

Steady State Gate Operation Model for Mun Bon Irrigation System

Varawoot Vudhivanich¹ and Supachai Roongsri²

ABSTRACT

The steady state gate operation model was formulated in this study to help irrigation engineers operating the complicated irrigation canal regulators. The computer program called GATEOP was developed for calculating the water surface profile of the canal reach and the gate opening. The model was applied to Mun Bon irrigation project. Six main regulators which are the entrance to 6 zones in water master 2 were selected for the model testing. The field data of the regulators and the canal sections such as gate length, gate sill elevation, canal bed elevation downstream of the regulator, full supply level, maximum design discharge, canal bed slope, bed width and side slope were investigated. The 6 regulators were calibrated intensively. The field test during June-November 1998 shown that the discharge control of the 6 regulators were less than $\pm 10\%$ error.

Key words: gate operation, canal operation, canal control, water control, Mun Bon

INTRODUCTION

The objective of irrigation water management is “to deliver the right amount of water to the right place at the right time”. To achieve this objective, one has to understand the importance of 3 main activities related to water distribution. These are (1) planning (2) controlling (3) monitoring and evaluation of water distribution performance.

Oftenly, many researchers have been emphasized their researches on improvement of planning, monitoring and evaluation such as the water allocation scheduling and monitoring system or WASAM (Ilaco/Empire M&T (1986a, 1986b); Vudhivanich *et al.*, 2000 ; RID, 1996), the geographic information system for daily monitoring (Molle and Pongput, 1997 ; Tienchai, 1997). But only a few works focus on the control of water distribution, particularly in Thailand. Most of the times, the control of water distribution in manually

operated canal networks is entirely left to the field staffs. Many canal systems may have more than 100 water level and discharge regulators. Operating one regulator (gate) will effect both upstream and downstream regulators, particularly when the gates are operated under submerged conditions. One important problem in the actual operation of canal system is the determination of the gate opening in order to control the desired discharge to the desired area.

Proper gate opening depends on the gate type, desired discharge, water level upstream and downstream of the gate, etc. Moreover, the water level at the gate may vary according to the back water effect from the adjustment of downstream gate.

Thus, the determination of gate opening is a complicated work. Any irrigation projects that do not give enough attention to this issue, may have problems on water delivery and distribution. It will

¹ Department of Irrigation Engineering, Faculty of Engineering, Kasetsart University, Kamphaengsaen, Nakhon Pathom 73140, Thailand.

² Regional Office 6, Royal Irrigation Department, Nakhon Ratchasima 30000, Thailand.

directly effect the irrigation and water delivery performance of the project and also the irrigation efficiency. The objectives of this research are (1) to develop the steady state gate operation model and the computer program for determination of gate opening (2) to test the accuracy and reliability of the method. Mun Bon irrigation project is selected as a case study.

MATERIALS AND METHODS

Theoretical backgrounds of steady state gate operation model

The calculation of gate opening depends on the flow conditions in the canal and the type of regulators. The flow conditions are classified into free flow and submerged flow.

Free flow gate operation

As shown in Figure 1, the free flow discharge can be calculated by the following orifice flow formula :

$$Q = C_d L G_o \sqrt{2gY} \quad \text{..... (1)}$$

when Q = Gate discharge, m^3/s .

C_d = Discharge coefficient which is a

function of $\frac{Y}{G_o}$

L = Gate length, m.

G_o = Gate opening, m.

Y = Upstream depth, m.

g = 9.81 m/sec^2 .

From the principle of upstream control, the upstream water level is maintained at full supply level (FSL). The upstream depth can be measured.

If C_d is a linear function of $\frac{Y}{G_o}$ and can be expressed as $\frac{Y}{G_o} = a C_d + b$, the gate opening (G_o) for a given Q can be determined by the following equation.

$$G_o = \left(\frac{Y}{b} - \frac{Q \cdot a}{b \cdot L \sqrt{2gY}} \right) \quad \text{..... (2)}$$

Submerged flow gate operation

As shown in Figure 2, the calculation of G_o under the submerged flow condition is more complicated than the previous case. The discharge through the upstream regulator may be influenced by the back water effect from the operation of the downstream regulator as shown in Fig. 3. Therefore, the back water effect has to be examined before calculating G_o .

(1) No back water effect

In case of no back water effect, the water depth downstream of the regulator (y_1 in Figure 3) is the normal depth when the flow reaches the steady state. The downstream normal depth can be calculated by Manning's formula, Eq.3. Since the normal depth calculation is in implicit form, the

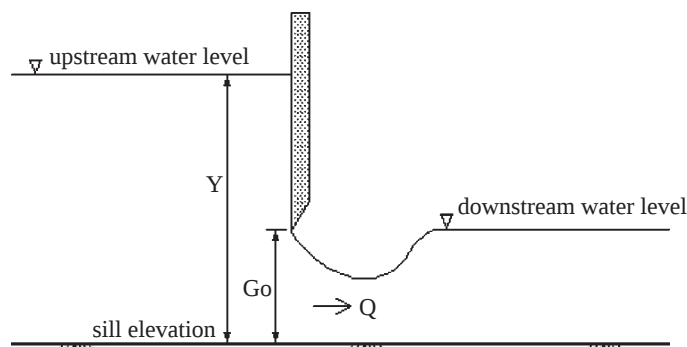


Figure 1 A regulator with free flow discharge.

Newton-Raphson technique is employed to solve for y_1 iteratively, as shown in Eq. 4. With the calculated y_1 , the G_o for the given Q can be calculated from the submerged flow formula and the C_s function as shown in Eq.5 and Eq.6 by assuming that the upstream depth is at FSL (RID.1997).

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2} \quad \dots\dots\dots (3)$$

$$y_{1j+1} = y_{1j} - \frac{1 - \frac{Q}{Q_j}}{\left(\frac{2}{3R} \frac{dR}{dy_1} + \frac{1}{A} \frac{dA}{dy_1} \right)} \quad \dots\dots (4)$$

when

y_{1j+1} , y_{1j} = Calculated y_1 at $j+1$ and j iteration

Q = Given discharge, m^3/s .

Q_j = Q evaluated at $y_1 = y_{1j}$

$$= \frac{1}{n} A_j R_j^{2/3} S_0^{1/2}$$

$\left(\frac{2dR}{3Rdy_1} + \frac{1}{A} \frac{dA}{dy_1} \right)$ = Geometric function of trapezoidal canal section

A = Cross sectional area of flow, m^2 .

R = Hydraulic radius, m .

S_0 = Bed slope

$$Q = C_s L h_s \sqrt{2gh} \quad \dots\dots\dots (5)$$

$$G_o = \frac{h_s}{a C_s^b} \quad \dots\dots\dots (6)$$

(2) Back water effect

In case of back water effect from the downstream regulator (regulator 2) as shown in Figure 3, the water surface profile between the downstream regulator and the operating regulator (regulator 1) has to be calculated in order to

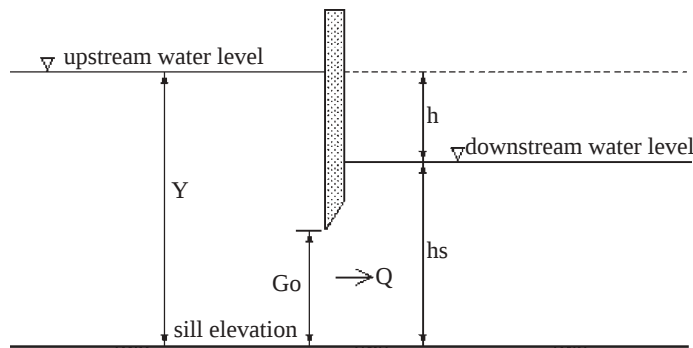


Figure 2 A regulator with submerged flow discharge.

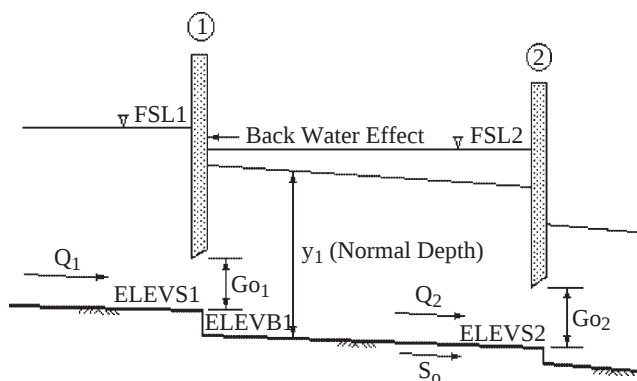


Figure 3 The back water effect from regulator 2 on the discharge through regulator 1.

determine the downstream depth of regulator 1 (y_1). It is assumed that the water level upstream of regulator 2 is maintained at FSL2. The step method called "Depth Calculated from Distance" is employed in the water surface profile calculation as shown in Figure 4.

From the energy balance equation,

$$E_1 + S_O \cdot \Delta x = E_2 + S_f \cdot \Delta x$$

$$E_1 - \frac{1}{2} S_{f1} \cdot \Delta x = E_2 - \frac{1}{2} S_{f2} \cdot \Delta x +$$

$$(S_{f2} - S_O) \Delta x \quad \dots\dots\dots (7)$$

when $E = \text{Specific Energy} = y + \frac{V^2}{2g}$ m.

$S_f = \text{Friction slope which can be calculated from Manning's formula} = \left(\frac{Qn}{AR^{2/3}} \right)^2$

$\Delta x = \text{Canal reach distance, m.}$

By Newton-Raphson technique, y_1 can be calculated iteratively by Eq.8. If the reach between regulator 1 and regulator 2 has laterals or farm turn out (FTO), this will reduce the discharge. The calculation of back water effect will have to take this effect into considerations. Once y_1 is calculated, the G_o can be determined similar to the case of no back water effect.

$$y_{1j+1} = y_{1j} - \frac{U_{1j} - U_1}{\left(\frac{df}{dy_1} \right)_j} \quad \dots\dots\dots (8)$$

$$\text{when } U_1 = \left(E_2 - \frac{1}{2} S_{f2} \cdot \Delta x \right) + (S_{f2} - S_O) \Delta x$$

$$U_{1j} = E_1 - \frac{1}{2} S_{f1} \cdot \Delta x$$

$$\left(\frac{df}{dy_1} \right)_j = 1 - \frac{Q(b_1 + 2z_1 y_{1j})}{g A_{1j}^3} + \frac{\Delta x (Qn)^2}{2(A_1 R_1^{2/3})_j} \left(\frac{2}{3R_1} \frac{dR_1}{dy_1} + \frac{1}{A_1} \frac{dA_1}{dy_1} \right)_j$$

If the downstream structure is a drop structure or inclined drop, that structure will act as a flow control. The flow at the control is the critical flow condition. The critical depth (y_c) for trapezoidal canal section can be calculated by Eq.9. Also the Newton-Raphson technique can be used to solve for y_c . Once the depth at the downstream control structure is calculated, y_1 can be determined by the step method. Thus, G_o is calculated as previous described.

$$\frac{Q^2 B}{g \cdot A^3} = 1 \quad \dots\dots\dots (9)$$

when $B = \text{Top width, m}$

$A = \text{Cross sectional area, m}^2$.

$$y_c = y_o - \frac{f(y_o)}{f'(y_o)} \quad \dots\dots\dots (10)$$

$$\text{when } f(y_o) = \left(\frac{Q^2 (b + 2zy_o)}{g \{ (b + zy_o) y_o \}^3} - 1 \right)$$

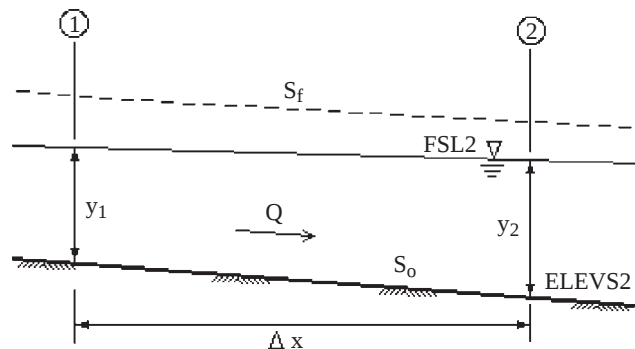


Figure 4 Step method - depth calculated from distance .

$$f'(y_0) = \frac{Q^2}{g} \left(\frac{2z}{A^3} - \frac{3B^2}{A^4} \right)$$

The computer program called “GATEOP” was developed to assist the irrigation project engineer in analyzing the steady state gate operation problem.

Model calibration and verification

Six main regulators which are the entrance to six zones of water master 2, Mun Bon irrigation project, are selected for the steady state gate operation modeling. Those regulators are (see Figure 5.):

- Irrigation Outlet
- Head Regulator of Right Main Canal (RMC (HR))
- Head Regulator of 9R-LMC (9R-LMC (HR))
- Check Regulator at Km. 21.000 of LMC (LMC (CH-21))
- Head Regulator of 38R-LMC (38R-LMC (HR))
- and Check Regulator at Km. 3.000 of 38R-LMC (38R-LMC (CH-3)).

The discharges and the water level upstream and downstream of each regulator were measured on daily basis. The field data of the regulators and the canal sections including gate length (L), gate sill elevation (ELEVS), canal bed elevation downstream of the regulator (ELEVB), full supply level (FSL), maximum design discharge (Qmax), canal bed slope (s), bed width (b) and side slope (z) were investigated. The discharge coefficients of each regulator were obtained from field calibration (RID, 1997 ; Roongsri, 1999). The design manning’s roughness coefficients (n) of the canal were initially used in the model, but the values were adjusted in order to obtain the satisfactorily water level calculation. The calculated gate opening (Go) and other parameters such as y and h_s were statistically compared with the actual values using t-test. Finally, the accuracy to control the discharge of the 6 main

regulators was determined.

RESULTS AND DISCUSSION

Field calibration

The discharge through the irrigation outlet was measured at different openings for 130 times during July 1996- February 1998. The average discharge coefficient (C_d) of the Irrigation outlet is 0.4863. Similarly the other 5 main regulators were calibrated under field conditions. The parameters of the calibration curve of the 5 regulators are shown in Table 1. It can be seen that the submerged flow discharge coefficient (C_s) is highly related to $\frac{h_s}{Go}$ and the free flow discharge coefficient (C_d) is also highly related to $\frac{y}{Go}$.

Model test

The statistic analysis (t-test) was performed to compare the mean values of the GATEOP calculated gate operation parameters (y, h_s and Go) with the actual values. It is found that the calculated values are not significantly different from the actual values at 0.01 significant level.

Finally, the GATEOP was actually tested for the gate operation of Mun Bon irrigation system during June-November 1998. The operation test covered the normal operating range of most regulators as shown in Table 2. The result shown that the GATEOP calculated discharge of the 6 main regulators has the error of $\pm 10\%$, which is acceptable for field operation.

Although the program GATEOP was specifically developed for Mun Bon irrigation system, it can be applied to any free flow and submerged flow gate operations which have similar configurations. Some modification in the computer code is needed if the gate configurations are different.

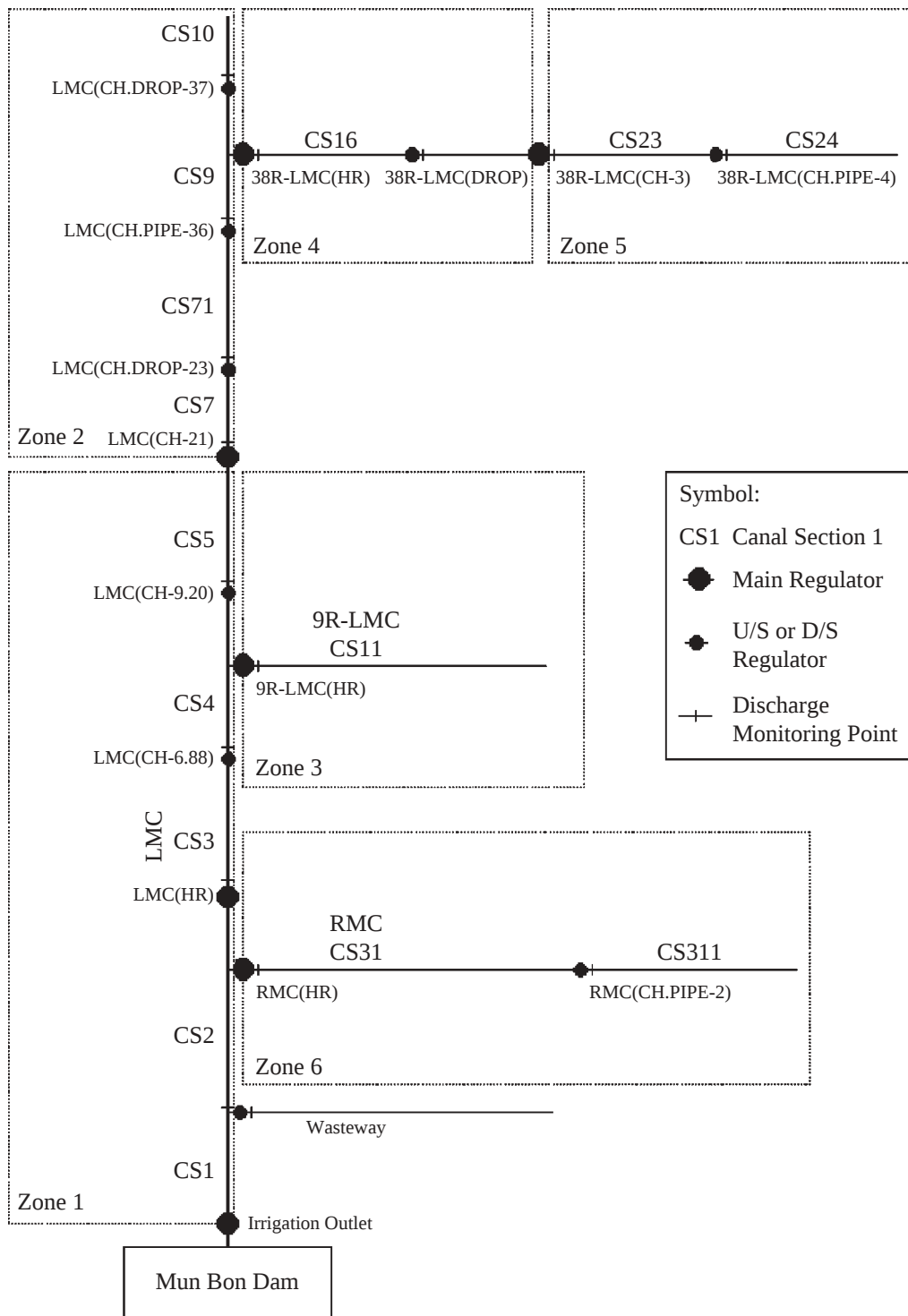


Figure 5 Location of the 6 main regulators and other regulators in gate operation of Mun Bon irrigation system.

Table 1 The calibration curve parameters of the 5 regulators.

Regulator	a	b	R ²
(1) Submerged Flow [$\frac{hs}{Go} = aC_S^b$]			
LMC (CH-21)	0.6685	-0.8193	0.9915
38R-LMC (HR)	0.5347	-0.8901	0.9514
38R-LMC (CH-3)	0.8512	-0.6858	0.9852
RMC (HR)	0.6910	-0.8233	0.9719
(2) Free Flow [$\frac{y}{Go} = aC_d + b$]			
9R-LMC (HR)	-17.0910	15.0830	0.9907

Table 2 The percentage error in discharge control at the 6 main regulators.

Regulator	Range of gate opening (m.)	Range of target discharge (m ³ /s.)	Actual discharge (m ³ /s.)	% Error of discharge control	Observation period
Irrigation Outlet	0.27 - 0.88	2.77 - 9.04	2.96 - 9.04	-7.46 - 6.33	Jun.25,98 - Nov. 8, 98
LMC (CH-21)	0.42 - 0.89	2.20 - 3.71	2.28 - 3.88	0.94 - 6.76	Sep.4, 98 - Nov. 9, 98
9R-LMC (HR)	0.20 - 0.50	0.65 - 2.32	0.66 - 2.26	-14.75 - 3.90	Aug.4, 98 - Nov. 6, 98
38R-LMC (HR)	0.20 - 1.00	0.59 - 2.82	0.57 - 2.89	-3.38 - 4.76	Sep.5, 98 - Nov. 10, 98
38R-LMC (CH-3)	0.30 - 1.00	0.49 - 1.41	0.50 - 1.51	-4.54 - 8.18	Sep.5, 98 - Nov. 10, 98
RMC (HR)	0.18 - 0.47	0.40 - 0.86	0.40 - 0.90	-5.99 - 4.81	Aug.4, 98 - Nov.11, 98

CONCLUSION

The steady state gate operation model and the program GATEOP were developed under the assumption that the gate was operated under the steady state conditions. The check regulator has to control the water level upstream at the full supply level. The field calibration must be done comprehensively in order to get the accurate and reliable flow parameters. The gate operation test shown that the error in controlling the discharges of the 6 main regulators of Mun Bon project during June-November 1998 is less than $\pm 10\%$.

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