Specialty Conference

Various gates and turnout structures are available and are being used to make the irrigation mechanics easy. Furrows, as well as close-growing crops, can be easily irrigated on level basins if secondary ditches are used to divert water into the furrows. The secondary ditch, when properly configured, can be used both to convey the water to and distribute it within a basin. The combination conveyance-distribution channel produces a means of draining some water off the basin, which can result in small net applications per irrigation as well as removal of excess water caused by overirrigation or rainfall.

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IMPROVEMENT OF IRRIGATION OUTLETS [1]

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ABSTRACT: In most irrigated areas of the World, irrigation outlets (turnouts) have received little systematic design study. Rather, outlet structures have developed haphazardly and usually do not give satisfactory delivery of water, control of channel erosion or provide water measurement with the same structure. In the USA, the common turnout is a pipe through the channel bank with the flow controlled by an upstream pipe gate.

This paper reports on the past use of irrigation turnouts in Egypt and the development of an improved design utilizing pipe with an upturned downstream elbow. A flow analysis is made utilizing both laboratory and field tests.

INTRODUCTION

Irrigation outlets (turnouts) as defined here are structures or openings for delivering irrigation water from a canal or irrigation ditch to another canal or directly to the farm. These outlets have many forms such as open bank cuts, open flumes, adjustable weirs and orifices, constructed headwalls with controlled openings and closed conduits such as pipe and orifices (5). The pipe conduits have many variations and are usually equipped with either upstream or downstream slide gates and with structures to control bank and/or bed erosion. On most irrigation systems there is a need to control and adjust the flow through individual turnouts and also to measure the flow. Except in highly developed areas, it is unusual to actually measure the flow, only to estimate it. However, as development progresses and as more efficient irrigation practices are stressed, there is a need for more positive control and measurement. Therefore, structures are needed where both control and measurement functions are incorporated in the same structure. Very few designs exist that combine both of these functions. Usually two structures are used, one for control and one for measurement and this is expensive to construct and difficult to operate and maintain.

Egypt has a long history and experience with irrigated agriculture. During the 20th century, two types of outlet structures have been used, the Fayoum

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[1] Based on studies made under a U. S. AID Contract with Colorado State University, Ft. Collins, Colorado through the Consortium for International Development and the Ministry of Irrigation, Cairo, Egypt. All opinions, conclusions & recommendations are of the authors and not of the U. S. or Egyptian Governments.

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weir and Dupuit pipe outlet. The Fayoum weir has a free overfall with fixed crest elevation and width and is used where there is sufficient elevation change. Its use is limited to the Fayoum area of Egypt.

Most of the irrigation outlets in Egypt are the pipe type, called Dupuit outlets. They consist of straight, metal pipe installed as in Figure 1 without valve or gate control (3). Several pipe diameters were calibrated and calibration tables were developed based on a constant upstream depth over the top of the pipe of 25 cm (10 in) with the downstream end submerged. Using these calibrations, modified by later studies, a design table was developed for pipe diameters (10-60 cm) and lengths (5-50 m) to serve a size of irrigated areas (6-817 feddans)[3]. The design assumed a water duty of 50 cubic meters per feddan per day [11.9 mm (0.46 in) per day] to determine the required discharge and pipe size.

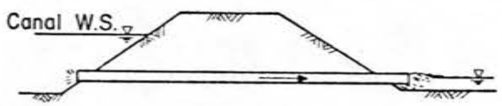

Figure 1 Present Field Outlets

There are several disadvantages and problems with the Dupuit pipes as now used: (a) There are ususally no valves or gates for regulating the flow on individual turnouts. (b) Upstream depths differ from the calibrated depth of 25 cm (10 in) thereby changing the flow. (c) Downstream water levels can be lowered by manually cleaning and lowering the ditch, thereby allowing a free discharge at the pipe end and increasing the flow. (d) Erosion occurs in the downstream channel from high velocity flow. (e) Because of the variable conditions the discharge cannot be accurately measured or estimated with the existing pipe outlets.

A study was made of irrigation outlets used throughout the World's irrigated areas to obtain ideas for improvement (3). Based on this study, a design evolved to improve the pipe-type outlets so that flows could be regulated and measured. Of particular interest were flows in the range of 10-100 ℓ/s (0.35-3.5 cfs) and upstream (canal) flow depth of 15-50 cm (6-20 in).

DESIGN

An improved turnout fabricated from steel pipe shown in Figure 2 was field tested at the Mansuriya site near Cairo. Additional tests under controlled conditions were conducted at the Hydraulics Laboratory, Colorado State University (4). At the upstream end, there is a small masonry or concrete wall to stabilize the structure. Generally, the inlet will be placed into the bank in order to minimize obstructions for mechanized ditch cleaning. In some case it

[3] 1 feddan = 0.42 ha = 1.04 ac

may be desired to have a canal gate on the upstream end and this should be set into the bank or installed in a sloping position with the bank in order to minimize the obstruction.

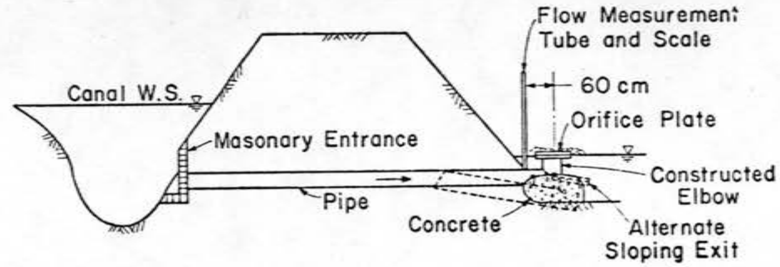

Figure 2 Proposed Design of Field Outlets

The downstream end has a mitered elbow with the flow discharging upward. There is a flange on the discharge end where orifice plates with opening diameters smaller than the pipe may be attached. With this design, the downstream water depth may vary over a wide range without changing the discharge until the outlet becomes submerged to some depth. For some situations it was projected that the orifice plates would not be used and the ability to measure the flow without them needed to be determined.

For flow measurement, a single manometer, located at a distance upstream from the vertical outlet, is used to determine the piezometric head. For the field and laboratory tests, the distance upstream was fixed at 60 cm (24 in) from the center of the vertical pipe opening. This location was determined after laboratory tests using several locations along the pipe. The depth of water in the tube is a function of the discharge and the tube can be marked in flow units for a direct measure of discharge. The reference base elevation is the elevation of the top of the orifice plate or the top of the flange when using the system without the orifice plate. The sloping pipe makes the system more flexible so that the discharge end may be lowered to: (1) obtain a greater working head for more discharge, (2) release the flow at a level near the field or ditch elevation, and (3) reduce erosion in releasing the flow in a ponded situation.

Field tests were made at Mansuriya, Egypt using two different sloping conditions of a 30 cm (12 in) pipe outlet. The slopes of the downstream section were 3°04' and 5°36'. Water was pumped from the Beni Magdoul Canal into the headbox of a lateral ditch and measured through a standard rectangular weir. Different series of tests were made with a 26.1 cm (10.25 in) orifice plate and with the 30 cm (12 in) pipe discharging without plate. The plastic tube was used to determine the piezometric head 60 cm (24 in) upstream by using a staff gage. For an actual field installation, the slope of the pipe would be greater than shown in Figure 2 so that the flow is discharged nearer to the field level and turbulence is reduced.

Laboratory tests conducted in the Hydraulics Laboratory, Engineering Research Center, Colorado State University, utilized the equipment shown in Figure 3 (4). Initially the tests were conducted with a 20.32 cm (8 in) diameter horizontal pipe and three different outlet conditions: 15.24 cm (6 in) diameter orifice, 17.78 cm (7 in) diameter orifice, and 20.32 cm (8 in) diameter pipe without an orifice plate. Piezometric heads were determined at the six locations shown in Figure 3.

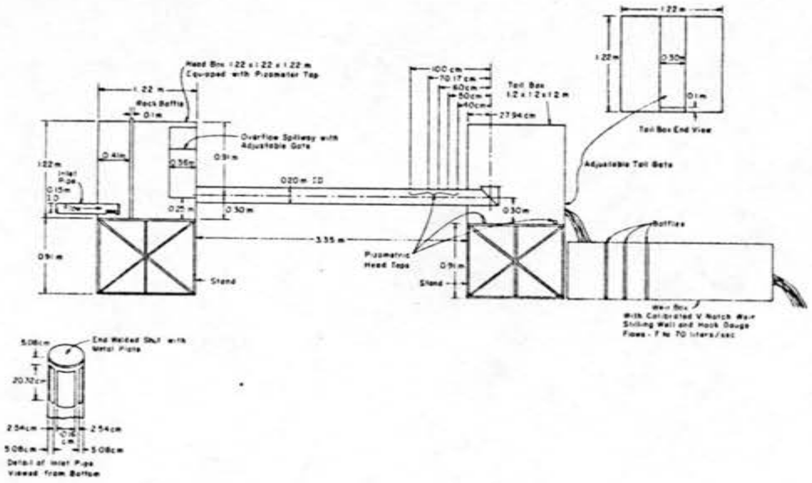

Figure 3 Test Model for Improved Turnout

The depth of water at the inlet and at the outlet were measured also. Flow was determined using a weir box with a 120° V-notch weir. Tests were performed with the downstream water level below the elevation of the orifice plate (nonsubmerged) and above this elevation (submerged). Flow through the entire system was controlled by varying the depth of water in the head box and thereby the head on the pipe outlet.

Tests were also made with the lower 3 m (10 ft) length of pipe sloped at 10°. The same conditions and tests as for the horizontal pipe case were imposed.

ANALYSIS

For this analysis the system shown in Figure 4 is assumed. Note that the piezometric head is measured at a distance L and referenced to the top of the orifice plate for the horizontal pipe case. The datum for the sloping pipe case is the point of intersection of the plane through the upper surface of the orifice plate and the center line of orifice plate.

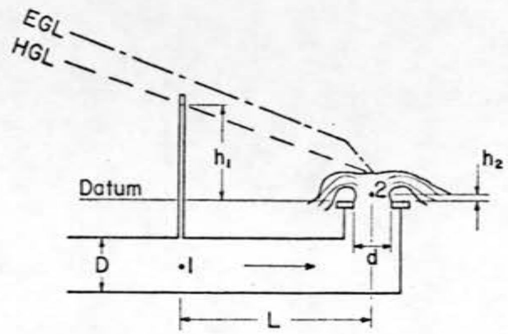

Figure 4 Flow in Nonsumberged Improved Turnout

The energy relationships from point 1 to 2 in Figure 4 for the nonsubmerged case is:

$$h_1 + \frac{V_1^2}{2g} - f\frac{L}{D}\frac{V_1^2}{2g} - K_b\frac{V_1^2}{2g} - \frac{1}{C^2}\frac{V_2^2}{2g} = h_2 + \frac{V_2^2}{2g} \qquad (1)$$

where V_1 = velocity in pipe
V_2 = velocity at point 2
f = Darcy-Weisbach friction factor
K_b = elbow loss coefficient
C = orifice discharge coefficient

with other variables defined in Figure 4. The term $(1/C^2)(V_2^2/2g)$ represents the head loss for the orifice.

For the nonsubmerged flow case assume that $h_1 = 0$. The contraction of the jet for the flow range of interest is small and can be neglected, therefore

$$Q = \frac{\pi}{4}D^2 V_1 = \frac{\pi}{4} d^2 V_2 \quad \text{and} \quad V_2 = \left(\frac{D}{d}\right)^2 V_1$$

Making the above substitutions and solving for the discharge results in:

$$Q = \frac{\pi}{4}D^2\left[\frac{2gh_1}{\left(\frac{D}{d}\right)^4 + \frac{fL}{D} + K_b + \frac{1}{C^2}\left(\frac{D}{d}\right)^4 - 1}\right]^{1/2} \qquad (2)$$

The relationship in Eq. (2) is for the case where the discharge is not affected by the depth of water downstream, i.e. submergence of the outlet. The system was initially designed so that there could be a large range of tailwater depths with no effect until reaching some depth above the vertical discharge of the outlet. The submerged system will not be analyzed in this paper.

For these studies utilizing steel pipe and flow Reynolds numbers ranging from 4.3×10^4 to 2.4×10^5, a constant friction factor f of 0.020 was used (2). There is limited data available for the case of a freely flowing orifice discharging vertically upward. Because the water rises, falls back and impacts on the jet discharging from the orifice for the nonsubmerged case, the turbulence and flow patterns are expected to affect the discharge coefficient C. Limited data indicate that the coefficient C remains almost constant near 0.60 for submerged orifices discharging horizontally (2). Considering the limited information available, a constant value of 0.60 was used for the discharge coefficient.

The hydraulic head losses through elbows (and orifices) are primarily functions of the geometry of the systems. This system is unique because of a very short downstream length from the mitered elbow and the nearness of the orifice plate and outlet. An examination of the literature reveals little information for losses through a mitered elbow. Values of K_b range from about 1.0 to 1.25 for miter bonds in pipe systems and a value of 1.25 was chosen for this study (1).

The emphasis of this study was to provide an improved turnout and water measuring device in one structure. An accuracy of ± 5% was considered to be satisfactory for flow measurement over the required flow range. For regulation the discharge could be changed or set by selection of orifice plate size, pipe size, elevation of outlet or possibly by gate control. The ultimate aim for the structure was better distribution and utilization of irrigation water.

EVALUATION

The relationships of discharge as a function of piezometric head (h_1) at the point 60 cm (24 in) upstream from the outlet as determined from the two experimental setups are given in Figure 5. The data represent observations made after setting a discharge and allowing approximately one-half hour to elapse for stabilization of flow. The piezometer depths were observed over a period of time and an average depth determined. Particularly at the lower discharges there were sizable fluctuations and also air bubbles so that the average reading using the piezometer was difficult to determine.

The laboratory and field experimental data shown in Figure 5 indicate essentially the same relationship for the horizontal and sloping pipe cases for a given pipe-outlet combination since the functions are continuous. Any differences due to slope might be attributed to conditions of ponding and jet impingement at the outlet depending on the sloped orifice or flange plate. The data indicate that reasonably accurate stable calibrations and flow measurements are possible even under field conditions.

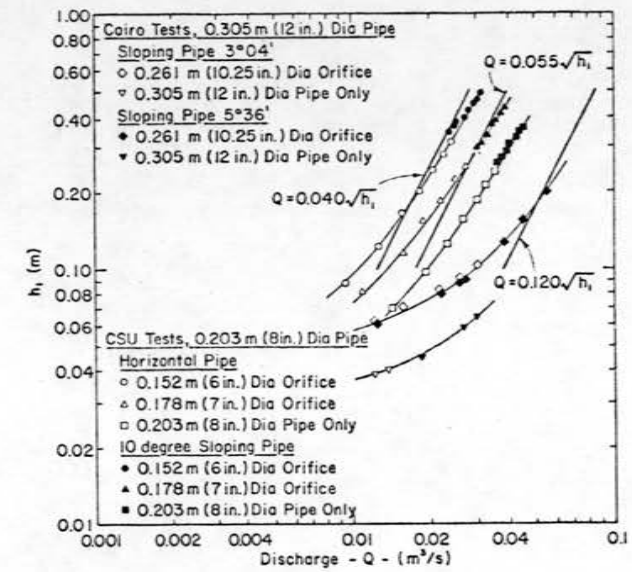

Figure 5 Relationship of Piezometric Head and Discharge for Improved Turnouts

The head-discharge relationship given by Eq. (2) results in Eq. (3) when using constant values of f = 0.020, K_b = 1.25 and C = 0.60.

$$Q = J \sqrt{h_1} \qquad (3)$$

Values of J for the different pipe and orifice combinations are tablulated as follows:

Pipe Diameter	Orifice Diameter	J
0.203 m (8 in)	0.152 m (6 in)	0.040
0.203 m (8 in)	0.178 m (7 in)	0.055
0.305 m (12 in)	0.261 m (10.25 in)	0.120

The discharge relationship using Eq. (3) are shown on Figure 5 and can be compared with the observed data. Within the range of piezometric head of 0.15 to 0.50 m, the difference in discharge is about ± 11% between the computed and the calibration data for the 0.203 m (8 in) turnout with orifice plates. This difference is somewhat greater than the desired accuracy of ± 5 % but is still acceptable for most irrigation uses. For both sizes of turnouts it is obvious from a comparison of the data on Figure 5 that calibrations are needed for each combination of pipe and orifice size until more accurate values of the constants used in Eq. (3) are known.

CONCLUSIONS

The improved irrigation pipe outlet has some features that are desireable and some that require further study and development. Among the desireable attributes are:

(1) The turnout can easily be constructed and installed with locally available materials and labor.
(2) For flow range adjustment, different sizes of pipe and orifices can be used.
(3) The pipe or a portion of it can be sloped so that additional head and flow are available and also the flow can be discharged at a desired level to reduce turbulence and/or erosion.
(4) With the piezometric head measured simply as in this study, a stable rating was determined for flow measurement for both horizontal and sloping pipe, with and without orifice plates. The location for the piezometric reading which was chosen near the downstream end, primarily for convenience and to have the tube away from the canal bank, was satisfactory.
(5) Downstream submergence of the system which offects the discharge will rarely occur with the mitered elbow design.
(6) Flow control and measurement can be accomplished with the same structure.
(7) Ditch erosion can be controlled.

Among the features that are undesireable may be:

(1) Until the hydraulics of the system have been given more extensive study, it will be necessary to initially calibrate each different pipe and orifice size combination for accurate flow measurement. Discharge measurements within an accuracy of ± 11 % are possible using standard coefficients in discharge equations.
(2) There may be entrained air in the flow.
(3) There is a possibility that sediment and debris may collect in the pipe system and reduce the flow.
(4) More expense and construction are required than with a simple Dupuit pipe system.

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