PAPER No. 146.

A THEORETICAL DESIGN OF A NEW TYPE OF OUTLET FOR IRRIGATION CHANNELS.

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1. Much has been said and done, by eminent Irrigation Engineers in recent years, on the important subject of the scientific distribution of canal water. That this science has been developed to a very advanced stage of efficiency, as compared to old crude devices, cannot be denied. But it is equally true, that we are yet nowhere near perfection in this branch of irrigation engineering, and that it will require many years of careful study of the various problems connected with outlet design before that stage is reached. In the following few pages I have endeavoured to contribute my little quota, in the hope that perhaps my ideas may appeal to those who can speak with authority on the subject and it may be possible for them to make use of these ideas while designing outlets in future.

2. In the past, the efforts of all engineers have been solely directed towards designing an outlet or outlets, which when fitted on a distributing channel, will lead to equitable distribution of canal water among the various zamindars, in exact proportion of the areas held by each. With this end in view, outlets were designed with unit proportionality, that is to say, if there was n per cent. increase or decrease in the discharge of the distributary the variation of outlet discharge was also **n** per cent. Or to express it mathematically, if q and Q be the discharge of the outlet and distributary respectively, then

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

3. If it was possible to construct outlets that will strictly behave like this in actual practice, it will solve the problem of distribution once for all. The adjustable proportionate Module or A. P. M. is said to have the desired unit proportionality. This claim is theoretically proved as follows :—

If

X =Channel depth.

Q =Channel discharge.

K =Constant.

$$Q = K X^{\frac{5}{3}}$$

$$\frac{dQ}{Q} = \frac{5}{3} \cdot \frac{dX}{X} \qquad \text{.............(i)}$$

Also if for A. P. M.

H =Depression of orifice floor.
h =Depression of orifice roof.
y =Height of orifice $= H-h$
B =Width of orifice.
q =Discharge of outlet.

then $q = 7{\cdot}3\,B\,y\,\sqrt{h} = C\,h^{\frac{1}{2}}$

$$\therefore \frac{dq}{q} = \frac{1}{2}\frac{dh}{h} \qquad \text{.............(ii)}$$

For unit proportionality

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

from (i) and (ii)

$$\frac{1}{2}\frac{dh}{h} = \frac{5}{3}.\frac{dX}{X}$$

Or $$\frac{h}{X} = \frac{3}{10}\frac{dX}{dh}$$

But $dX = dh$

$$\therefore h = \frac{3}{10}X \qquad \text{.............(iii)}$$

i.e., if the depression of the orifice roof is kept $\frac{3}{10}$ths of the channel depth, the outlet ought to be exactly proportional.

4. Similarly it can be theoretically proved that if in the case of open flume type outlet or S. W. O.,* the crest level is kept $\frac{1}{10}$th of the channel depth, above distributary bed level, the outlet will have unit proportionality.

5. It will thus appear that if A. P. M.'s and S. W. O.'s were fitted on any channel from head to tail, it will result in equitable distribution of water from head to tail. In fact in some Divisions such remodelling has been done. In Burala Division, Lower Chenab Canal for example, A.P.M.'s and S.W.O.'s have been substituted for older type outlets on most channels and it was expected that dry tails would become only a question of the past and that there will be absolutely no trouble whatsoever in the future. But unfortunately the expected has not happened and zamindars still complain of short supplies at tails or even in intermediate reaches. That such complaints are valid can very easily be proved by comparing the areas irrigated per cusec of designed supply on each

*S. W. O. = Standing Wave Outlet.

outlet. Such comparison will reveal the discouraging fact that the distribution of the water is far from equitable. Outlets in the head reach generally get the lion's share of water while tails seldom, if ever, get the proper supply.

6. This great disparity between theoretical formulæ and practical results seems a paradox. The mathematical formulæ are flawless but in practice the outlets designed on the basis of those formulæ do not behave as expected. There must be something fundamentally wrong with the assumptions on which the formulæ are based and this must be discovered before any further improvements are contemplated.

7. The first and the most obvious cause contributing to the failure is the inaccurate hydraulic data on which the design is based. That this is generally so, cannot be denied. But the reason why the wrong data is supplied to the designer is a question difficult to answer. The executive engineers who, after having taken great pains in remodelling their channels on new lines, find that every thing goes wrong, are generally too eager to throw the blame on poor sub-divisional officers for not being careful in supplying the correct data or for not constructing the outlets at correct levels. But it does not occur to anybody that it is the seasonal variation of silt that causes the whole mischief. In the design it is assumed that with a certain slope, bed width and full supply depth, the channel will give the same discharge all the year round and will have the designed full supply levels at all points for ever. But in practice it is not so. A few months after even the most careful remodelling, the regime of channel changes again and the outlets need altering. This is the first cause of failure of any remodelling scheme.

8. There is yet another and a more serious cause of failure, which as far as I am aware, has never been taken into account in theoretical designs. This cause is so serious that nothing short of a fixed module like the Gibb's can effectively meet the menace. I mean the highly commendable habit of some zamindars to head up supplies at night to increase the discharge of their outlets. I have purposely called this practice commendable, because it keeps the irrigation staff always on the alert and thus prevents them from becoming lethargic and lazy. That this habit of heading up supplies is general and chronic is quite apparent from the great number of cases of unauthorized irrigation in every subdivision. But whether this disease is widely prevalent or is limited to certain localities does not concern me at present. What I want o discuss is its effect on the distribution of canal water.

(*a*) Let us suppose that there is a cluster of three or four open flumed outlets combined with a fall at certain point of a distributary and let us assume that the designed depth of water over the crest is kept one foot. Also suppose that at night some one puts a few branches of trees and sarkanda on the crest of the fall and thus heads up the supply by one foot. The discharge of each outlet will be increased to

$\left(\frac{2}{1}\right)^{\frac{3}{2}}=2{\cdot}88$ times its authorized discharge and may mean thousands of rupees to the zamindars in the shape of increased area of matured crops if the mischief remains undetected. If such a thing happens on each fall or bridge even once a week, the tail reach must remain constantly dry at night. Also the channel at points of heading up and for a long way above it will silt up and thus permanently increase the discharge of some of the outlets. If this permanent silting up is say 0·2 feet, which is quite ordinary, the permanent increase in discharge will be

$$\left(\frac{1\cdot 2}{1}\right)^{\frac{3}{2}}=1\cdot 31 \text{ times},$$

or an increase of 31 per cent. in the discharge without any increase of the discharge in the parent channel. If such things do happen, all talk of proportionality vanishes into thin air and the money spent on remodelling must be regarded as pure waste. I am aware that such a state of things did happen in one sub-division immediately after remodelling. The Sub-Divisional Officer imposed "tawan" fines in all cases that came to his notice. But the increase in government revenue by fines is no consolation to the poor zamindars at the tail, whose share of water is thus stolen.

10. I have briefly referred to some of the drawbacks of modern remodelling, in order to prove its inefficiency in certain respects and also to show the necessity of inventing some other type of outlet or outlets that cannot be so easily interfered with by zamindars. The new outlet should be such that nothing short of its actual dismantling should give zamindars much more than their authorized share and yet at the same time it should not be rigid like the Gibb's module.

11. I do not think it is necessary for me to go into the merits and demerits of Gibb's patent module. Suffice it to say that it has not proved useful in the past and is not likely to be extensively used in the future for the pure and simple reason that it is incapable of passing a drop more than the designed supply even in cases of emergency.

12. The outlet described below has for its aim the more or less equitable distribution of water under all circumstances with certain limitations. Even if the supply in the parent channel is headed up by a foot, the discharge of this outlet increases only from 8 per cent to 23 per cent, depending upon the initial working head. The variation of discharge by seasonal variation of silt is less than 5 per cent. even in the worst conditions. I have called it

"Double Module Outlet" or "D. M. O."

D. M. O.

13. In its simplest form it is an A. P. M. fitted into a masonry cistern instead of its being fitted into the distributary bank. The cistern is connected to the distributary by means of an ordinary bell-mouthed pipe or barrel. The arrangement is diagramatically shown in the drawing attached (Plate I).

Notation :—For pipe.

A =Area of cross section.

Hp =Working head of pipe, *i.e.*, the difference of level in the cistern and the channel.

C =Co-efficient of discharge.

For. A. P. M.

B =Width of orifice.

Ho =Depression of orifice crest from water level in the cistern.

h =Depression of the orifice from the water level in cistern.

y =Ho—h=opening or height of orifice.

Other symbols used

H =h+Hp=Depression of orifice roof from channel F. S. L.

q =Discharge through the outlet in cusecs.

Q =Discharge in parent channel.

D =Depth in the parent channel.

hw =Total working head of the outlet.

hm =Min^{m} module head for A. P. M.

Formulæ :—

Discharge through pipe$=C\,A\,Hp^{\frac{1}{2}} = q$......(i)

Discharge through A. P. M.$=7{\cdot}3\ By\sqrt{h} = C_1\,h^{\frac{1}{2}} = q$....(ii)
where $C_1 = 7{\cdot}3\ By$=Constant for any given outlet.

∴ Equation (i) and (ii) we have

$$q = C\,A\,Hp^{\frac{1}{2}} = C_1\,h^{\frac{1}{2}}$$

$$\therefore \frac{dq}{q} = \frac{1}{2}\cdot\frac{d\,Hp}{Hp} = \frac{1}{2}\cdot\frac{d\,h}{h}$$

$$= \frac{1}{2}\cdot\frac{d\,(Hp+h)}{Hp+h} = \frac{1}{2}\,\frac{dH}{H} \quad \text{.........(iii)}$$

i.e., if discharge varies by n %, H must vary by 2 n % .

Practical Designs.

Case I. Data Discharge=2·5 cusecs.

Minimum Working Head =Above 4 feet

For pipe

$q = C\,A\,Hp^{\frac{1}{2}} = 5\,A\,Hp^{\frac{1}{2}}$ [C=5 for iron pipes]

If A=0·5 square feet.

$$Hp^{\frac{1}{2}} = \frac{q}{5 \times 0{\cdot}5} = \frac{2{\cdot}5}{2{\cdot}5} = 1$$

∴ Hp = 1 foot.

For A. P. M.

hm =4—1=3 feet.

Keep the ratio $\frac{y}{Ho} = 0{\cdot}10$.

Then according to Mr. Colyer (*vide* paper No. 26 A Class A)

$\frac{h\ m}{Ho}$=0·580 *i.e.*, Ho=1·74 h m =5·22 feet.

y =0.1 Ho =0·174 hm =0·522 feet.

& h=Ho—y =1·74 hm—0·174 hm=1·566 hm=4·69 feet.

$q = 7{\cdot}3\ B\ y\sqrt{h} = 7{\cdot}3\ B \times 0{\cdot}522\ \sqrt{4{\cdot}698}$

$= 8{\cdot}25\ B$

$\therefore B = \frac{q}{8{\cdot}25} = \frac{2{\cdot}5}{8{\cdot}25} = 0{\cdot}3$

$H = h + Hp = 4{\cdot}698 + 1{\cdot}0 = 5{\cdot}698$ feet.

If the distributary full supply level is increased by 1·0 by heading up.

Increase in $H = \frac{100 \times 1{\cdot}0}{5{\cdot}698} = 17\ \%$

$\therefore$ Increase in supply $= \frac{17}{2} = 8{\cdot}5$ per cent. which is negligible.

From the above it is clear that if the working head available is above 4·0 feet, we can design an outlet that will give practically a fixed discharge for wide variation in the level of parent channel.

Only 1·0 feet heading up has been assumed, as it is not possible to head up further; otherwise channel banks will be breached.

Case II.

Minimum Working Head (hw) greater than 3·0 feet.

Other data as before.

For pipe

Let A = 0·75 feet.

$\therefore q = 5 \times 0{\cdot}75\ Hp^{\frac{1}{2}}$

$Hp^{\frac{1}{2}} = \frac{q}{3{\cdot}75} = \frac{2{\cdot}5}{3{\cdot}75} = \frac{2}{3}$

$Hp = \frac{4}{9} = 0{\cdot}44$

For A. P. M. hm = 3·0 — 0·44 = 2·56 feet.

keep $\frac{y}{Ho} = 0{\cdot}15$

Then by Colyer's paper $\frac{h\ m}{Ho} = 0{\cdot}480$

$Ho = \frac{hm}{0{\cdot}48} = 2{\cdot}08\ hm = 2{\cdot}08 \times 2{\cdot}56 = 5{\cdot}33$

y = 0·15 Ho = 0·8 feet.

h = 5·33 — 0·8 = 4·53 feet.

$\therefore B = \frac{q}{7{\cdot}3\ y\sqrt{h}} = \frac{2{\cdot}5}{7{\cdot}3 \times 0{\cdot}8 \times \sqrt{4{\cdot}53}} = 0{\cdot}2$

H = 4·53+0·44 = 4·97 feet.

For 1·0 feet increase in full supply level of parent channel

$$\% \text{ increase in } H = \frac{1 \cdot 0 \times 100}{4 \cdot 97} = 20 \text{ per cent.}$$

$\therefore$ Increase in discharge $= 10$ per cent.

Case III.

Minimum Working Head (hw) greater than 2·0 feet

q=2·5 cusecs as before.

For pipe

Area of cross section=1·0 square feet.

$$q = 5 \times 1 \cdot 0 \, Hp^{\frac{1}{2}}$$

$$\therefore Hp^{\frac{1}{2}} = \frac{q}{5} = \frac{2 \cdot 5}{5} = 0 \cdot 5$$

$$\therefore Hp = 0 \cdot 25.$$

For A. P. M.

$$h\,m = 2 \cdot 0 - 0 \cdot 25 = 1 \cdot 75 \text{ feet.}$$

$$\text{Keep } \frac{y}{H_o} = 0 \cdot 20$$

$$\text{Then } \frac{hm}{Ho} = 0 \cdot 407$$

$$Ho = 2 \cdot 48 \, hm = 2 \cdot 48 \times 1 \cdot 75 = 4 \cdot 32 \text{ feet.}$$

$$y = 0 \cdot 20 \, Ho = 0 \cdot 86 \text{ feet.}$$

$$h = 4 \cdot 32 - 0 \cdot 86 = 3 \cdot 46 \text{ feet.}$$

$$\therefore B = \frac{q}{7 \cdot 3 \, y \sqrt{h}} = \frac{2 \cdot 5}{7 \cdot 3 \times 0 \cdot 86 \times \sqrt{3 \cdot 46}} = 0 \cdot 216.$$

$$H = 3 \cdot 46 + 0 \cdot 25 = 3 \cdot 61$$

For one foot rise in supply level

$$\text{Increase in } H = \frac{1 \cdot 0}{3 \cdot 61} \times 100 = 28 \text{ per cent.}$$

$$\therefore \text{Increase in discharge} = \frac{28}{2} = 14 \text{ per cent.}$$

Case IV.

Minimum Working Head (hw)=1·0 feet.

q=2·5 cusecs.

For pipe

Area of cross section $= 1{\cdot}0$ square feet.

$$Hp = \left(\frac{2{\cdot}5}{5}^2\right) = 0{\cdot}25.$$

For A. P. M.

$$h\,m = 1{\cdot}0 - 0{\cdot}25 = 0{\cdot}75.$$

keep $\frac{y}{H_o} = 0{\cdot}40$, then $\frac{h\,m}{H_o} = 0{\cdot}237$

$$H_o = \frac{hm}{0{\cdot}237} = 4{\cdot}22\,hm = 4{\cdot}22 \times 0{\cdot}75 = 3{\cdot}17$$

$$y = 0{\cdot}40\,H_o = 1{\cdot}268 \text{ feet.}$$

$$h = 3{\cdot}17 - 1{\cdot}268 = 1{\cdot}902 \text{ feet.}$$

$$B = \frac{q}{7{\cdot}3y\sqrt{h}} = \frac{2{\cdot}5}{7{\cdot}3 \times 1{\cdot}26 \times \sqrt{1{\cdot}902}} = 0{\cdot}2$$

$$H = 1{\cdot}902 + 0{\cdot}25 = 2{\cdot}152$$

If 1·0 foot is the rise of supply level

Increase in $H = \frac{1{\cdot}0}{2{\cdot}152} \times 100 = 46$ per cent.

Increase in $q = \frac{46}{2} = {\cdot}23$ per cent.

Below one foot working head, this type of outlet has no advantage over the ordinary A. P. M.

14. It will thus be seen that this type of outlet has got a very low flexibility that is to say its discharge is affected to a very limited extent, even with wide variations of full supply levels in the parent channel. Fluctuations of F. S. levels due to seasonal variations of silt deposits will have practically no effect on the discharge, for if the level in the parent channel varies by 0·2 foot due to this cause, the variation in discharge will be within 5 per cent. in all cases.

15. The outlet being essentially an A. P. M., it possesses all the good points of that excellent module and in addition possesses many other advantages, some of which are enumerated below:—

Advantage of Double Module Outlet (D. M. O.) over an A. P. M.

Cheapness.

(*a*) A D. M. O. will be cheaper to construct than an A. P. M. in cases of channels in high filling and also when the depth of parent channel is great and banks wide. In fact this will be the most economical design for direct outlets from a branch canal or from major distributaries.

Lesser flexibility.

(*b*) The flexibility of a D M.O. is much less than that of an A. P. M. or in fact less than that of any other type of outlet. It will at first sight appear that if an A. P. M. were built with its h=h+Hp or H of the D.M.O., the flexibility in both cases wil lbe equal. It must, however, be remembered that in a D.M.O. the whole available working head is utilized and that H is, in several cases, greater than the depth of parent channel which is not possible in the case of direct A. P. M. As a matter of fact, full advantage of working head is not taken in any existing type of outlet.

Suitable for high level channels.

(*c*) A D. M O. is the only outlet that can be used as a direct outlet on high level channel. All other type of outlets will be very expensive on account of excessive length of downstream splays, etc. Moreover as the working head in such cases is much more than 4 feet, the maximum variation of outlet discharge will be less than 5 per cent., *i.e.*, for all practical purposes the outlet will work as a rigid module.

Adjustability.

(*d*). It will be easier to adjust a D. M. O. than an A. P. M. for it can be adjusted even when the channel is running full supply. But an A. P. M. can only be adjusted at the time of closures.

Takes its share of silt.

(*e*) A D. M. O. can be made to take any desired amount of silt simply by lowering or raising the pipe without any variation in the outlet discharge. It is not possible to do so in the case of an ordinary A. P. M.

16. *Defects of D. M. O.*—The only drawback of a D. M. O. is the excessive working head required for its proper working. But the working head required is not more than that required for K. G. O.s* which were so extensively used in the past and which are even now being used on some channels. But all the same it has got to be admitted that this is its defect for which it cannot be universally used. It can only be used with advantage if available working head is more than one foot.

17. *Conclusion.*—On any channel whatsoever, there are always over 75 per cent. of outlets with more than one foot working heads. The outlets with low working heads are generally in the tail reach where ordinary opened flumed outlets or S. W. O.'s are quite suitable. If in exceptional cases, any outlet in a head reach has got a poor command, it can be fitted with a S.W. O. or a Gibb's module which is said to be workable with 0·5 feet head for discharges up to 3·5 cusecs. It is thus possible to install this new type of outlet on most of the channels in the Province. It is hoped that irrigation engineers will give the benefit of their valuable criticism to this device. It is so far only a paper design. Its real worth can only be judged by experiments on a large scale by adopting it with modifications, if necessary, on any channel.

I hope a fair trial will be given to this type of outlet.

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* K. G. O.= Kennedy's Gauge Outlet.

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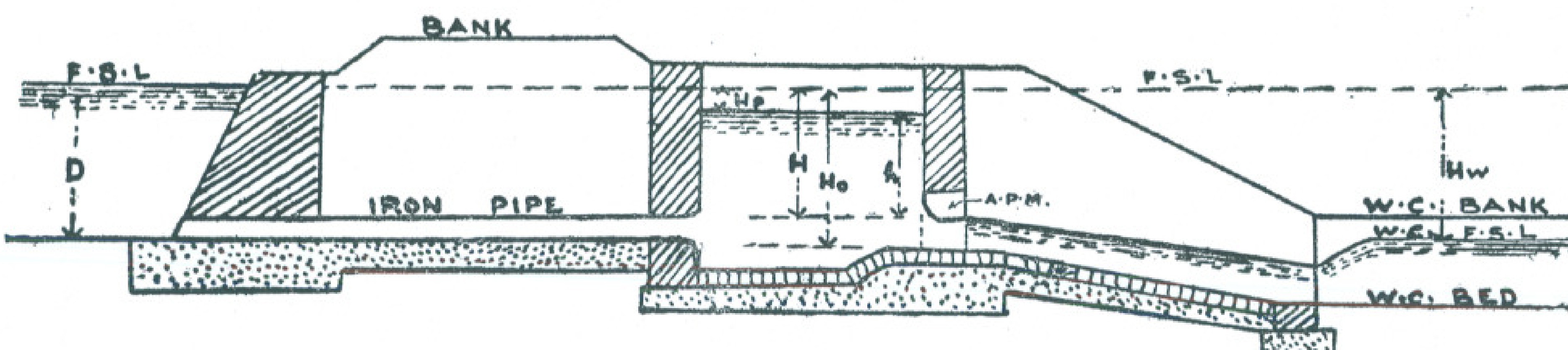
DIAGRAMATIC SKETCH OF D·M·O



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DISCUSSION.

THE AUTHOR introducing his paper, said that it was written in 1927 when he was an apprentice engineer. He was afraid he had not been able to clearly explain the object underlying the design of this new type of outlet or D. M. O. as he had called it, and therefore, took this opportunity to lay before the members of the Congress in some detail the advantages claimed for this new device.

This new type of outlet was designed to meet a specific demand, *i.e.*, to ensure that irrigation outlets did not get more than their designed share of water supply running in any channel so long as the discharge passing into the parent channel at the head remained constant. In actual practice, outlets in the head reach generally got excessive discharge while tails usually suffered. As he had explained in the body of the Paper, there were two factors contributing to this variation of discharge. One was the rising of full supply level of the parent channel by silt deposits and the other, the unauthorized heading up of water by interested parties. The only obvious way of dealing with both of these evils was to design an outlet with very low flexibility or proportionality. Flexibility or proportionality of an outlet was the ratio of fractional variation of outlet discharge to the fractional variation of channel discharge. If any outlet had 100 per cent. flexibility, it meant that if the discharge of the parent channel was increased by 100 per cent. the discharge of the outlet would also be increased by 100 per cent.

The flexibility of an A. P. M. was generally kept as cent. per cent. The theoretical minimum flexibility of an A. P. M. was 35 per cent. which was very seldom attained in practice. The minimum practical flexibility of an existing type of outlet was that of the K. G. O., its value being 37 per cent. There was no other type of outlet, excepting of course the rigid modules, that possessed a flexibility lower than this value. The D. M. O. on the other hand could have a flexibility as low as 5 per cent. provided good working heads were available. With one foot working head and 2 feet depth of the parent channel, the flexibility of the D. M. O. would be 31 per cent.; with 2 feet working head and the same channel department, the flexibility worked out to only 14 per cent. and for greater working heads it would be still less. Thus it was clear that a D. M. O. was the most efficient module where low flexibility was desired. With such low flexibility of outlets, it would not pay any one to head up water in the channel and risk detection and punishment for so small an increase in the outlet discharge and the habit of heading up would automatically die out. The silt deposit in the channel bed would have practically no effect on the discharge of the outlet, the minimum variation on this account being less than 5 per cent.

The D. M. O. did not require excessive head for its proper working. Its minimum modular head was that of the ordinary A. P. M. plus the frictional loss of head in the pipe portion of the outlet. This additional loss of head in ordinary cases would hardly be more than 2″ or 3″ and should not be a very great obstacle in the way of using the D. M. O. in practice. The examples worked out with 3 feet and 4 feet working heads were only meant to show the very low value of flexibility where excessive working heads were available.

The idea of using a cistern between the outlet and the parent channel was not a new one. It had been very successfully employed in the case of the K. G. Os. on the Lower Chenab Canal. The K. G. O. itself required greater working head than an A. P. M. If working heads could be made available for the cistern type of K. G. O., there was no reason why it should not be possible in the case of a D. M. O.

One practical difficulty in the case of the cistern type of the K. G. O. was that it was easy enough to increase the discharge of the outlet by dismantling a few bricks. To counteract this, it was proposed to build the tank of the D. M. O. of cement concrete reinforced with expanded metal. This would prevent unauthorized interference with the outlet by anyone.

Other advantages claimed for the outlet were briefly mentioned on pages 112 and 113.

MR. G. LACEY observed that the Author was to be congratulated on an interesting and provocative paper. The Author had reproduced formulæ commonly employed for proportionality and had suggested that the mathematics was flawless. The subject could be better understood if the general case was presented.

If Q was the discharge in the parent channel, q the discharge of the offtake, and E the elevation of water surface in the parent channel, the general expression for proportionality was

$$\frac{q}{Q} = \frac{dq}{dQ} = \frac{dq}{dE} = \frac{dE}{dQ} \quad \ldots\ldots (1)$$

The offtake formula for discharge presented no difficulty in outlets of the ordinary orifice of flume type and could be written in the rational form

$$qm = kh^{n} \quad \ldots\ldots (2)$$

The discharge formula for the parent channel presented greater difficulty. A formula very commonly employed was

$$Q = KH^{\frac{5}{3}} \quad \ldots\ldots (3)$$

It was very frequently overlooked that this was merely an empirical formula, that there was little evidence that the power was always precisely five-thirds, and that for the formula to be even approximately true, it was necessary to assume that the horizontal bed as excavated was indefinitely preserved, that the side slopes remained at ½ to 1 and that the water surface slope was constant at all stages. The formula was doubtless of some utility as it stood, but for its differentiation there was no possible justification. Accepting the empirical formula and differentiating it, the following general equation resulted

$$\frac{h}{H} = \frac{\text{offtake index}}{\text{channel index}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

From this equation it was clear that if the empirical formula was accepted as correct, the value of the ratio was for an orifice outlet 0·30 and for a flume outlet 0·90.

This method was however incorrect, and it was desirable to evolve another. Reverting to the first equation and solving for h in terms of dE/dQ it was clear that

$$\frac{q}{Q} = \frac{kh^n}{Q} = n.k.h^{n-1}\left(dE/dQ\right)$$

and therefore

$$h = nQ\ (dE/dQ) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

He suggested that this formula was rational and practical for the following reasons. It was clear that no attempt should be made to remodel a channel until the discharge of the channel was known and also the reduced level of the water surface corresponding to that discharge. It was necessary also to know the variation of the discharge with the water surface and for this purpose an accurate stage discharge curve was also essential. These were required at approximate intervals throughout the channel. When this was done, dE/dQ was known at any point and for any discharge.

It was necessary to know both Q and dE/dQ and he suggested that these factors did not always demand sufficient attention. The introduction of a mythical value of H was both complicated and unnecessary. It was well known that cross sections after some years of running differed from the record sections, and often from anything approaching a true prismoidal section with horizontal base. The accepted method of having a 'shot' at D was far from satisfactory. It was infinitely better to measure Q and dE/dQ on the spot than to assess it by referring to Kennedy's diagrams or to record sections which were frequently a delusion and a snare.

The general formula, it should be noted, could be applied to channels taking off from parent channels which were curved in cross section and with beds which were anything but horizontal laterally.

The Author had not stated the degree of silting or scouring in inches, which in his opinion vitiated the proportionality of semi-modules. It was difficult to believe that seasonal variation would be so great as to render semi-modules a failure, although of course progressive silting if unchecked in a silting channel would be objectionable. Certain channels with poor slopes would always function badly if neglected. It was better to anticipate the silting and clear below the bed level at the beginning of the working season.

The remedy, if cultivators put obstructions in a channel, was to enforce the local Canal Act. It was very true that any type of outlet with the orifice set low was a quasi-rigid module; variations in head had then relatively little effect. Unfortunately, few channels were deep enough, nor was the water surface sufficiently elevated above the prevailing ground surface.

The D. M. O. which the Author had evolved had exactly the same proportionality as a simple semi-module sited in the same place. It was of use only when the water surface was greatly elevated above the ground surface, and the example which the Author had sketched could with economy be replaced by the old-fashioned pipe outlet. The submergence would be negligible.

The Author has referred to the practice of placing obstructions in channels so as to raise working heads. Cultivators who did that kind of thing, and he did not think there were very many as a matter of fact, would soon hit on the idea of syphoning water out of the tank of the D. M. O. by a short and very inexpensive pipe. The D. M. O. thus lent itself to a form of interference which was much more difficult to detect than branches of trees in a distributary bed, since the latter usually left traces of some kind behind.

Mr. M. D. Mithal said that at the outset he wished to congratulate the Author on his lucid paper which gave so much food for thought.

For the information of Mr. Sharma and other young engineers, he would mention however that too much weight should not be given to flexibility in the head reach of a channel, where the silt generally deposited. The lesser it was from unity the better it was for the tail reach. He recognised that the D. M. O. was an attempt in that direction by making flexibility equal to half.

He had made a drawing, the night before of a simple barrel outlet using Hume pipes. Comparing it with Case I of the Author, he had kept the working head of this outlet =4·0, so that there was a free fall at all times.

The flexibility of this outlet was :—

$$r_o = {}^3/_{10}\frac{X}{G} = 3/10 \times \frac{5 \cdot 0}{4 \cdot 0} = \cdot 375$$

which was less than 0·5 of the D. M. O.

At a glance it could be seen that the D. M. O. was much more expensive than the outlet free fall. The latter, besides being cheap, had no disadvantage as regards silt exclusion.

In regard to Case II, the pipe should go down from bed level to 3·0 below the W. L. at the exit. The flexibility of this outlet would be :—

$$r_o = {}^3/_{10}\frac{X}{G} = 3/10 \times \frac{2 \cdot 0}{3 \cdot 0} = \cdot 2$$

if the F.S. D.—2.0.

In Case III, $r_o = {}^3/_{10}\frac{X}{G} = 0 \cdot 3$ if F. S. D. = minimum working head.

In all these cases the r_o of the Author's Outlet was presumed to be 0·5 by him and the r_o, of the free fall outlet was less than it. The Author did not mention his F. S. D. of the channel in each case and the speaker was unable therefore to calculate the flexibility. The depth was a factor in the calculations and the Author seemed to have missed it, but y taken by the Author was so small that the flexibility would not materially differ from 0·5.

The speaker continuing said that he could say once for all that if the F. S. D. was less than the minimum working head of the outlet, the flexibility of a free fall outlet, utilising all that working head, would be less than 0·3. When the F. S. D. was more than h_m, the flexibility would be greater than 0.3.

So it could be concluded that the Author's D. M. O. could not stand any compaiison to the barrel free fall.

The flexibility of an A. P. M. could not be less than—

$$3/10 \times \frac{10}{6} = 0{\cdot}5, \text{ for } 6/10 \text{ setting.}$$

$$3/10 \times \frac{10}{8} = 0{\cdot}375, \text{ for } 8/10 \text{ setting.}$$

$$3/10 \times \frac{10}{10} = 0{\cdot}3, \text{ for setting at bed level.}$$

Therefore for outlets with good working heads, the barrel outlet was incomparable. But good working heads were not so common as the Author seemed to imagine. If they were, on any channel, then the design of the channel itself was very expensive and somebody had cocked up the channel for the benefit of a few high spots of land which could, with advantage be left out.

In case of major channels the " commendable " practice of " daff " by zemindars could not be tried and it was only on such channels that there was a possibility of big working heads for outlets. In case of minor channels and especially in their tail reaches, we wanted flexibility to be as near unity as was possible. Too much stress should not be laid on the mal-practices of zemindars, and the outlet D. M. O. would not help the tail in case a cut in the upper reaches was made. The speaker contended that all the conclusions of the Author could be criticised at length, but that he would take only a few. Referring to paragraph 7 of the Paper the speaker said that he had been a Sub-Divisional Officer now for 8 years and had not found Executive Engineers so unreasonable. Moreover, Sub-Divisional Officers were not generally 'poor'. The Author seemed to think that the seasonal variation of silt had been noticed by him alone for the first time in the Irrigation Department and the speaker thought that the Author seemed to have contented himself with scanning Mr. Crump's Paper No. 26 and so had missed section (e) of paragraph

11, page 3, and it was to combat this that the outlet which Mr. Crump advocated was made "adjustable" at a small cost for every crop.

Referring to paragraph 8, the zemindars could head up a channel, by 1·0 only, in the tail reaches and there the minimum working heads were never so high as discussed in Cases I, II and III given in the Paper. If they were, the channel needed lowering in the supply levels. If it was not possible, then the speaker recommended the use of the free fall outlet with advantage. He had not come across "daffs" in latest remodelled channels with F. S. D. greater than 2·0. In the old days, zemindars could put in jungle "daffs" in notched falls but these falls were fast going out and Crump meters were taking their place. Assuming that "daffs" could be put in channels up to 2·0 depths, then for barrel outlets, in Case—

(1) the flexibility would be

$$3/10 \times \frac{2·0}{4.0} = 0·15, \text{ against } 0·5 \text{ of D. M. O.}$$

(2) $3/10 \times \frac{2·0}{3·0} = 0·2,$ ditto.

(3) $3/10 \times \frac{2·0}{2·0} = 0.3,$ ditto.

(4) $3/10 \times \frac{2·0}{1·0} = 0·6,$ ditto.

In Case (4) an A. P. M. at bed level would give

$$r_o\ 3/10 \times \frac{2·0}{2·0} = 0.3,$$

and the Author's outlet would be beaten therefore in every case by one or other of the two devices he had mixed up in the D. M. O. if one or the other of them were used exclusively according to the conditions of each case.

In Paragraph 15, the Author mentioned the good points of the D. M. O., which the speaker criticised as follows :—

referring to section (*a*) in high channel, the barrel would be cheaper than any outlet going ;

referring to section (*b*) the barrel was proved to have lower flexibility than the D. M. O.;

referring to section (*c*) the speaker found the downstream slope as prominent and expensive in the D. M. O. as in any other outlet which was expected to pass water without danger to the public at large, and channels in general ;

referring to section (*d*) it was not for a Sub-Divisional Officer to say that the A. P. M. could not be adjusted in running water,

referring to section (*e*) the barrel outlet and the D. M. O. stood on the same footing on this point.

In regard to defects, the main feature of well-designed channels was the low working head for most of the outlets and the failure of the D. M. O. in this respect was a serious matter.

Mr. N. D. Kapur said that he wanted to say something regarding flexible modules in general, and pointed out that the Author himself admitted that the D. M. Outlet would be of no use with working heads less than one foot and of very little use with a working head of about 2 feet, which meant that this outlet would definitely be of very little utility, and no better than the proportional modules already in use. For instance in the speaker's Sub-Division, at least 60 per cent. outlets had less than one foot working head and there were exceedingly few that had more than 2 feet or even 2 feet working head, and consequently, with such cases in view, its use would be confined only as direct outlets on branches, which however had been banned some time ago. That meant that this D. M. O. would not go much further in the solution of the problem of water distribution.

The speaker said that other flexible modules also had not proved a complete success owing to their flexibility and consequent sensibility to regime changes and that they were liable to be tampered with by zamindars in various ways. As regards the proportional modules, these lost their proportionality as soon as a slight scour took place in the channel bed or a slight deposit of silt occurred, after which they did not give the results expected of them.

One of the main requisites of a good outlet was that it should help to maintain the parent channel in regime, but these flexible or proportional modules invited zemindars to head up supplies in the parent channel, which in turn caused regime changes.

Theoretically, every channel should sooner or later settle into regime which should be more or less permanent, but no channel ever assumed a final regime. In spite of the time and labour taken in evolving flexible modules, their actual utility was easily affected, and notwithstanding a few remodellings and silt clearances, supplies at tails suffered to a great extent.

The speaker instanced a distributary in his charge, was which fitted with A. P. M.'s about a couple of years ago, during which time the distributary head gauge had risen by about 0·6 and the tail gauge stood at 0·87 against the permissible figure of one foot.

He did not believe that flexible outlets were a success; remodelling had become so difficult and problematic on account of the various restrictions placed on the same during recent years, and in view of the fact that zamindars had become so rigid in their demands, he believed that outlets as well as distributary head regulators and branch head regulators and finally, the canal head regulators should all be made rigid.

Gibb's Module was tried in 1909-10 on the Shahkot Distributary of the Mian Ali Branch of the Lower Chenab Canal, and for the time being it succeeded very well as would be seen from the inspection note, dated

9th June, 1911, by the Hon'ble Mr. W. B. Gordon, then Chief Engineer, but he wondered how its use came to be finally discontinued. The chief objection to the use of rigid modules was their inability to absorb fluctuations of supply in the distributaries but he considered that the likelihood of such fluctuations should be eliminated or their possibility minimised to such an extent as to render them negligible, and he was sure that that could be done. He pointed out that the methods of regulation at the heads of distributaries were very primitive and crude and was inclined to believe that evolution of flexible modules was responsible for allowing this state of affairs to continue.

He advocated the use of rigid modules such as Gibb's Module and immediate and drastic improvement in the methods of regulation at canal heads, branch heads and distributary heads and added that excess supplies caused by showers of rain could be absorbed by using a few S. W. outlets in the tail reaches, and that would form a sort of compromise between the use of rigid modules and flexible modules. He held that there should be no necessity at any time of running distributaries with part supply.

The speaker finally remarked that owing to his having received the paper late, he could not collect statistics or figures to show the behaviour of A. P. M. and S. W. outlets, but he was definite that these had not yielded the results expected of them.

MR. H. L. VADEHRA said that he hesitated in calling the outlet a Double Module, and suggested that a more appropriate name in his opinion would have been "Sharma's combination outlet." In plain language, this outlet was an ordinary A. P. M. in which the fluctuations of H, or depression of orifice from water surface level in the distributary had been slightly retarded, by introducing a barrel in front of the A. P. M. This combination did not offer any advantage, as the Author admitted, where they could not afford to waste the working heads of outlets, as in most cases, they could not. Where the command was good, the A. P. M. and C. O. Fs. were found to work quite satisfactorily. He did not think that it was a common practice with zamindars to block the channels with bushes and sarkanda for heading up supplies, except where the command was poor, and where therefore the remedy suggested by the Author for this practice could not be successfully applied. The statement (page 109) that if discharge varied by n per cent., H must vary by 2n per cent. would be true if the variation was small, but if the supply had been headed up by a zamindar, the variation would not be so small and in that case, this relation would not hold good, and the fluctuation in discharge would be somewhat greater than that anticipated by the Author.

Comparing an A. P. M. with this D. M. O., even in the worst case worked out by the Author, *viz.*, Case IV, pages 111 and 112, in which the variation in discharge was proved to be 23 per cent. (although actually it would be 23·8 per cent.), the corresponding variation in the discharge of a similar plain A. P. M. without the front barrel, would be

25·8 per cent. if 'h' be increased from 1·902 to 2·902. The difference in variations of discharges of both the outlets was therefore not more than 8 per cent. which was not very much and not worth the trouble of providing a long barrel in front of the A. P. M. As regards silting, the speaker was doubtful whether it would improve materially the condition of a channel liable to silting.

Mr. C. C. INGLIS drew attention to the Paper presented by Mr. E. S. Lindley in 1922 before the Congress which might be regarded as a classic on the subject. Semi-modules should be somewhat rigid in the upper reaches and proportional near the tail.

Modules, semi-rigid semi-modules and proportional semi-modules all had advantages and disadvantages. These had been set forth clearly by Mr. Lindley and others in the discussion on the paper above mentioned and need not be restated. It was stated in Mr. Sharma's Paper that "Gibb" modules failed because they would not take an excess discharge." This was not correct. There was no difficulty in arranging for them to take an excess discharge. Experiments had been carried out in Poona to ascertain the rigidity, range and other points connected with "Gibb" modules and a Technical Paper on the subject was in preparation. The objections to "Gibb" modules were cost, the smallness of the range of modularity and a certain amount of difficulty in resetting. The first could be partly overcome by constructing them of reinforced concrete, This was being done on the Nira Left Bank Canal in Poona District, where they were being adopted on all channels. The smallness of range—which was less than one foot—might in some cases necessitate resetting until such time as stable regime had established itself in the distributary; but the difficulty of resetting could be reduced by contructing the module taking off from a small downstream cistern.

A double module was no more rigid, theoretically or otherwise, than a single standing wave outlet, working with the same available head. These outlets were in use on the Nira Right Bank Canal *vide* Bombay P. W. D. Paper No. 23 (Inglis on standing wave pipe outlets).

MR. C. A. COLYER remarked that one thing that struck him about this Paper was that it dealt with conditions such as they seldom had the pleasure of dealing with, unless the Author by the expression "one foot working head" meant "one *hissa*". The only place in which the speaker had heard of the existence of 3 or 4 feet of working head quoted by the Author was, in what Sir Thomas Ward had told him was the oldest canal irrigated tract, *viz.*, the "Garden of Eden" and it was important to note that these ideal conditions existed before the disturbances caused by the first *fall*, designed by Eve.

The AUTHOR replying to the discussion, agreed with Mr. Lacey that syphons could very successfully be used to increase the discharge of any type of outlet, but he said that it was no reason why the design of better types of outlets should not be attempted. As regards working heads, the D. M. O. did not require greater working heads than that required by the K. G. O., and if K. G. O.'s were so successfully used on almost all canals in the past, it was reasonable to expect that it would be possible to use the D. M. O. at some places at least. Where sufficient working head was available, a D. M. O. would be preferable to an ordinary pipe on account of its lower flexibility.

Mr. Mithal had not been able to understand how the flexibility had been worked out and had quoted a certain formula. The formula

$$r_{o.} = \frac{3}{10}\frac{X}{G},$$

quoted by Mr. Mithal was taken from Mr. E. S. Crump's Punjab Irrigation Branch Paper No. 26. The Author was not unaware of this formula, and in fact he had calculated the flexibilities from it. He then worked out an example on the black board to show that the flexibility could be very low and not 30 per cent. only as supposed by Mr. Mithal. The new outlet would certainly have a flexibility very much lower than that of the pipe outlet proposed by Mr. Mithal.

Mr. N. D. Kapur had doubted if large working heads were anywhere available. The Author pointed out that very large working heads were available in the head reach of Tandlianwala distributary and in several miles of the Bahlak Branch distributary in the very Sub-division which Mr. Kapur was in charge, *viz.*, the Tandlianwala Sub-division of the Burala Division, Lower Chenab Canal.

Mr. Kapur had also advocated the use of Gibb's module in preference to any other type of outlet. Mr. Inglis in his criticism had already pointed out some objections against the use of Gibb's module. Another and more serious objection was that the rigid outlets could not take any supply over and above their designed discharge, even when needed in emergencies and at the time of slack demand or in heavy rains when tail reaches of distributaries, fitted with such outlets, were in danger of being washed away.

Mr. Vadehra had objected to the name of the outlet. The Author agreed that the correct name of the design should be "Sub-proportional Semi-Module" but for the sake of simplicity it had been called D.M.O. The choice of a name was immaterial and did not affect the utility of the device. Mr. Vadehra had expressed his opinion that heading up was not common except for low working heads. The Author disagreed with this view. Mr. Vadehra had doubted the correctness of the formulæ deduced in the paper and the Author said that if Mr. Vadehra would be so kind as to send him his calculations he felt sure he would be able to convince him of the accuracy of the formulæ. As for the doubt expressed by Mr. Vadehra regarding silt trouble, the Author said that by raising or lowering the pipe, silt trouble could be effectively met with in almost all cases.

Replying to Mr. Inglis, the Author mentioned that he had studied Mr. Lindley's Paper. Mr. Inglis had suggested the use of pipe outlets, where large working heads were available, but the Author considered that pipe outlets were incapable of securing as low a flexibility as the D.M.O. could give.

Replying to Mr. Colyer, the Author referred him to certain channels on the Lower Chenab Canal and said that large working heads might be somewhat rare but nevertheless, they did occur, and in such cases the D. M. O. would be extremely useful. He had never thought of using the new type of outlet as a "cure-all" and it was designed to be used only in places where large working heads were available.