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FIELD PERFORMANCE EVALUATION OF AN AUTOMATED CONSTANT HEAD ORIFICE OFF-TAKE STRUCTURE AT THE SUNGAI MUDA IRRIGATION SCHEME IN MALAYSIA

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ABSTRACT: *Constant Head Orifice (CHO) off-take structures are built at the head of tertiary canals to facilitate measurement and control of constant irrigation water supply. Presently, most of the CHO off-take structures in Malaysia are manually operated. Target discharges are seldom met due to upstream water level fluctuations, and in some cases, the operators are unable to cope with the opening and closing of the many orifice and turnout gates. This study was undertaken to evaluate the performance of an automated CHO off-take structure in terms of discharge, orifice gate and turnout gate openings and operational time requirements. A double barrel CHO structure at Block M2 at the secondary canal TB (Taliair B) in the Sg. Muda Irrigation Scheme, Seberang Perai Utara (SPU), Penang was chosen for the installation and testing of the automation system. Test results indicate a general increase in orifice gate opening for manual measurement compared to the automatic control. There was an overall increase in average discharge values between automation supply and manual gauging. Generally, the manual gauging discharges were higher than automation discharges for most of the flow settings, possibly due to human error. The time required to open the gate by the automation system increased with increase in orifice gate opening. Since the opening of the orifice gate was accomplished at a constant pitch, the wider it opened, the more time was required. A similar trend was observed for the manually operated CHO. As expected, for any particular orifice gate opening, the time requirement for the automated CHO was always less than that required for the manual operation due to the fact that manual operation is dependent on human involvement rather than using a computer control system. The Department of Irrigation and Drainage of Malaysia should create public awareness of the importance of automation of CHO as it ensures better irrigation water management. This will require the commitment of all arms of government, the private sector and the general public.*

1.0 INTRODUCTION

The success of any irrigation project in meeting water requirements depends to a large extent on the proper functioning of its water conveyance and distribution system. Proper functioning is essentially identified with proper operation of the system so that equitable and reliable apportionment of water among users and the conveyance of water with minimum losses are ensured. While operation of an irrigation system is dependent on good organizational and institutional backing, its effectiveness is basically dependent on a well planned, designed and constructed network from the source of the water supply down to farmers' fields. Presently, there are a number of Constant Head Orifice (CHO) off-take structures in irrigation schemes in Malaysia which function as intakes for the irrigation compartments. At the head of tertiary canals serving an Irrigation Service Area (ISA), a CHO off-take structure is provided to facilitate measurement and management of irrigation water supply. Figure 1 illustrates the schematic diagram of a CHO off-take structure.

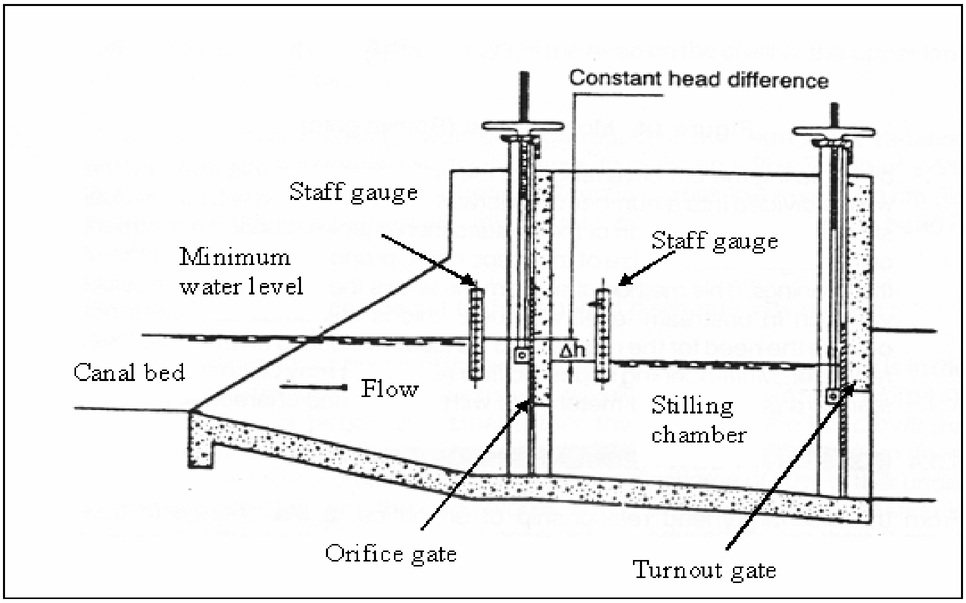

Figure 1. Schematic diagram of a Constant Head Orifice Structure (Adapted from Goussard, 1993)

Past experiences in the United States of America, People's Republic of China and Malaysia, have revealed that it is difficult to operate an irrigation project 24/7 (24 hrs/day; 7 days/week) in manual mode. It has been concluded from many projects that automation can substantially reduce operating expenses and can also enhance efficient water management. With respect to system design, an automated CHO system provides several benefits, including fast response in water supply, computerized control of water supply, easy and efficient operation, well regulated irrigation water supply, remote operation, easy maintenance and the system is web enabled. From management point of view, the automated CHO system can help maximize the usage of limited water resources available for paddy cultivation, reduce the dependency on human labour for operation, ensure stable supply of water on required time schedules and can act as a tool for decision support systems for precision farming.

In a field evaluation of a CHO off-take structure in the Tanjung Karang Irrigation Scheme in Malaysia, Amin and Tameez (1995) found that the CHO off-take structure generally had a lower discharge coefficient than average due to prevailing poor maintenance conditions. They also observed that, under the same pattern of upstream fluctuations, the relative flexibility of the CHO structure increased from lower gate opening to higher gate opening for the same flow conditions. Furthermore, better results could be obtained from maximizing the available differential head by reducing the gate opening.

This study was undertaken with the ultimate aim of evaluating the performance of an automated CHO off-take structure in terms of discharge, orifice gate and turnout gate openings and operational time requirements. More specifically, the objectives were:

1. to establish mathematical relationships between discharges and the orifice gate and turnout gate openings of the automated CHO off-take structure,
2. to verify the outputs of the automated CHO system in terms of discharge and orifice gate opening against manual measurements, and
3. to compare the automated CHO system with manual operation in terms of time requirements for operating the orifice gates.

2.0 MATERIALS AND METHODS

2.1 Study area

The study was carried out in the Sungai Muda Irrigation Scheme, in the Kepala Batas District, Penang State Malaysia. The scheme covers an area of 9035 hectares, and is divided into five irrigation compartments of paddy land, comprising of Sungai Muda, Pinang Tunggal, Sungai Jarak, Tasek Gelugor and Jarak Tengah (Ministry of Agriculture Malaysia, 1997). The CHO structure with double barrel gates, located at the secondary canal Taliair B of Sungai Muda, was chosen for the installation and testing of the automation system.

2.2 The CHO system components

The CHO system evaluated consisted of 2 chambers having four 1.52 m x 1.52 m square gates. It was structurally strong with acceptable limits of leakage, required minimum maintenance, and was suitable for motorization. Basically, the CHO automation system consisted of two separate units, namely the site control unit and the station monitoring unit, controlled from the Department of Irrigation and Drainage (DID) office at Seberang Perai Utara (SPU) located about 5 km away from the test site. The automation system comprised of sensors, controller and other instrumentation, interfaced in order to make the CHO automation fully operational. The CHO site station equipment consisted of the controller unit for gate automation, actuator control system, measuring equipment for water level monitoring, power supply system, communication equipment, a protective device against lightening and surge, and system interfacing.

2.3 Principle of operation of system

CHO is a water-measuring device frequently used in irrigation management. It is a combination of a regulating (orifice) gate and measuring (turnout) gate structures, which is operated by setting and maintaining a constant head differential between the main canal and the stilling chamber water levels. The CHO structure provides for an accurate measurement of irrigation water with low head loss through the structure when required. A low head loss structure is advantageous in irrigation systems being more efficient and provides for a better command of water for the surrounding land.

The automated CHO system is capable of supplying a constant flow of water to the paddy field at minimum and maximum rates of 0.31 m^3s^{-1} and 1.2 m^3s^{-1}, respectively. Real time data from the system are gathered and displayed in the computer at the master controller station. The master controller controls and monitors the water level, discharge and gate opening at site on a real time basis. The CHO users at the master station can remotely control or configure some parameters at site according to the required irrigation flow rates via a Public Switch Telephone Network (PSTN) link. The controller unit located at site records the river level through ultrasonic water level sensors. The unit accepts inputs from the water level sensors and gives command to the actuator for the gates to open. By setting the required discharge in the control page at the master controller, the orifice gate and turnout gate are opened automatically according to the set discharge. Gate opening readings are then processed and stored in the controller unit at site. This information is transmitted to the master station via the PSTN link when activated at the master controller station. The operators at the master station can monitor what is happening without having to be physically present at site, as long as the system is working properly. Figure 2 shows the configuration of the automated CHO system.

2.4 System Performance Evaluation Procedure

The discharge was calculated by Equation 1 proposed by Bos (1978). This function was set as a control algorithm in the automation system for the determination of discharge when C_d is given as a constant, A_{og} for the orifice gate opening is given by the actuator and the differential head is provided by the water level sensors for different water levels at the main canal and chamber.

$$Q = C_d A_{og} \sqrt{2g\Delta h} \qquad [1]$$

where Q = discharge rate (m^3s^{-1}); C_d = coefficient of discharge; A_{og} = area of orifice gate opening (m^2); Δh = differential head (m); g = acceleration due to gravity (ms^{-2}). The present study assumed $C_d = 0.66$ (Bos, 1978) and $\Delta h = 100$ mm (Komarakul na Nokorn, 1977).

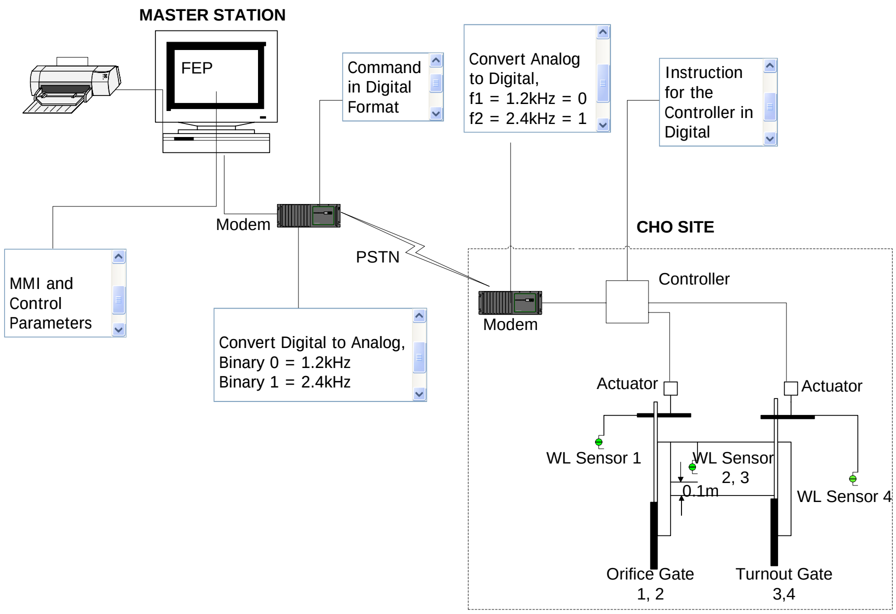

Figure 2. Configuration of the automated CHO system

The differential head between the main canal and chamber was maintained at 100 mm to ensure that the water is flowing under designed conditions. The preset value of the differential head was checked every 5 minutes of operation. The turnout gate opening was regulated such that it was always lower than the orifice gate opening. The orifice gate opening was verified by manual measurement at various discharge rates and flow settings of 0.31, 0.5, 0.7, 0.9 and 1.1 m^3s^{-1}. The data on the orifice gate opening was then plotted in a bar chart in order to compare the outputs from the automation system with data obtained by manual measurement at the various flow settings. The automated CHO was also calibrated by manual gauging using a current meter at the secondary canal at a constant differential head of 100 mm between the main canal and chamber level. The readings in revolutions per second of the current meter were converted to velocity in ms^{-1} using the rating, *n* of 0.21 (SEBA Standard Calibration Manual, 2000). The values obtained were then multiplied by the river cross sectional area to obtain values for the discharges at the specified points. The discharges for the automatic control and manual operation of the CHO at the secondary canal were also recorded for each specific gate opening and at the various flow settings. The data obtained was also plotted in a bar chart to compare the discharges of the two CHO systems. The performance of the automated CHO system was also evaluated in terms of operational time. The time taken for the orifice gate to open at the required flow rates by the automation system was recorded. The data collected was processed and presented in such a way that the CHO users can easily analyse. The analysis of data was done basically by two methods, namely through trend graph analysis and by using system performance reports. The system generated daily, weekly, and monthly reports as the summary for the gate operation. Through simple linear regression, mathematical relationships were established between discharge and orifice gate and turnout gate openings. Graphs of gate opening versus time for automated system and manually operated system were then plotted for the purpose of comparison.

3.0 RESULTS AND DISCUSSION

3.1 Discharge and Gate Opening Relationships

The data on discharges and the orifice gate and turnout gate openings obtained from the database in the master controller are illustrated in Figures 3 and 4, respectively. Linear relationships were observed to exist between discharge and both the gate openings. At a 100 mm constant differential head, the discharge increased with an increase in both the gate openings.

The relationship between discharge and orifice gate opening is expressed as:

$$Q = 1.15 * OG + 0.15 \qquad (R^2 = 0.96) \qquad [2]$$

Where Q = discharge (m^3s^{-1}) and OG = orifice gate opening (m). A maximum discharge of 1.03 $m^3 s^{-1}$ was attained at the orifice gate opening of 0.74 m.

The relationship between discharge and turnout gate opening is expressed as:

$$Q = 2.16 * TG + 0.13 \qquad (R^2 = 0.98) \qquad [3]$$

Where Q = discharge (m^3s^{-1}) and TG = turnout gate opening (m). A maximum discharge of 1.03 m^3s^{-1} was attained at the turnout gate opening of 0.43 m.

3.2 Verification of Orifice Gate Opening of the Automated CHO

Table 1 presents the orifice gate opening tested at the flow settings of 0.31, 0.5, 0.7, 0.9 and 1.1 m^3s^{-1} at the master controller, represented as setting 1, setting 2, setting 3, setting 4 and setting 5, respectively. Test results indicated a general increase in orifice gate opening for manual measurement compared to the automatic control. A maximum increase of 10.5% in orifice gate opening by manual measurement over the automatic measurement was observed for the different flow settings.

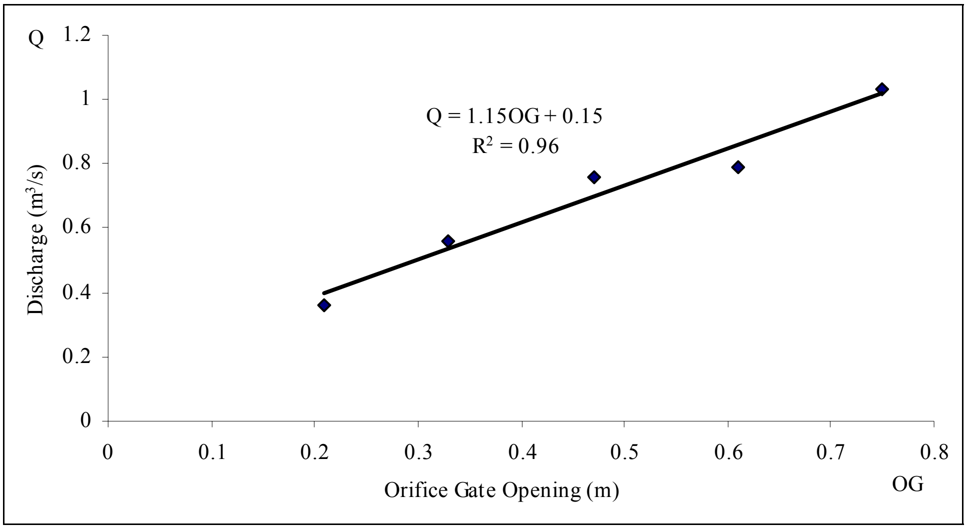

Figure 3. Relationship between discharge and orifice gate opening

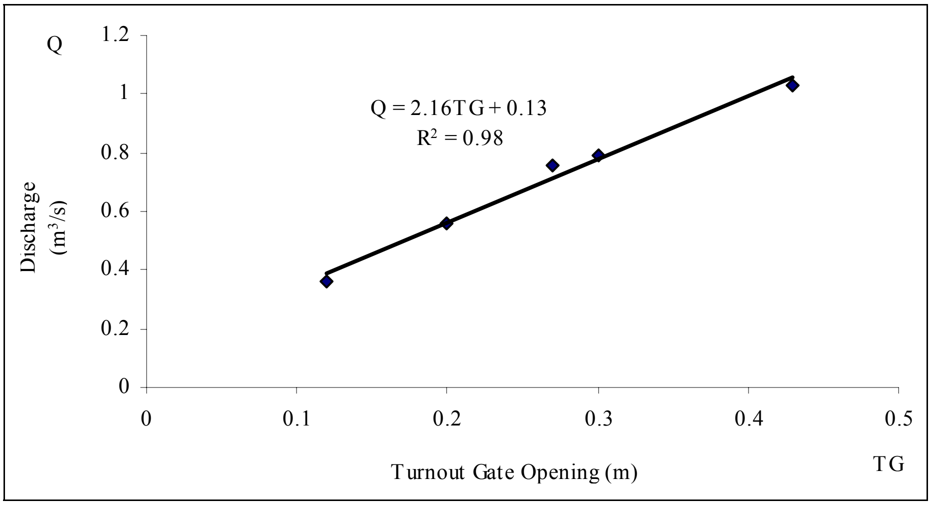

Figure 4. Relationship between discharge and turnout gate opening

Table 1. Automatically measured and manually measured orifice gate opening for different flow settings

Flow Setting	Orifice Gate Opening (m)		% Increase
	Automatically Measured	Manually Measured	
Setting1	0.19	0.21	10.5
Setting2	0.30	0.33	10.0
Setting3	0.45	0.47	4.4
Setting4	0.55	0.60	9.1
Setting5	0.69	0.74	7.2

3.3 Verification of Discharge of the Automated CHO

Table 2 presents the discharge rates for the various flow settings of 0.31, 0.5, 0.7, 0.9 and 1.1m^3s^{-1} at the master controller, represented as setting 1, setting 2, setting 3, setting 4 and setting 5, respectively. Test results showed that there was an overall increase in average discharge values between automation supply and manual gauging. Generally, the manual gauging discharges were higher than the automation discharges for most of the flow settings. A maximum increase of 39.8% in discharge for manual gauging over the automation supply was observed at the flow setting of 1.1 $m^3 s^{-1}$.

Table 2. Automated CHO and manual gauging discharge rates for various flow settings

Flow Setting	Discharge rates ($m^3 s^{-1}$)		% Increase*
	Automation Supply	Manual Gauging	
Setting 1	0.36	0.27	-25.0
Setting2	0.56	0.48	-14.3
Setting3	0.76	0.83	9.2
Setting 4	0.79	0.82	3.8
Setting 5	1.03	1.44	39.8

* Negative means a percentage decrease in discharge for manual gauging compared to automation supply

3.4 Comparison of the Automated CHO System and Manual Operation

Figure 5 illustrates the operational time requirements of the automated system and manual system. A great difference in time requirements was observed between manual operation and the automated CHO system. The time required to open the gate by the automated CHO system increased with increase in orifice gate opening. A similar trend was observed for the manual operation. For any particular orifice gate opening, the time requirement for the automated CHO was always less than that required for manual operation of the CHO. For example, for an orifice gate opening of 0.21 m, the time requirements were 27.26 s and 300 s for the automated and manual operation, respectively.

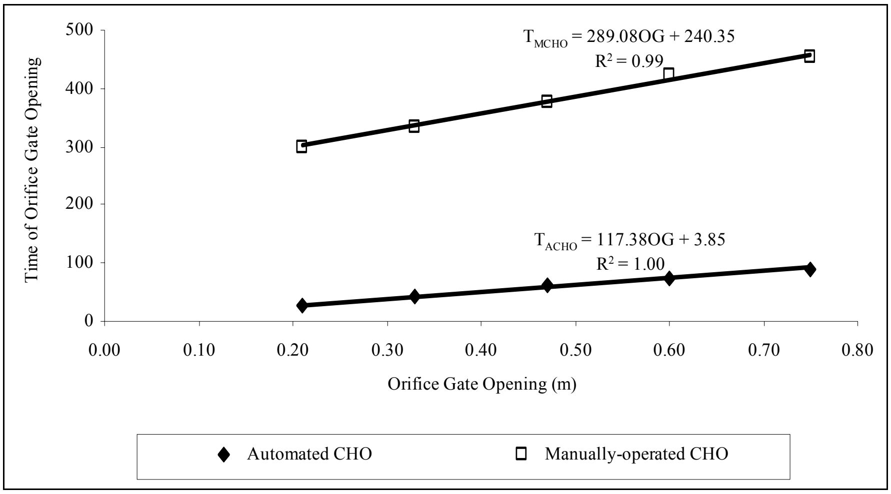

Figure 5: Operational time for manual operation and the automated CHO at various orifice gate openings

The mathematical relationships established between orifice gate opening and the time required to open the gate by the automated CHO system and manual operation were as follows:

$$T_{MCHO} = 289.08 * OG + 240.35 \qquad (R^2 = 0.99) \qquad [4]$$

$$T_{ACHO} = 117.38 * OG + 3.85 \qquad (R^2 = 1.00) \qquad [5]$$

Where T_{MCHO} = time required for manual operation (s); T_{ACHO} = time required by automated CHO to open the gate (s); and OG = orifice gate opening (m).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The operation of the automated CHO system involved two major aspects, namely the mechanization of the system's operation and information communication technology (ICT) application. Through the use of actuators, the need for human workforce was drastically reduced, and precise opening and closing of the CHO gates were ensured, resulting in a more accurate water level monitoring. The ICT application also ensured remote monitoring of the system and execution of the programmed standard operating procedure in the master controller. The CHO control system hardware for paddy irrigation at the Block M2 of the Sungai Muda Irrigation Scheme was initially configured. The master controller at DID, Seberang Perai Utara (SPU) office was integrated with the CHO structure at site, interfaced with a Supervisory Control and Data Acquisition (SCADA) system. The CHO control system software was integrated with the master controller to control the operation of the orifice gates at site according to the irrigation water requirements, ranging from 0.4 m^3s^{-1} to 1.2 m^3s^{-1} for the study area.

The performance of the automated CHO off-take structure was evaluated in terms of discharge at the secondary canal, orifice gate and turnout gate openings, and the time requirement for operating the orifice gates manually and by the automation system. Positive linear relationships were found to exist between discharge and both the orifice gate opening and turnout gate opening. At 100 mm differential head, a maximum discharge rate of 1.03 m^3s^{-1} was attained at an orifice gate opening of 0.74 m and turnout gate opening of 0.43 m. The time requirement for the automated CHO to open the orifice gate was less than that required for manual operation.

There is room for making improvements in the existing automated CHO system through interfacing with a rainfall telemetry system. Installation of flow meter equipment at the beginning and water level sensors at the end of the secondary canal could ensure an accurate measurement of discharge from the CHO. This study also suggests the automation of CHO structures in all the irrigation schemes within the granary areas of Malaysia and link them to one master controller, particularly those CHO structures getting water supply from the same source.

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