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# Testing and Evaluation of Surge Flow Gate for Discharge Measurement under Different Operating Conditions

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*A B S T R A C T*

With surge irrigation, applying surges to an area is a cheap labor task. In industrialized nations, a variety of electronic valves for discontinuous water application (surges) are available; but their pricing prevents their usage in emerging regions. Additionally, these valves are too advanced for use by growers in underdeveloped nations. As a result, a basic Automatic Surge Gate was developed and tested in the labs to assess its effectiveness in terms of producing on-off surges. The reservoir was built to hold or collect low inflows for barrier functioning, and the gate was positioned on the suction side of the reservoir. Inflow rates, pinions, and poundage placements on the gate lever were the working parameters defined for the gate functioning. In the current investigation, three inflow rates 134, 169, and 187 l/s were employed. By leveraging the low inflows to the reservoir, the automatic surge gate demonstrated the possibility for automating the on-off action. The surge gate produced sizeable outflows even at the lowest inflow rate of 134 l/s into the reservoir. Power-law equations were discovered to be a good representation of the behavior in the statistical models that were also created using quasi statistical method.

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## NOMENCLATURE

| | | | |
|---|---|---|---|
| $C_d$ | Coefficient of discharge | $Q_{out}$ | Outflow from the gate ($m^3/s$) |
| $h$ | Hydraulic head over the crest of V-notch (m) | H | Height of the gate (m) |
| $\theta$ | Angle of the notch (degree) | A | Area of water surface in the reservoir ($m^2$) |
| g | Gravitational acceleration ($m/s^2$) | ρ | Mass per unit volume of the water ($kg/m^3$) |
| $Q_{in}$ | Flow into the channel ($m^3/s$) | t | Time (s) |

## INTRODUCTION

Pakistan possesses approximately 17.5 million hectares of irrigated land. Most of this area is surface irrigated. Automated surface irrigation is being tested on a very small fraction of this large potential area. Surface irrigation systems are mostly labor intensive, and studies shows that even a partial automation of a surface irrigation system can decrease the labor involve and improve the irrigation performance [1, 2]. Unlike uninterrupted watering, surge irrigation refers to water being applied in cycles [3, 4]. Surge irrigation involves applying a collection of short bursts of freshwater to an area. Surge irrigation may be superior to ongoing watering because it advances water more quickly, improves penetration homogeneity, uses less water overall, and is more effective [5-12]. Several of the

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key components of successful irrigation farming is the administration of the appropriate ratio at the proper moment; however, this necessitates precise metering of fresh water even during on-times of the surges. The foundation for controlling and regulating water throughout surge watering is flow monitoring. Most of the rural carry out this activity physically, making it an employment process. If indeed the on-off operation is controlled, surge irrigation may be more useful. This not only enhances the effectiveness of surge irrigation and yet also motivates producers in underdeveloped nations to use it [13]. Ismail et al. [14] designed an autonomous fall gate for dispensing soil moisture in surge irrigation using various on-off methods of time frames. The barrier has undergone outdoor and lab work. A small pond is filled with intermittently modest inflows. Because when the reservoir's water hits a specific level, the gate allows users to enter. Till its water level reaches a different specified low level, the gate is left open. This barrier mainly permits minor volumes [14]. Martinez-Austria and Aldama [15] created and evaluated a surge irrigation system and gave it the title “Diabeto”. It is made up of a siphon and a tank. An unfilled tank was filled with a constant supply, which gradually raised the tank level. Fluid starts to pour as soon as the reservoir pressure rose to the prominence of the siphon, prompting the wave. The off stuff started once the siphon stopped operating after the sea level receded far enough. They concluded that Diabeto is a straightforward complex work instrument that produces the appropriate periodic charge after carrying out numerous laboratory tests and on the ground. The amount of intake to the tank can be used to adjust the surge length. There is not a lot of progress made in surge irrigation technology. The focus of this research was to narrow or make up the difference [15]. The suggested Automated Surge Gate by Ismail et al. [14] was constructed in a lab [16]. Such gate can be used by producers with limited expertise, especially in underdeveloped nations. As a result, it was intended for such an investigation to examine the autonomous surge barrier for producing surges and figuring out the discharge from the gate throughout a surge beneath various process circumstances. Application of water to the field by surge irrigation is a laborious and time-consuming job.

The present study aims the fabrication of a semi-automatic surge gate for the application of water on the border creating on-off cycles. The gate is designed on the principle of the momentum and operating torque. Application of water by the gate is simple, needs no energy and the least engagement of manpower. Gate is cost-effective and easily operative in those areas where sophisticated equipment like surge valve is not available.

## MATERIAL AND METHODS

To meet the aims of the research, a scientific setup is designed as illustrated in Figure 1. This was accomplished using a sample route in the hydraulics facility of the Centre of Excellence in Water Resources Engineering (CEWRE), Lahore, Pakistan. The rectangular test channel has two sections, upstream and downstream, and is constructed of cement and bricks. The downstream part has a surge gate and a V-notch, while the above pump empties its input into the inlet opening. At 4.28 m available the V-notch, the 0.3 m x 0.3 m automated surge gate (Figure 2) was built, creating a reservoir with a met regularly to the channel's width for the gate operation. To determine the inflow velocity to the reservoir, a weighing instrument was put on the upstream side of the water close to the V-notch. Using the gate, this configuration assisted in building up the low flow and producing a series of succeeding surges. To continue the test under various flow circumstances, several pluronic and their placements were established to assess how well the surge gate performed in calculating the outflow gate discharges during surge on-cycles. Throughout this study, the research methodology process described below was used.

### Inflow discharge estimation

Three water inflow rates for reservoir storage were selected by adjusting the control valve on the pump. After adjusting the valve for a specific discharge, the flow inside the test channel was allowed to stabilize. Water was allowed to flow freely through the gate for about 30 minutes. The water levels in the upstream of the channel near the permanently installed V-notch were recorded with the help of a point gauge. Five readings of head were taken at an equal time interval and then an average value of the head was used to determine the discharge from V-notch with the help of following equation as given by Bos [17]:

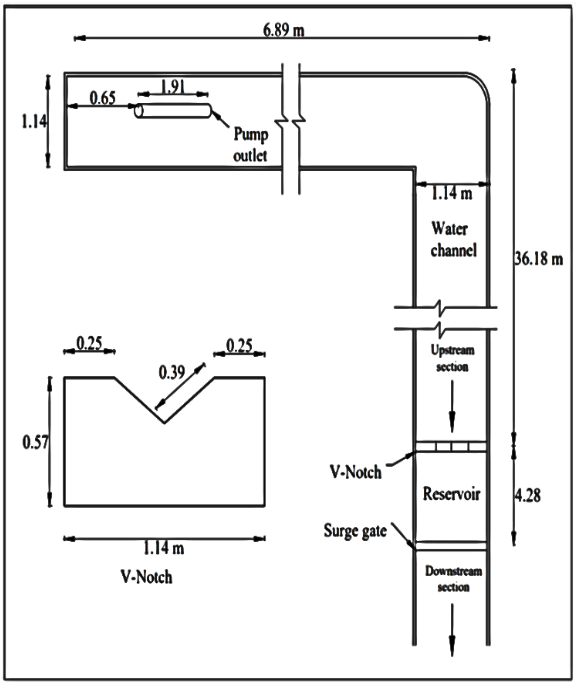


**Figure 1.** Plan view of the experimental setup in the lab

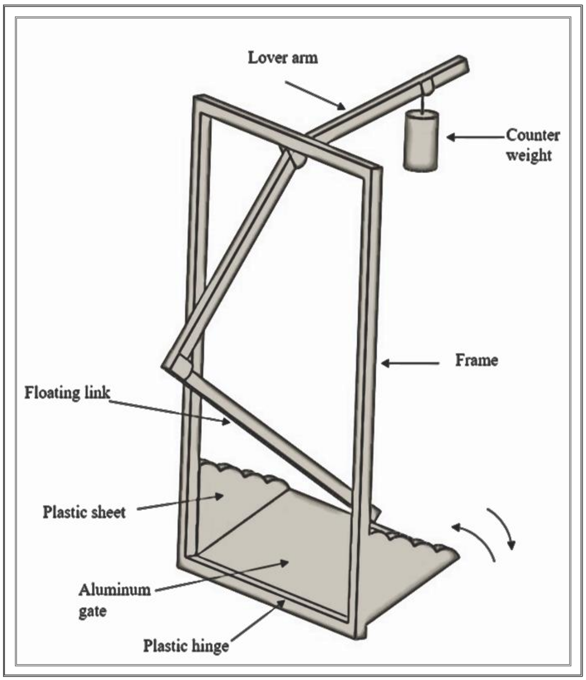


**Figure 2.** A schematic diagram of surge gate

$$Q = 0.533h^{2.5}C_d\sqrt{2g}\tan\frac{\theta}{2} \tag{1}$$

$$\rho Q = A\frac{dH}{dt} \tag{2}$$

where $C_d$ is coefficient of discharge; h is hydraulic head upstream over the crest of V-notch (m); θ is angle of the notch (degree); and g is gravity 9.81 m/s$^2$. While estimating the outflow discharge from the surge gate, three inflow discharge values derived from the aforementioned formula were used.

### Depth vs. time data collection

A reservoir was created in the space between the V-notch as well as the surge gate. To measure the reservoir's sea level, a measuring scale was put on its upstream side (dead storage). The gate was closed by applying a specified load to the suspension that was suspended from the lever arm at a specific distance from the set location when the flow regime had stabilized (Figure 2). The timer was activated as soon as the liquid started to fill the container. With aid of a tape measure, the reservoir's water level was tracked throughout time. Due to hydrostatic pressure, the surge gate usually exposed once the water hits a specific depth. The same measuring instrument that was mounted to the lake was used to chart the decrease in water depth over time. To acquire average depth measurements for estimating discharge, the study was carried out three times.

### Discharge estimation of the gate

Ismail et al. [14] established a quick method for estimating discharge as from gate using a continuity equation to the constant volume (Figure 3). The method is founded on the measurement of the water depth as a time interval during one surge cycle. The outflow characteristic from the surge gate is curvilinear, whereas the inflow function to the reservoir is linear. Because of this, the continuity equation created for control volume is shown in Equation (3). Since the density $\rho$ is constant, therefore:

$$Q_{in} - Q_{out} = A\frac{dH}{dt} \tag{3}$$

where H is the height of the gate when it is about to open. To avoid water from running over the gate while it is locked, 90% of the gate's entire elevation is used during design; dH/dt is the rate of variation in head-time; and A is the area of the reservoir's water. The outflow is essentially zero when the gate is closed (referred to as off-time).

The volume of the reservoir's consistent water surface and the water's rate of increase were measured to determine $Q_{in}$. In the head-time charts created by the functioning of the barrier, this is the slope of a straight line [14]. The outflow fluctuated when the gate was opened (referred to as on-time), hence the rate of fluctuation of dH/dt (head-time) were accounted for. So, the following formula was used to determine the gate's outflow ($Q_{out}$):

$$Q_{in} = A\frac{dH}{dt} \tag{4}$$

$$Q_{out} = Q_{in} - A\left(\frac{dH}{dt}\right)_{on} \tag{5}$$

$$Q_{in} = A\left(\frac{dH}{dt}\right)_{off} \text{ (dH/dt when gate is closed)} \tag{6}$$

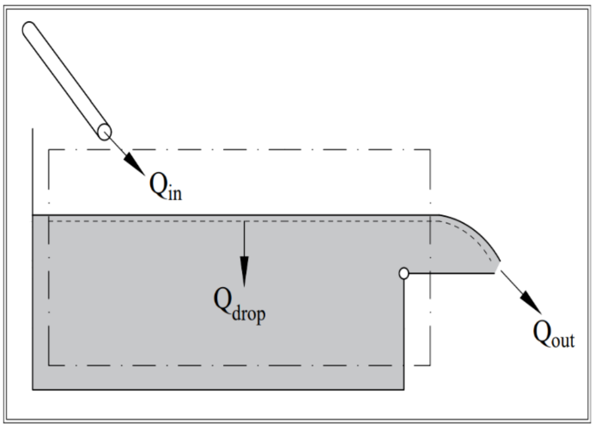


**Figure 3.** Control volume used in the continuity equation of the gate

$$Q_{out} = A\left(\frac{dH}{dt}\right)_{off} - A\left(\frac{dH}{dt}\right)_{on} \quad (7)$$

$$Q_{out} = aH^r \quad (8)$$

Theoretical correlations were established for the obtained data collected under various surge gate operating settings using the MINITAB statistical software.

## RESULT AND DISCUSSION

### Inflow rate and counter weight

As previously mentioned, the estimation of the outflow discharges from the surge gate was done using head data aggregated over hangar locations for three distinct counterweights. Table 1 displays the measured and anticipated outflow rates. The table illustrates that, for pulleys of 2.4, 2.9, and 3.3 kg, correspondingly, the peak value outflow outputs from the gate were 70, 69, and 91 l/s below a steady input of 134 l/s to the lake. As anticipated, the sudden reduction in reservoir heads caused the gate's maximum water output to quickly decline once it opened. The outflow from the gate follows a distinct trend; when the reservoir's head falls or decreases, the discharge follows suit, delivering an increased incidence when the gate opens when the reservoir's head is at its highest. In comparison to other pivots, a larger volume of water must be held above of the gate to fully open it. The outflow discharge from the gate for the 2.9 and 3.3 kg counterweights were discovered upon its opening at 17 and 83 l/s, respectively, despite the 169 l/s intake rate. The discharge was caused by loss from the gate that happened at the commencement of its opening, which is why the low value of 17 l/s for a head of 0.24 m in the reservoir was caused by the gate not introducing entirely.

Table 1 makes it clear at a weight of 2.9 kg, the abrupt implementation caused by the torque of the weight going upwards the releasing torque caused by the moisture on the gate were small. As a result, the gate opened slowly, causing a sluggish loss of liquid. After a brief period, the opening torque increases, causing the gate to open quickly and discharge 65 l/s of energy. Due to the inflow rate being equal to the stored outflow rate at a head equal to or higher than the intended shutting heads, the gate opened for 2.4 kg of weight but failed to close. It also observed that all these weights were improvised to control the on-off function of the surge gate for counterweights of 2.4 kg and 3.3 kg and reservoir input of 187 l/s. A closer look at the table also showed that the counterweight of 3.3 kg for an intake of 134 l/s is ideal for running the surge gate's on-off function.

### Inflow rate and weight hanger position

As shown in Table 2, the estimated flow discharges again from surge gate were calculated using head data summed across counterweights for three distinct hanger placements. The output discharges were 55, 69, and 91 l/s for counterweight locations of 0.10, 0.08, and 0.06 m, respectively, for an inflow rate of 134 l/s and 0.24 m head in the reservoirs. The opening torque out about hinge caused by the reservoir's moisture was less than the shutting torque caused by the counterweight at counterweight positions of 0.06 m.

It was determined from Table 2 that the counterweight position of 0.06 m, particularly with an intake of 134 l/s, is the best location to achieve the greatest water outflow as from surge gate. The outflow discharges at the reservoir's entrance with an input rate of 169 l/s and 0.20 m head were 55 and 65 l/s for counterweight locations of 0.10 and 0.08 m, correspondingly. As when the increase in the supply to the reservoir was higher than what was needed to maintain the occasion than the constructed outflow from the gate, i.e., the highest outflow from at its entrance, because when water reaches 90% of the surge gate altitude, the entrance did not show pledge for surge implementations at 0.06 m counterweight situation.

As a result, once the gate has emerged, it never closes. The releasing torque caused by the water was more than the weight's torque for the counterweight that was placed at 0.10 m. As a result, additional water accumulated in front of the gate. However, the gate did open as the water's torque increased, enabling for a higher discharge than at other counterbalance locations. Waters gathered ahead of the gate to a height of 0.20 m, which was the intended elevation, at which point the gate released, causing a greater discharge. For a weight position of 0.08 m, the responding torque caused by gravity and the opening torque caused by water on the gate originally differed only slightly, causing the gate to open gradually and cause water leaks. After a little period of time, the difference in torque abruptly rose, opening the gate instantly and allowing the greatest amount of outflow. The outflow discharges for two counterweight positions were 100 and 84 l/s when counterweights were positioned at 0.10 and 0.08 m, accordingly, for input of 187 l/s and reservoir head of 0.20 m. The outflow gate discharge pattern is in line with what was previously stated.

**Table 1.** Measured outflow discharges from the gate for different counter weights

| Inflow to reservoir (l/s) | Counter weight (kg) | Outflow gate discharges $Q_{out}$ (l/s) Head in the Reservoir (m) | | | | |
|---|---|---|---|---|---|---|
| | | 0.07 | 0.10 | 0.15 | 0.2 | 0.24 |
| 134 | 2.4 | 8 | 13 | 25 | 43 | 70 |
| | 2.9 | 6 | 11 | 32 | 59 | 69 |
| | 3.3 | 7 | 13 | 31 | 67 | 91 |
| 169 | 2.9 | 22 | 28 | 39 | 65 | 17 |
| | 3.3 | 21 | 30 | 53 | 83 | - |
| 187 | 2.9 | 25 | 30 | 46 | 80 | - |
| | 3.3 | 28 | 32 | 50 | 87 | - |

Because moment arm of the weight, which was bigger than the moment arm of the water since the weight was lying at a longer distance of 0.10 m from the fixed point, was the source of the high discharge for the 0.10 m weight location. Water had to build up for a long period ahead of the gate before it could be released, and once it reached the desired elevation, the gate opened with the greatest possible discharge. Because the inflow was large and the torque of the waters was greater than the torque of the mass in the event of the 0.08 m location, the gate was opened at 0.20 m head and a lower outflow was achieved than with a 0.10 m hanger role of mass. The gate opened but failed to close at a level of the counterweight on the hangers of 0.06 m.

Due to the strong influx, the moment of weight about the fixed point of the lever could not be more than the moment of water in the opened position. Analyzing the data critically demonstrated that its inflow rate of 134 l/s, which significantly increased outflow from the gate for each of the three counterweight hanger settings, had the great outcome.

## Inflow rate and gate discharge

Determining the output gate discharges are summarized in Table 3 using head values aggregated across counterweight and hanger positions for three separate inflows. The table shows that for inflows of 134, 169, and 187 l/s, accordingly, the projected outflow from the gate for 0.24 m head was 86, 65, and 58 l/s. The findings in Table 3 indicate that discharge is inverse to reservoir inflow, with outflow gate discharges of 85, 65, and 58 l/s for reservoir inflows of 134, 169, and 187 l/s, correspondingly. The gate for a high inflow opens sooner than a little inflow, i.e., at a lower depth of water in the reservoir for the bigger inflow, and conversely, because the head rises with a low input but relatively quickly with a high inflow.

This finding is corroborated by the determination coefficient (Table 4), that declines with increasing inflow discharge, or experimental data collecting inaccuracy. Additionally, it should be observed that (Table 3) for a given input, as the head increases, so does the discharge. The presence of head close to the top of the gate is what causes a rise in discharge with a rise in head. As a result, the gate releases the most water possible when it opens. Since head instantly drops after the gate opens, as was shown during calibration, discharge similarly drops quickly in respect to head. The minimum inflow of 134 l/s causes water to begin steadily increasing ahead of the gate. The gate opened when the water level reached the desired level, and it behaved or opened in the same manner for outflow as described earlier. For 169 and 187 l/s, however, water collected upstream of the gate in a smaller amount of time, and an event caused by the torque of the water and pressure happened at 20 m, which led to the entrance gate.

The set of equations were created for three inflow rates using multiple regressions (Table 4). $R^2$ has a range of values between 0.99 and 0.97, suggesting a slight inaccuracy.

## Optimal discharge

The minimal inflow, or 134 l/s, was discovered to be the ideal inlet discharge to achieve a large outflow for effective surge watering in low land after rigorous analysis of the data. Because of this high outflow, the water will move at a supersonic speed, allowing the area to be effectively watered with low inflows (Table 3).

## General discharge equation

In Table 5, as well as visually in Figure 4, are the predicted discharges from the gate aggregated across various counterweights, hanger locations, and inflows from the lab experiments. The outflow when the gate opens is shown in the figure to be 41 l/s. The outflow behavior is consistent with what it ought to be, i.e., it rises as the reservoir's head rises. Because the maximal head was close to the top of the gate, the entire discharge was emitted when the gate opened. Discharge also falls out when head does. The link between the head and discharge was represented by the given formula below.

$$Q_{out} = 4278.74LH^{0.81} \qquad R^2 = 0.99 \tag{9}$$

**Table 2.** Measured outflow discharges from the gate for different hanger positions

| Inflow to water reservoir (l/s) | Weight position on hanger form lever (m) | Outflow gate discharges $Q_{out}$ (l/s) Head in the reservoir (m) | | | | |
|---|---|---|---|---|---|---|
| | | 0.07 | 0.10 | 0.15 | 0.20 | 0.24 |
| 134 | 0.10 | 10 | 17 | 28 | 42 | 55 |
| | 0.08 | 7 | 12 | 26 | 59 | 69 |
| | 0.06 | 5 | 11 | 40 | 72 | 91 |
| 169 | 0.10 | 26 | 33 | 50 | 55 | - |
| | 0.08 | 19 | 27 | 38 | 65 | 16 |
| 187 | 0.10 | 30 | 36 | 35 | 100 | - |
| | 0.08 | 18 | 27 | 73 | 84 | - |

**Table 3.** Outflow discharge from the gate for different inflow rates

| Head (m) | Outflow gate discharges (l/s) Inflow to water reservoir (l/s) | | | | | |
|---|---|---|---|---|---|---|
| | 134 | | 169 | | 187 | |
| | $Q_{out}$ | $Q_{cal}$ | $Q_{out}$ | $Q_{cal}$ | $Q_{out}$ | $Q_{cal}$ |
| 0.07 | 7 | 6 | 21 | 22 | 27 | 25 |
| 0.10 | 12 | 13 | 30 | 32 | 30 | 33 |
| 0.15 | 30 | 30 | 41 | 47 | 41 | 44 |
| 0.20 | 51 | 55 | 65 | 63 | 58 | 54 |
| 0.24 | 86 | 80 | - | - | - | - |

**Table 4.** Head-discharge relationships for different reservoir inflow rates

| Discharge (l/s) | Power regression equation | $R^2$ |
|---|---|---|
| 134 | $Q_{cal} = 1520\ t_{ii}^{2.07}$ | 0.99 |
| 169 | $Q_{cal} = 309\ t_i^{0.99}$ | 0.99 |
| 187 | $Q_{cal} = 170\ t_i^{0.72}$ | 0.97 |

where L is the width of gate (30 cm); H is depth of water in (cm) and Q is the outflow discharge from the gate, in l/s.

From the Figure 4, it is clear that the outflow when the gate opens is 41 l/s. The behavior of discharge is the same, as it should have to be i.e., the discharge increases as the head in the reservoir increases. It is because the maximum head was near the top of the gate so when the gate opened, maximum discharge was released. With decrease in head, discharge also decrease. The following general equation with $R^2$=0.99 was considered representative for head and discharge relationship.

**Table 5.** Measured and calculated outflow gate discharges averaged over gate operating conditions

| Head (cm) | Outflow gate discharges (l/s) | |
|---|---|---|
| | $Q_{out}$ | $Q_{cal}$ |
| 07 | 15 | 15 |
| 10 | 21 | 20 |
| 15 | 26 | 28 |
| 20 | 35 | 35 |
| 24 | 41 | 40 |

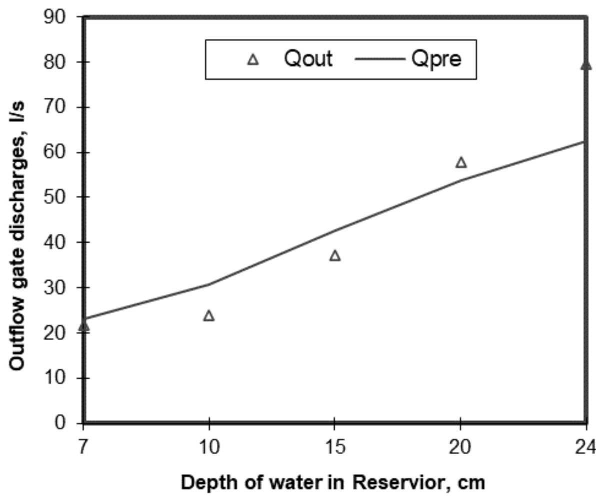


**Figure 4.** Outflow gate discharge averaged over all operating conditions

## CONCLUSIONS

The findings of this investigation led to the following assertions:

- Low inflows are the greatest candidates for the surge gate. When the small reservoir holds the low incoming discharges, it produces high discharges. Enormous water velocities are caused by these high flows. Thus, the purpose of surge can be accomplished. By leveraging the low flows at the intake end, the constructed automatic surge gate demonstrated the possibility for smart water regulation. It operated as intended
- A weir kind expression was discovered to be the finest depiction of the relationship after statistically analyzing head-discharge connections. With an $R^2$ of 0.99, a universal head-discharge formula derived from $Q = 4278.74\ LH^{0.81}$ was determined to be the most typical of the behavior.
- The optimum hanging point for a 134 l/s input was determined by the effect of hanger location, and among 0.10 and 0.08 m, 0.06 m produced the highest outflows discharge. However, at an intake of 169 l/s, it was discovered that the hanger position of 0.08 m was the ideal for all counterweights to reach optimal discharges.
- Reservoir inflow rates effects in the opening of gate and on the quantity of water pouring from the gate. The greatest outflows recorded at the gate's activation were 86, 65, and 58 l/s for corresponding reservoir inflows of 134, 169, and 187 l/s. Because of the low pressure caused by the limited inflow flow to the reservoir, the outflow discharge rises as the head increases.
- The minimal intake of 134 l/s was determined from the current study to be the ideal intake outflow to achieve a high outflow for effective surge watering. Due to the large outflow's contribution to the water's supersonic speeds, the land can be effectively watered with modest inflows.

After several field assessments, extensive testing of the Automatic Surge Gate shows that it functioned properly and can be utilized for surge watering. Nevertheless, the gate should undergo rigorous experimental research and practical assessment to see whether it can be made to work better for surge irrigated in basins and borders of various sizes by altering the gate's width, design, and composition. This will enable the gate to be used in a variety of environments.

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## CONFLICT OF INTEREST

There is no conflict of interests.

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**Persian Abstract**

**چکیده**

با آبیاری موجی، اعمال نوسانات در یک منطقه کاری ارزان قیمت محسوب می‌شود. در کشورهای صنعتی، انواع شیرهای الکترونیکی برای کاربرد ناپیوسته آب (سرنگ) موجود است. اما قیمت‌گذاری آنها از استفاده آنها در مناطق نوظهور جلوگیری می‌کند. علاوه بر این، این شیرها برای استفاده توسط تولیدکنندگان در کشورهای توسعه نیافته بسیار پیشرفته هستند. در نتیجه، یک دروازه اصلی سرج خودکار توسعه داده شد و در آزمایشگاه‌ها مورد آزمایش قرار گرفت تا اثربخشی آن از نظر تولید موج‌های روشن و خاموش ارزیابی شود. مخزن برای نگهداری یا جمع‌آوری جریان‌های ورودی کم برای عملکرد مانع ساخته شده بود و دروازه در سمت مکش مخزن قرار داشت. نرخ‌های جریان، پینیون‌ها و قرارگیری پونداژ روی اهرم دروازه از جمله پارامترهای کاری تعریف شده برای عملکرد دروازه بودند. در تحقیق حاضر از سه نرخ ورودی ۱۳۴، ۱۶۹ و ۱۸۷ لیتر بر ثانیه استفاده شد. با استفاده از اهرم ورودی کم به مخزن، گیت سرج خودکار امکان خودکارسازی عمل خاموش و روشن را نشان داد. گیت سرج جریان خروجی قابل توجهی را حتی در کمترین میزان ورودی ۱۳۴ لیتر در ثانیه به مخزن تولید کرد. معادلات قانون قدرت به عنوان نمایش خوبی از رفتار در مدل‌های آماری که با استفاده از روش شبه آماری نیز ایجاد شده‌اند، استخراج و معرفی شد.