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Design of an on-farm irrigation gate for lined lateral canals

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ABSTRACT

Lining of irrigation lateral canals (marwas) is one of the considerable methods in irrigation water conservation. It could save up to 80 % of the lost water through seepage. Outlet metal gates are installed on the marwa conveyance and distribution system. The simple design of the irrigation gates caused many defects like leakage, rapid corrosion of rubber seal, difficult sliding, and rapid depreciation. The objective of this work is to design a developed irrigation gate to come over the defects of the under use irrigation gates and can be calibrated to estimate water discharge through it. The criteria that were taken into consideration in designing the developed irrigation gate were: the suitable discharge capacity, leakage prevention, ease of operation and maintenance, manufacturing in rural workshops, and calibrated for flow rate. On-field tests were carried out to estimate discharge of the developed irrigation gate as a function of water head over gate crest. The most essential parameter in calculating the gate discharge was the coefficient of discharge C_d that determined as a ratio between the actual and theoretical discharge. The discharge values Q_g that calculated values of C_d = 2.339 gave a good agreement with the actual discharge measured values of Q_{act}.

***Keywords*:** lateral canals (marwas), irrigation water, conservation, leakage, rapid corrosion.

Introduction

The growing population of Egypt and the related demand of food have increased in the recent years pressure on the limited available water resources. The Ministry of Agricultural and Land Reclamation (MALR) has interested the rationalization of irrigation water through the implementation of on-farm irrigation development projects by modernization of traditional earthen irrigation canals (marwas) using buried pipes and elevated lined marwas. Possible benefits of lining a canal include water conservation that it can save up to 80 % of the lost water by seepage which in turn reduces pumping costs, no seepage of water into adjacent land or roads what could damages to grow crops, reduced canal dimensions, and reduced maintenance that the bed and sides of lined canals are stable and less susceptible to damage or erosion (Bosch *et al.,* 1993). The typical elements of implemented elevated lined marwas are diesel pumping unit with a discharge of 20 l/sec or 40 l/sec installed permanently at the intake, conveyance and distribution system constructed of a concrete floor and side walls are then built with bricks and the whole construction internally covered with cement, distribution control structures which are division boxes provided with metal gates that divide the flow of water into sections of the canal, and metal irrigation gates as water outlets (FAO, 2019). The simple design of the irrigation gates caused many defects like leakage, rapid corrosion of rubber seal, difficult sliding, and rapid depreciation. It is also, non-calibrated for water discharge through its opening.

A gate consists basically of three elements: leaf, embedded parts and operating device. The leaf is a movable element that serves as bulkhead to the water passage and consists of skin plate and girders. The embedded parts are the components embedded onto the concrete, which serve to guide and house the leaf, to redistribute to the concrete the forces acting on the gate, acting also as a protection to the concrete edges and support element for the seal. The operating device is the means directly responsible for the opening and closure of the gate (Erbisti, 2014).

The weir is a notch of regular form through which water flows (French, 1987). Trapezoidal weirs are used more, due to their shape and simplicity to design and implementation in open irrigation and

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circular sewage channels (Arvanaghi and Azimi, 2016). The advantage of trapezoidal weir is that it can be fixed both to the plumb and also to level as it has crest similar to rectangular weir. Further, the discharging capacity will increase with the increase in head similar to a V-notch weir. These two features are important as the weir is to be fixed symmetrical to axis else the computed values will be erroneous (Prakash *et al.,* 2018).

The essential parameter of each weir is to determine the flow coefficient. Coefficient of discharge is defined as the ratio of actual discharge to the theoretical discharge delivered by the structure. This coefficient of discharge is related to others parameters all well especially the head of water over the crest. In case of trapezoidal notch when the head is decreased the C_d is increased but after some level it get decreased (Kumar *et al.,* 2017). The Coefficient of discharge C_d is not constant and it is not recommended to use a unique C_d for different flow conditions (Naderi *et al.,* 2014).

The objective of this work is to design a developed irrigation gate to come over the defects of the under use irrigation gates and can be calibrated to estimate water discharge through it.

Materials and Methods

Design criteria

Many aspects were taken into consideration in designing the developed irrigation gate as follows:

- The suitable discharge capacity of irrigation water.
- Leakage prevention.
- Ease of operation and maintenance.
- Can be manufactured in rural workshops.
- Calibrated for flow rate as a function of water head over gate crest.

Gate components

A gate consists basically of three elements as shown in Figs. (1) and (2): leaf, embedded parts and operating device. The leaf is a movable element that serves as bulkhead to the water passage and consists of skin plate and girders. The shield plate directly responsible for the water dam is called the skin plate. It is made of 4 mm thickness sheet metal with trapezoidal shape to meet the fixed weir of the gate and two side guides to adjust the skin plate up and down movement. A girder made of two steel angles of 25 x 25 mm with 3 mm thickness and fixed at the upper edge of the skin plat to hang it to the lifting screw axle.

The embedded parts are the components embedded on to the brick walls, which serve to guide and house the leaf. The embedded parts consist of two frames of 40 x 40 mm steel angles of 3 mm thickness with dimensions of 400 x 750 mm. The weir of the gate is assembled between the two frames. The weir plate is made of 4 mm thickness sheet metal with trapezoidal notch. The notch has ends with a slope of 1: 4 horizontal to vertical. Generally, this slope was chosen to provide sufficient additional discharge to compensate for the end contractions The seal, the component responsible for the water tightness, consists of a rubber U channel strip screwed to the weir notch with two metal strips from the both outer and inner sides.

The operating device is responsible for the opening closing of the gate. It consists of a screw axle, lifting sleeve, cross bridge, and hand wheel. The screw axle allows the full opening of gate leaf, its length is 450 mm with 23 mm diameter. The lifting sleeve is machined for several purposes: to allow axial movement of the screwed axle, to fasten the hand wheel, and to be assembled with the cross bridge. Its total length is 120 mm with an outer diameter of 55 mm. An aluminum hand wheel with 200 mm diameter is used for rotating the lifting sleeve.

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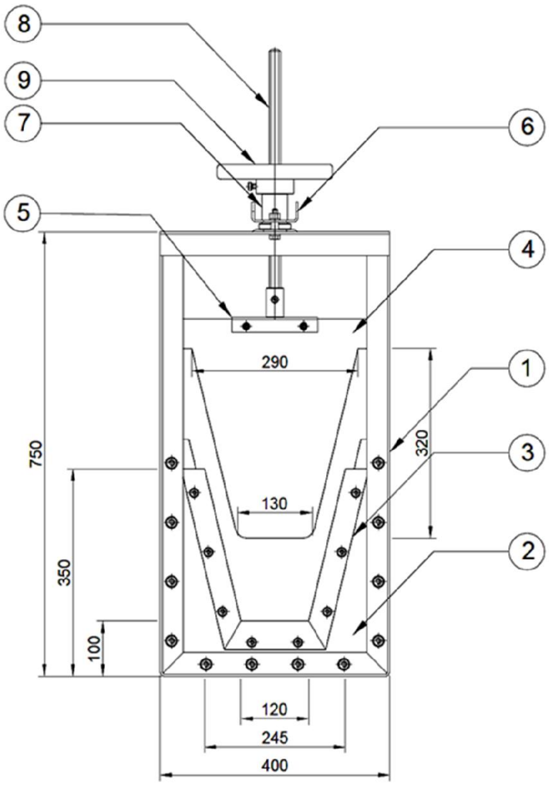

1.	Main frame	4.	Leaf skin plate	7.	Lifting sleeve
2.	Weir plat	5.	Operating device coupling	8.	Screw axle
3.	Metal strips	6.	Cross bridge	9.	Hand wheel

Fig. 1: The main assembly of the developed irrigation gate components.

Fig. 2: The developed irrigation gate installed on elevated lined marwa.

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On-field tests

The irrigation gate was installed on an elevated lined marwa named El Tellawe at Farasha village, Markaz Abu Kabir, Al Sharqia Governorate. The system components of the elevated lined marwa are diesel pumping unit installed permanently at the intake, conveyance and distribution system constructed of a concrete floor and side walls are built with bricks and the whole construction internally covered with a cement layer of 2.5 cm, distribution control structures which are dividing metal gates that divide the flow of water into sections of the canal, and metal irrigation gates as water outlets. The lined marwa cross section as shown in Fig. (3) is 0.4 m × 0.6 m with a total length 671 m and 0.0002 m/m slop. The average water height upstream over the developed gate was 0.29 m. Manning formula was applied to determine the average discharge as expressed in equation (1).

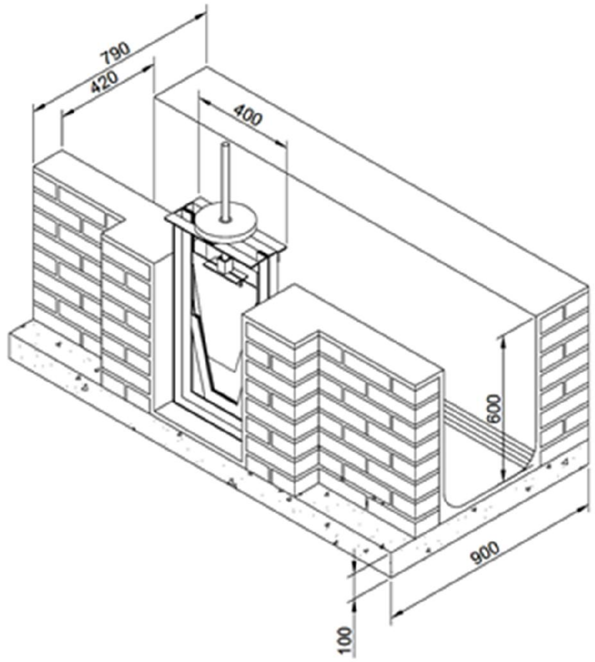

Fig. 3: Dimensions of the lined marwa cross section

$$Q = \frac{1}{n}\left[\frac{A^{5/3}}{P_w^{2/3}}\right](S_f)^{1/2} \qquad (1)$$

where:

Q	= Water discharge through the open canal	(m^3/s)
A	= Cross-sectional area of the open canal = 0.11707	(m^2)
P_w	= The wetted perimeter of the flow = 0.89416	(m)
S_f	= The slope of the energy gradient = 0.0002	(m/m)
n	= Manning's roughness factor = 0.015	For cement surface

$$Q = \frac{1}{0.015}\left[\frac{0.111707^{5/3}}{0.89416^{2/3}}\right](0.0002)^{1/2}$$

$Q = 0.02635\ m^3/s \approx 95\ m^3/hr$

Test procedure:

An on-field test was carried out to determine the actual water discharge of the developed irrigation gate using a V-notch weir with the dimensions shown in Fig. (4). Water flow measuring procedure was as follows:

- The V-notch weir was placed at a suitable distance (about 3 m from the gate) on the main irrigation canal of the field.
- The pump was operated until the steadiness of water surface height in the marwa.
- The gate was fully opened to accept water flow through it until the steadiness of water head over crest of both the gate and the V-notch weir.
- The water flow through the gate was changed by partially open of the water gate that lies before the tested gate.
- The previous step was performed in several times and the water head over crest of both the gate and the V-notch weir was measured using a measuring tab at every time.

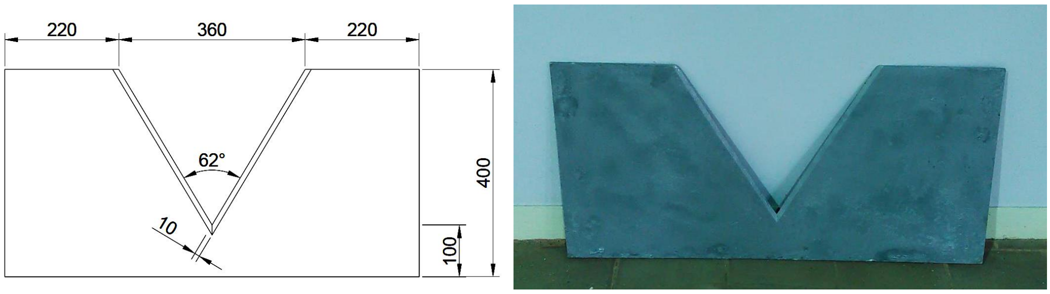

Fig. 4: Dimensions of V-notch weir.

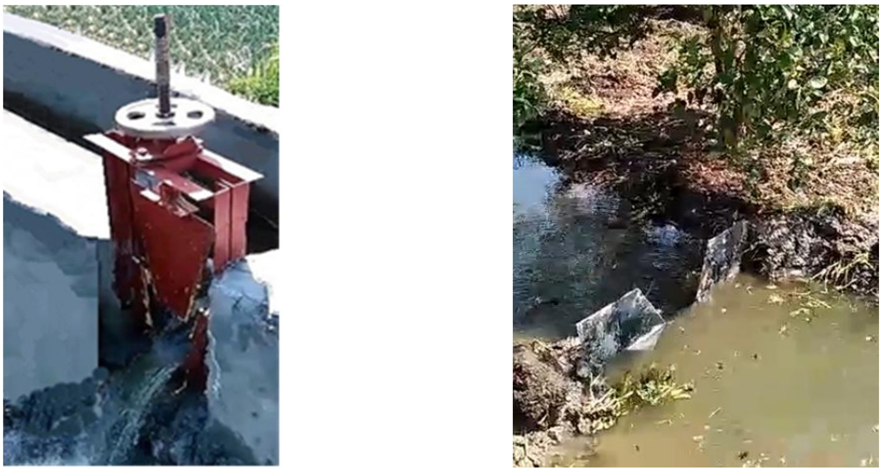

Fig. 5: The operation of the developed irrigation gate and V-notch weir during on-field test.

Theoretical flow equations for the trapezoidal weir:

A weir is a notch on a large scale, used to measure the flow of a river, and may be sharp edged or has a substantial breadth in the direction of flow. Taking the datum for potential energy at the centre of the weir and applying Bernoulli's equation (2), the flow velocity can be expressed as:

$$v = \sqrt{(2gh)} \qquad (2)$$

Where:

v	= Water velocity	(m/s)
h	= Head over the weir	(m)
g	= Gravitational acceleration	(m/s^2)

Theoretically, if A is the cross sectional area of the weir, the discharge well be:

Q_{th} = Area × Velocity

$$Q_{th} = A\sqrt{(2gh_1)} \tag{3}$$

Where:

Q_{th}	= Theoretical discharge	(m^3/s)

In practice, the actual discharge is considerably less than the theoretical discharge given by which must, therefore, be modified by introducing a coefficient of discharge C_d, so that the actual discharge is:

$$Q_{act} = C_d A\sqrt{(2gh)} \tag{4}$$

If the weir has a horizontal crest of length L the cross sectional area of the weir is:

$$A = h_1 L \tag{5}$$

Then, the general form of the equation used for horizontal crested weirs is:

$$Q_{act} = C_d L h^{\frac{3}{2}} \tag{6}$$

$$C_d = \frac{Q_{act}}{Q_{th}} \tag{7}$$

$$C_d = \frac{Q_{act}}{L h^{\frac{3}{2}}} \tag{8}$$

Where:

Q_{act}	= Actual discharge	(m^3/s)

The standard equation of trapezoidal weir is (USBR, 2001):

$$Q = 1.858 L h^{\frac{3}{2}} \tag{9}$$

V-Notch weir equation of any angle

The Kindsvater-Shen relationship can be used for fully contracted notches of any angle between 25 degrees and 100 degrees. The equation which includes the angle θ as a variable is written according to (USBR, 2001) as:

$$Q = 0.121 C_d \tan\left(\frac{\theta}{2}\right) h_{le}^{\frac{5}{2}} \tag{10}$$

Where:

Q	= Water discharge over weir	(m^3/s)
C_d	= Effective discharge coefficient	
h_1	= Head on the weir	(m)

h_{1e} = $h_l + k_h$
θ = Angle of V-notch

Fig. (6) shows the head correction factor, k_h, and C_d is a function of θ.

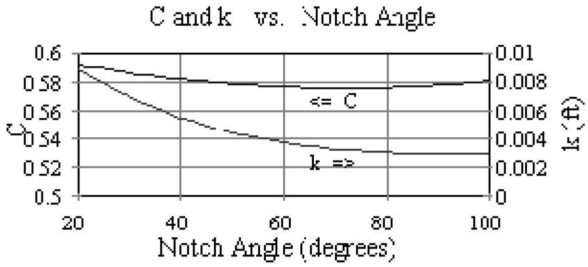

Fig. 6 : The head correction factor, k_h, and C_d is a function of θ.

The following equations give a best fit for C_d and k curves (LMNO, 2015):

$$C_d = 0.607165052 - 0.000874466963\ \theta + 6.10393334\text{x}10 - 6\ \theta^2 \quad (11)$$

$$k_h = 0.305 \times (0.0144902648 - 0.00033955535\ \theta + 3.29819003\text{x}10\text{-}6\ \theta^2 - 1.06215442\text{x}10\text{-}8\ \theta^3) \quad (12)$$

Results and Discussion

Water Gate Application

The innovative design of the developed irrigation gate accomplished many advantages at the on-field operation. The on-field observations of the new developed irrigation gate insured a complete leakage prevention because of the rubber seal screwed to the trapezoidal notch of the gate and the operating device which worked together for water tightness. The trapezoidal design of both the leaf and the down apposite notch had no direct friction during operation and closure of the leaf which in turn lessen the rapid corrosion of the rubber seal. The operating device, the side guides and frame track elevated over the water surface facilitated leaf operation and cause no leaf move restriction inside the gate frame track. The gate components are all screw bolted together that make it easy to perform maintenance and replace the depreciated parts. The irrigation gate flow rate was calibrated to determine discharge according to the water head over the gate crest.

Irrigation gate coefficient of discharge:

Coefficient of discharge C_d is defined as the ratio of actual discharge to the theoretical discharge delivered by the notch. The actual discharge Q_{act} was determined applying equation (10) for the head of water h_l over the V-notch weir, where the theoretical discharge Q_{th} was calculated applying equation (3) and substituting the values of flow cross section area A form equation (5) as shown in Table (1). The results indicated that C_d as shown in Fig (7) was not constant for different values of h_l and its values were increased by the decrease of h_l within $0.25 \geq h_l \geq 0.17$ which agree with (Kumar *et al.,* 2017, and Naderi *et al.,* 2014). The values within $0.16 \geq h_l \geq 0.125$ were abnormal and it could be put down to the experimental errors. It can be also noted that, the values of C_d was somehow constant within $0.25 \geq h_l \geq 0.21$ by an average value of 2.339.

Table 1: The water head over of both gate and weir crest and corresponding values of actual discharge measured using V-notch weir, theoretical discharge, coefficient of discharge, and the calculated discharge.

h_g (m)	h_l (m)	Q_{act} (m^3/s)	$Q_{th} = L\,h_l^{3/2}$ (m^3/s)	$C_d = \frac{Q_{act}}{Lh_l^{3/2}}$	$Q_{trp} = 1.858Lh_l^{\frac{3}{2}}$ (m^3/s)	$Q_g = 2.339Lh_l^{\frac{3}{2}}$ (m3/s)
0.205	0.25	0.02585	0.01067	2.42222	0.01983	0.02497
0.195	0.24	0.02336	0.00990	2.35867	0.01840	0.02316
0.17	0.22	0.01881	0.00806	2.33358	0.01498	0.01885
0.165	0.215	0.01776	0.00771	2.30480	0.01432	0.01803
0.16	0.21	0.01675	0.00736	2.27647	0.01367	0.01722
0.16	0.205	0.01578	0.00736	2.14406	0.01367	0.01722
0.15	0.195	0.01394	0.00668	2.08582	0.01241	0.01563
0.13	0.185	0.01223	0.00539	2.26813	0.01002	0.01261
0.115	0.18	0.01142	0.00448	2.54662	0.00833	0.01049
0.105	0.17	0.00991	0.00391	2.53253	0.00727	0.00981
0.105	0.16	0.00852	0.00391	2.17854	0.00727	0.00915
0.1	0.155	0.00788	0.00364	2.16629	0.00676	0.00851
0.085	0.135	0.00559	0.00285	1.96208	0.00530	0.00667
0.08	0.125	0.00462	0.00260	1.77562	0.00483	0.00609

Where:
h_g is water head over gate crest (m), **h_l** water head over V-notch weir crest, **Q_{act}** water discharge measured using V-notch weir (m^3/s), **Q_{th}** theoretical discharge (m^3/s), **C_d** coefficient of discharge, and **Q_{trp}** gate discharge calculated for (**C_d**=1.858), and **Q_g** gate discharge calculated for (**C_d**=2.339).

The standard equation of trapezoidal weir (9) was applied using h_l values to calculate the discharge Q_{trp} of $C_d = 1.858$ and compared with the calculated Q_g of $C_d = 2.339$ and the resulting values were presented in Table (1) and Fig. (8). The Analysis of Variance was performed to compare among Q_{act}, Q_{trp}, and Q_g at $p < .01$. The results as shown in Table (2) indicated that, the *f*-ratio value was 1.07314 and the *p*-value was 0.351816 and the result is *not* significant at $p < .01$ among Q_{act}, Q_{trp}, and Q_g. By observing the plotted values of the three groups of discharge, it can be noted that there is a good agreement between the calculated values of Q_g with $C_d = 2.339$ and the actual measured values of discharge Q_{act}.

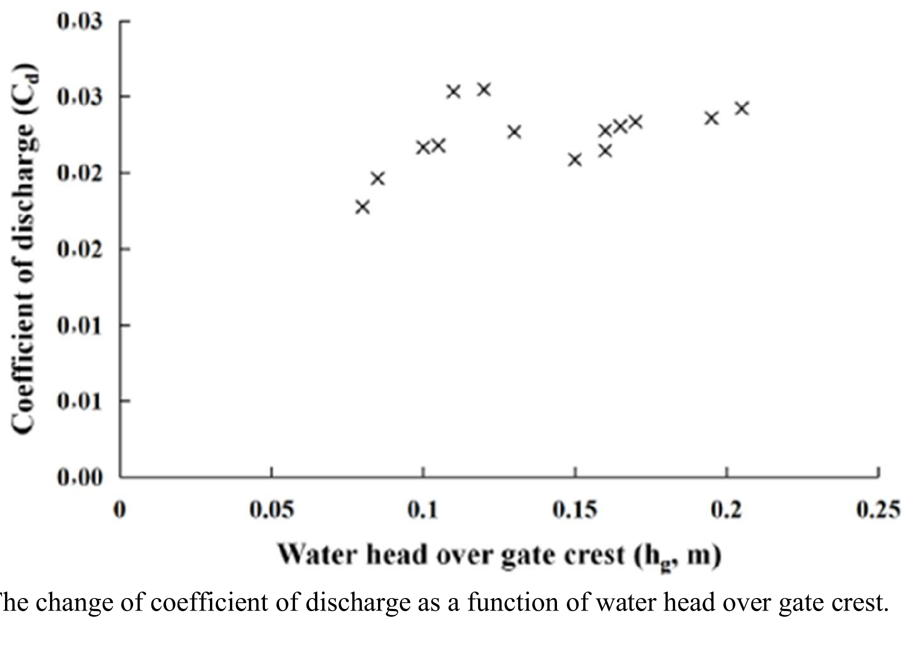

Fig. 7: The change of coefficient of discharge as a function of water head over gate crest.

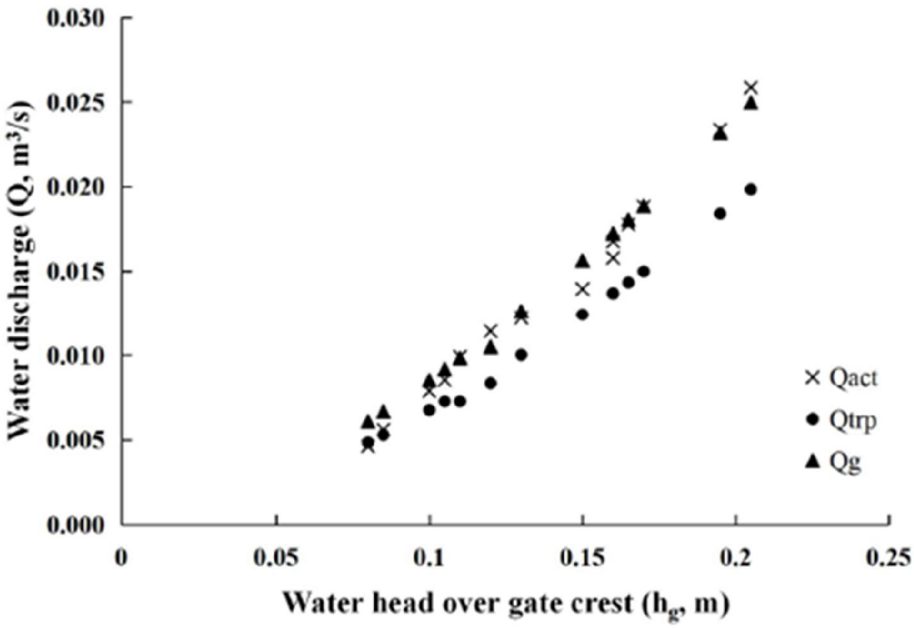

Fig. 8: The relationship among the actual and calculated discharge and water head over gate crest.

Table 2: The means and standard deviation of Q_{act}, Q_{trp}, and Q_g

	Q_{act}	Qtrp	Qg	Total
N	14	14	14	42
∑ X	0.1924	0.1571	0.1984	0.5479
Mean	0.0137	0.0112	0.0142	0.013
∑ X2	0.0032	0.0021	0.0033	0.0085
Std.Dev.	0.0064	0.0048	0.006	0.0058

Table 3: Analysis of variance for the actual measured and the calculated discharge of the irrigation gate.

Source	*SS*	*df*	MS	
Between-treatments	0.0001	2	0	F = 1.07314
Within-treatments	0.0013	39	0	
Total	0.0014	41		

The change in C_d value of Q_g than its value of Q_{trp} because C_d is not constant and it is not recommended to use a unique C_d for different flow conditions (Naderi *et al.,* 2014). It can putted down to that, not only does the flow pattern of one weir differ from that of another, but the flow pattern for a given weir varies with the discharge. Furthermore, the number of variables involved is so great as to defy a rigorous analytical approach (French, 1987).

Conclusion

An innovative design of a developed irrigation gate was established to come over the disadvantages of the under use irrigation gates installed on lined marwas. The criteria that were taken into consideration in designing the developed irrigation gate were: the suitable discharge capacity, leakage prevention, ease of operation and maintenance, manufacturing in rural workshops, and calibrated for flow rate. The irrigation gate was installed on an elevated lined marwa at Farasha village, Markaz Abu Kabir, Al Sharqia Governorate. On-field tests were carried out to estimate discharge of the developed irrigation gate as a function of water head over gate crest. The most essential parameter in calculating the gate discharge was the coefficient of discharge C_d that determined as a ratio between the actual and theoretical discharge. The discharge values Q_g that calculated values of $C_d = 2.339$ gave a good agreement with the actual discharge measured values of Q_{act}.

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