more fully explain and illustrate the above, the author gives the Surab branch of the Puran Canal as an example of remodelling actually carried out by him, which has been fully tested. Before remodelling, there were six stop dams on the channel, at which water was headed up in turn, but it was found possible, by converting three of these into permanent falls, to obtain such a grading that the whole area was fully commanded without any further heading up. Plate No. 1 gives the longitudinal section and Plate No. 2 the detailed calculations for a few of the outlets.

Another example is the Thalwah, a distributary of the Maggi Canal. In this channel there were no stop-dams, but the head reach of the channel was much too steep and had a much larger capacity than was required. The result was that, in order to command the land at the head, it was necessary to flood out the tail outlets, but by the introduction of a fall and reducing the section of the channel, this was entirely obviated.

Necessity of making Remodelling Effective.

A point sometimes overlooked in remodelling is that it is not sufficient to draw a longitudinal section and to expect the channel to conform to it without taking practical steps to make it do so Notch falls must, of course, be built wherever required by the section ; banks must be raised and strengthened, if necessary, to enable the channel to carry the proposed supply at the

designed grading without danger ; silt clearance and berm cutting must be carried out if required, and, *vice versa*, steps must be taken to encourage the growth of berms and to induce bed silting if the channel is too loose. In particular, all bridges and other masonry works must be carefully considered, and any that are not capable of passing the full supply required, without heading up, must be redesigned and rebuilt.

When designing notch-falls, if the existing bed below the fall is much lower than the level of the proposed bed, it will be necessary to make sure that the downstream floor is sufficiently long to prevent any risk of this low bed affecting the working head of the notch and causing it to pass more water than the quantity for which it was designed. In such a case, a fall, designed on the principle of the semi-module outlet described below, is especially valuable, as the discharge through the fall and the heading up above it are independent of the bed level downstream.

There are many well-known methods of growing berms and inducing bed silting. On the Thalwah and elsewhere the author employed two lines of stakes, driven into the bed of the channel and connected by cross pieces to form crates, every five hundred feet. These were very successful on straight reaches, but if used on curves, the outer bank, for a short distance upstream, must be protected with fascine work to prevent the channel breaking away and outflanking the profile. On the Surab, the crests of the three stop dams, which were not converted into notch falls, were slightly raised above the proposed bed level, and this proved to be all that was required.

It is very important to carry out all the work required to make a channel conform to a new grading at the same time, as otherwise the work done is liable to be useless for want of the work not done, and much extra expense may be caused.

Semi-module Masonry Outlets.

It has been stated that pipe outlets are replacing the open cuts, but for the tail clusters and the larger outlets a type of semi-module is in use which was introduced by Mr. A. E. Jeffries, and is very similar, if not identical, with the semi-module outlet described by Mr. Harvey at this Congress last year in the course of the discussion on Mr. Waterhouse's paper. It consists of a flat floor, with two vertical side walls, converging at a slope of 2 to 1 in plan to a slit, the width of which determines the discharge of the outlet, and then diverging at a slope of 5 to 1 to the width of

the water course, the top being open. It has been found that if the depth of the water over the floor is H and the width of the slit L, the discharge will equal

$$3{\cdot}7\ L H^{\frac{3}{2}}$$

whatever the level of the water in the water course. The effect of the converging and diverging appears to be to form a standing wave, when the water-level in the water course is below that in the distributary, and this standing wave appears to absorb the extra energy due to the extra head.

This semi-module, as already stated, is mostly used for tail clusters, but it is also useful for large outlets, drawing over eight or nine cusecs. For smaller outlets the slit required becomes in most cases too narrow. Plate No. 3 gives drawings of a two outlet tail cluster and an ordinary outlet on this principle. In the tail cluster the slit is widened above the full supply level to enable it to pass extra supplies without undue heading up.

The same principle can be used for bifurcations, for works to take the place of notch-falls, as explained above, or to ensure the proper level of water being maintained in newly remodelled distributaries, the floor being at bed level, and the semi-module designed to pass the required full supply without undue heading up. An interesting example of the use to which works designed on this principle can be put is the case of a minor, where a supply of thirty cusecs had to be divided between two large outlets drawing nine and eight cusecs respectively, and two tail areas requiring six and seven cusecs. Instead of pipes, bifurcations designed on the above principle were built at the two outlets, the first designed to pass nine and twenty-three cusecs through each slit, and the second to pass eight and fifteen cusecs ; a tail cluster on the same principle being also built. The result was a considerable saving over what the cost would have been if pipes had been used, and a channel that would really automatically distribute any supply it received among its various outlets, giving each its proper share.

Large Water Courses

There are several water courses in the district drawing over twenty cusecs ; some as much as fifty cusecs. These are really branch channels, but only managed by cultivators, who are incapable of doing it and should be brought under the control of the Irrigation Department. This, however, is usually strenuously opposed by the larger cultivators at the head, who, under

present conditions, get things entirely their own way, and this opposition has to be gradually overcome by teaching the cultivators at the tail their rights, and doing all that is possible to help them to get them, thus overcoming the opposition, by doing away with the privileged position at present enjoyed by individuals, which causes it.

A peculiar Case.

One rather curious case with which the author had to deal was a channel, which, below the fourth outlet, was fed by spills from the river during floods It was then impossible to run a supply from the head which would command the land in the *chaks* of the first four outlets. The difficulty was overcome by digging a new minor to irrigate only these *chaks*.

General Results.

At present about half the channels in the district have been remodelled and fitted with some form of outlet, but the progress, for various reasons, has been very uneven in the various sub-divisions. In the best, only ten per cent of the outlets remain open cuts, while in the worst there are some seventy per cent. The results have been remarkable. In 1915-16, in spite of bad rivers, the area matured was the second highest and the percentage of remission the lowest on record. In 1916-17 both the areas irrigated and matured were the highest on record. In 1917-18, although, owing to the excessive rain and consequent flooding that occurred after the end of July, the totals were bad, the area irrigated up to end of July, in spite of exceptionally low rivers, was higher than in the previous record year. It is also remarkable how much more evident these improved figures are in the case of the best subdivision noted above than in the case of the others. These facts, in the author's opinion, conclusively prove how successful the improved methods of distribution have been.

DISCUSSION.

MR. G. W. DUTHY, introducing his paper, remarked that the paper might be of limited interest, as little was known about inundation canals, and it was with a view to giving some idea about them that he had written it.

THE HON'BLE MR. P. J. FAGAN, Financial Commissioner, Punjab, was afraid that it was very daring of him, as a layman, to intervene in the deliberations of a highly expert conference such as that which had assembled there. His excuse was that a good deal of his service had been spent in more or less close contact with inundation canals, and in the consideration of revenue questions connected with them. It would be quite improper for him to attempt anything like a history of the inundation canals of the province. As they all knew, they were a link with the past, and a relic of an indigenous form of irrigation. They might be inclined to laugh at these in their original form, before the British Government had anything to do with them, but still even at that time they did yeoman service in the province in the hands of administrators like Sawan Mal and others of his type. They certainly indicated and emphasized to them, when they first came to the pr. nce, the possibility and potentialities of irrigation. In British hands they had been developed, and they always struck him as a very signal instance of that great central and fundamental problem of Indian administration, the adaptation of indigenous forms to modern requirements.

The success of the inundation canals from the financial point of view had been great, and about their benefit to the cultivators of the tracts which they served there could be no doubt. Much, of course, still remained to be done, but, so far as he could see, it would be a long time before there remained no scope for inundation canals in the province. For many of them there was a good prospect of continued success, while others might with benefit be converted into perennial channels with an assured supply, but so far as the south western portion of the province was concerned they had a long lease of life before them. They afforded a fine field for the exercise of the best energies of the officers of the Irrigation Department. Around the yearly struggle which the officer in charge of the inundation canalshad to carry on with the vagaries of a great river, there was an element of romance which was perhaps wanting in the more staid and uniform regularity of a great perennial canal, magnifi cent though the achievements of the latter undoubtedly were.

In the past perhaps the inundation canals had financially been left somewhat in the cold and their fair requirements somewhat starved. There had been a tendency to regard them merely as more or less respectable watercourses or even irrigation ditches, but that state of things, he believed, had passed away, and funds were now more freely forthcoming to carry out improvements, such as those which had been so ably dealt with in Mr. Duthy's interesting paper. He hoped that the usefulness and capabilities of inundation canals would be more and more kept in view, and that they would not be marred by anything of the nature of financial starvation.

MR. E. S. LINDLEY said that he preferred and had applied outlets which distributed the very variable supplies on inundation canals more or less proportionately, to the cast iron pipe outlets advocated by Mr. Duthy. With regard to the low critical velocities found on the Muzaffargarh canals he had noticed similar velocities on the inundation canals about Bhera.

MR. F. W. WOODS remarked that Mr. Duthy had described and advocated a system of remodelling inundation canals with a view to working them on much the same principles as permanent ones. This system assumed a constant supply in each canal throughout the season, with the water surface at a constant level, sufficient to command the highest land within the sphere of irrigation of the canal, by direct gravitation flow, through outlets (*i. e.* pipes or masonry culverts) in the banks of the canal; and notwithstanding the success claimed for the results of this system of remodelling the Muzaffargarh inundation canals during recent years, it might well be doubted whether it was sound in principle.

At the point where an inundation canal took off from a river a the flow of the river was not controlled by any weir, barr ge, or dam, built across it, and there was no means of raising or lowering its water surface level. An inundation canal did not receive any water until the level of the river rose through the melting of snow in its mountains of origin, or through rainfall in its catchment area, and even after the river had risen high enough to feed the canal, there was no means of preventing it from rising higher, or sinking lower, through floods or droughts. The water supply of the canal must, therefore, be variable and precarious, and the soundest principle of design would seem to be to design the canal with a capacity far in excess of its average volume of flow, so as to enable it to take the greatest advantage of the brief periods of flood in order to

compensate for alternating periods of scanty flow. Its irrigation outlets should, for the same reason, be of capacity far greater than that required for uniform flow, and from this point of view the open cut in the bank (lined with masonry, but open at the top) seemed preferable to the close culvert or pipe, since, in the case of the latter, the discharge increased only with the square root of the head of pressure, instead of nearly as the square of that head.

The difficulty of coping with the intermittent or variable discharge of inundation canals might be met by the use of the semi-module or roofless culvert, referred to in Mr. Duthy's paper,* but he had claimed credit for the successful control of irrigation on the Muzaffargarh canals by means of closed culverts or pipes working under pressure, and this claim seemed to be open to criticism on theoretical grounds. In order to deal with a variable intermittent flow, the system of control adopted ought, in reason, to be essentially different from that which experience had suggested as the best for perennial canals of constant, or fairly constant, discharge, completely under control.

The control of the flow from the open outlets of inundation canals could not conveniently be carried out by Government officials, but the solution of this difficulty might be found in the control of irrigation and the distribution of the supply by co-operative societies of irrigators.

MR. W. B. HARVEY thought the design given for a tail luster would be improved, in the case of outlets where there was little loss of head, by making the rate of divergence less rapid. This might suitably be 1/20 for a length of two or three feet on eachside and then 1/10 for a similar length.

The co-efficient quoted by Mr. Duthy in his formula† $Q=3{\cdot}7D^{1{\cdot}5}$ had been arrived at several years ago, when he was making some rough experiments on a flume. More recent experiments showed that it was too high, and that the index was not necessarily 1·5. The approximate equation $Q=3{\cdot}3\ D^{1{\cdot}5}$ would be nearer the true formula, but he hoped to publish his later results by an early date.

MR. DUTHY, in reply, pointed out that his introductory remarks, as to how little was known about inundation canals, were amply borne out by the discussion. None of the professional speakers, apparently, had any ideas of such inundation canals as were referred to in his paper. With Mr. Fagan's remarks he

* Pages 46-47. † Page 47.

entirely agreed, and he would add that he believed th inundation canals in the Muzaffargarh District were more suitable to the conditions of the district than any other form, and would eventually survive, and for this reason he believed that it would be justifiable to spend a good deal of money in controlling and remodelling them. With regard to Mr. Lindley's and Mr. Woods's remarks, he would point out that the systems in the Muzaffargarh District consisted of a long supply channel, from which no irrigation was done, but which enabled ample command to be obtained. At the tail of this channel the system divided into two, or usually more, branches and generally split up again at the tail of these branches. As a precaution against water-logging canals were not opened till fixed dates, when there was invariably sufficient supply to run at least one of the branches full supply, and as the supply rose the whole system was gradually brought into use, and thus it was able to take advantage of all the water it could get except during floods, when to do so, even if it were possible, would flood the whole country. The method was thus exactly analogous to the methods of dealing with alling supplies on a perennial canal during the cold weather, by running the branches full supply in turn. It thus followed that similar outlets were suitable for both kinds of canals. He attributed the low critical velocities on inundation canals to the low silt charge ; the water dropping most of its silt charge in the creeks and supply channels, from which it was removed during the winter when the canals were not in flow.

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