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Physical Model Design of Tertiary Box Combined with Overflow and Orifice

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Abstract: This research aimed to design tertiary boxes combined with overflow and orifices. The methodology consists of a physical model test of the orifice. The model dimensions used in this research are adapted to the field conditions required in the criteria of irrigation design and as trial variables: channel width = 0.42 m; channel height (h) = 0.78 m; and crest height (P) = 0.25 m. The crest width uses two alternatives: 0.42 and 0.33 m. However, the diameter of the orifice uses three alternatives: 0.08 m, 0.06 m, and 0.04 m. The orifice placement also uses three alternatives: in the channel bed, the distance of the orifice from the channel bed is $\frac{1}{2}$ of the diameter, and the distance of the orifice from the channel bed is the same as the diameter. Several orifices also use three variations: one, two, and three orifices. However, discharge uses eight variations: 25 l/s, 30 l/s, 35 l/s, 40 l/s, 45 l/s, 50 l/s, 55 l/s, and 60 l/s. Based on the variation of variables above, we obtained 448 scenarios, consisting of 432 scenarios using orifices and 16 scenarios without orifices. The research result will produce the average discharge coefficient of the orifice, the difference ratio limits of the downstream and upstream water levels so that it does not cause submerged flow, and produce ideal dimensions and positions of the orifice to the accuracy of proportional discharge division under the condition of free and submerged flows.

Keywords: physical model, overflow, orifice, tertiary box.

溢流與孔板結合的三級箱體實體模型設計

摘要：本研究旨在設計結合溢流和孔口的三級箱。該方法包括孔口的實體模型測試。本研究中使用的模型尺寸可適應灌溉設計標準中所需的現場條件並作為試驗變數：渠道寬度 = 0.42 米；通道高度 (h) = 0.78 米；波峰高度(磷) = 0.25 米。波峰寬度有兩種選擇：0.42 和 0.33 米。然而，孔口的直徑使用三種選擇：0.08 米、0.06 米和 0.04 米。孔口佈置也採用三種替代方案：在通道床中，孔口與通道床的距離為直徑的 $\frac{1}{2}$ ，孔口與通道床的距離與直徑相同。有些孔口也使用三種變體：一孔口、二孔口和三孔口。然而，排放使用八種變化：25 升/秒、30 升/秒、35 升/秒、40 升/秒、45 升/秒、50 升/秒、55 升/秒和 60 升/秒。根據上述變數的變化，我們得到了 448 個場景，其中使用孔口的場景 432 個，不使用孔口的場景 16 個。研究結果將產生孔口的平均流量係數、下游和上游水位的差值比例限制，使其不引起淹沒流，並在比例流量分配精度下產生理想的孔口尺寸和位置。條件。

关键词：實體模型、溢流口、孔板、三級箱。

1. Introduction

A factor that influences the increase in agricultural production is the condition and function of the irrigation network, including the supporting structure that can prepare and flow water to the rice fields area [1]. From several levels of water division, the interaction of water division directly with farmer rice fields, most of them happened at the tertiary or quarterly level and generally occurred downstream of the network. Therefore, the area in the downstream network can be isolated and far from the range of water regulator officers [2]. Tertiary boxes must be easily operated so farmers can receive adequate irrigation water.

To provide easy irrigation water service for farmers, at the tertiary and quarterly levels, a tertiary/quarterly box or turn out that can divide proportionally discharge. Nowadays, the layout of box-turn-out structures most commonly used is the side form, in which the planned discharge division is proportionally less accurate. After all, the velocity from the straight direction is larger than that from the side direction.

There is an alternative to box-turn-out structure development, such as spear form. This form is suitable for proportionally discharge division, but it has a weakness that requires a relatively broader area than the side form. Therefore, there is a need for an alternative to rehabilitation and modification of the existing box structure that fulfills two unsure such as close to proportional [3-5], and there is no need for area expansion. Previous research has developed an orifice crest that is the control structure of practical discharge, such as a crest that is given circle holes in the width side of the crest with the hole position being one way with the flow direction. This research intends to increase the efficiency of box structure turnover by changing an existing structure with simple construction. One of the results expressed that the discharge coefficient [6-7] produced by the orifice is better or larger, and this research was carried out in two flow directions.

In three flow directions of the existing box condition at this time, there is the potential for alternative development in the other structure type that combines the available structure and research results of orifices, and it can be hoped that it will be more efficient from the accuracy side of the water division.

2. Materials and Methods

The flow in an opened channel that is through a pipe has some conditions that are free flow, transition flow, and pressure flow. Free flow occurs if the water passes through an orifice and is not fully charged with the unsubmerged water. Transition flow occurs if the water

surface upstream touches the inlet top end, which is maintained until the maximum water discharge. Pressure flow occurs if in all orifices, the flow cross-section is full of water until there is a pressure flow [8].

The pattern of discharge division that occurs in the orifice is a lateral discharge flow in which this flow is perpendicular to the main flow with a constant additional volume along the main channel width. If in orifice bed part without slope and area of intake hole cross-section is the same, in permanent condition will give guarantee that discharge that is pulled to the right and left is the same. According to [9], the process takes place under specific energy conditions that are assumed constant, so it can be studied regarding the applicable rules and principles of hydraulics.

By considering that there does not need an area, this research is more likely to modify the box-turn out structure in spear form, which intends to reach proportionality. This structure combines outflow in the overflow form and orifice, which has not been explored in previous research.

2.1. Location

The research was conducted in the Laboratory of Applied Hydraulic Engineering, Department of Water Resources, Faculty of Engineering, University of Srivijaya.

2.2. Scope of Research

This research aims to obtain the discharge coefficient and design parameter of a box structure that combines overflow and orifice that is more efficient from the accuracy level of water division so that the service of water division in an irrigation network can be run effectively and optimally.

2.3. Physical Model

The physical model that was used for testing in this research was a box-turn-out tertiary model with three flow directions that combines overflow and orifice with model scale: prototype model = 1:1. The model was constructed using a flume/open channel.

3. Results and Discussion

3.1. Dimensions of the Model Test

The dimensions used in this research is adjusted with field condition that is required in the Criteria of Irrigation Design. The dimensions of the model test are as follows:

Channel width: 0.42 m

Channel Height: 0.78 m

Crest height: 0.25 m

Crest width (1): 0.42 m

Crest width (2): 0.33 m
 Diameter 1: 0.08 m
 Diameter 2: 0.06 m
 Diameter 3: 0.04 m

3.2. Orifice Placement

a_1 - orifice in the bed channel
 a_2 - distance of orifice from channel bed is 1/2 of diameter
 a_3 - the distance of the orifice from the channel bed is the same as the diameter
 Number of orifices

n_1 - 1
 n_2 - 2
 n_3 - 3

Fig. 1 presents the physical model test of the box structure combined with the overflow and orifice, and Fig. 2 presents the physical model test scheme of the turn-out structure combined with the overflow and orifice.

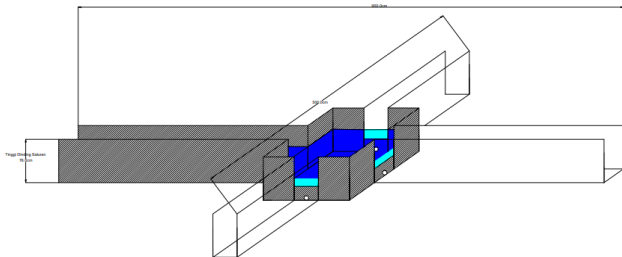


Fig. 1 Physical model test of box structure combined with overflow and orifice (The authors)

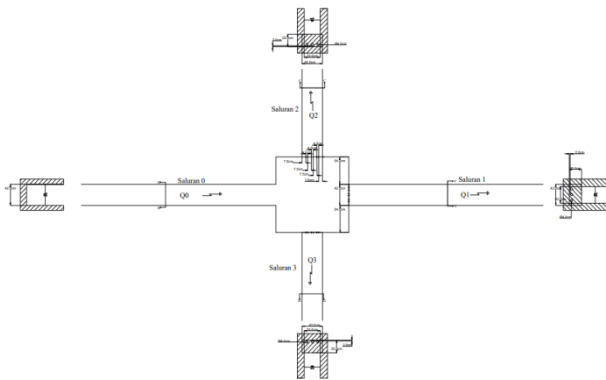


Fig. 2 Physical model test scheme of a turn-out structure combined with overflow and orifice (The authors)

The flow discharge in the physical model test was varied from 20 l/s until the maximum capacity of the channel cross-section was 60 l/s. The minimum discharge in the secondary channel is more than 25 l/s

(based on the KP 05). Although the discharge treatment fulfills the requirement, the minimum discharge that is treated must fulfill the range of the measured minimum discharge customized to the dimensions of the Rechbox and Thompson measuring tools. The use of the largest discharge variation also considers the draonage condition in the physical model, so the requirement of the measurer tool flow is fulfilled. In addition, the mechanism by which the flow drainage from the physical model returns to the storage pond is also considered. Therefore, the discharge flow in the designed model is 60, 55, 50, 45, 40, 35, 30, and 25 l/s. The analysis of discharge in the rechbox for obtaining an h beachboy customized to the designed discharge for trial with various scenarios is as follows (Fig. 3).

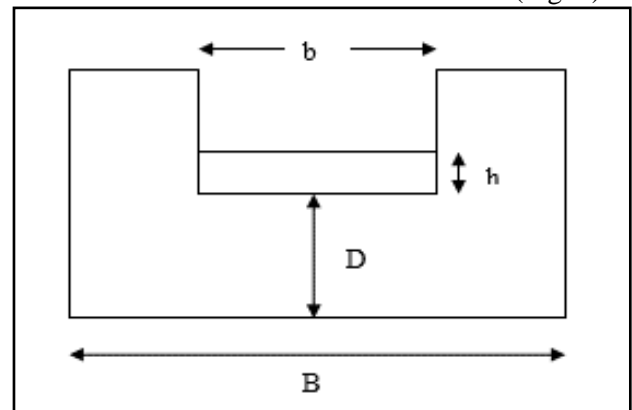


Fig. 3 Measurement tool of Rechbox [10]

Explanation: b - mercu width of Rechbox (m); h - water level over mercu (m); B - Rechbox width (m); D - height from bed to merck (m)

According to [10], the discharge equation of Rechbox measurer tool is as follows:

$$Q = K \times B \times h^{\frac{3}{2}} \tag{1}$$

where:

Q - theoretical calculation of discharge of Rechbox equation (m^3/s)

K - discharge coefficient over the Rechbox crest: $107.1 + (0.177/h) + 14.2 (h/D) - 25.7 \{[(B-b)h]/DB\}^{1/2} + 2.04 (B/D)^{1/2}$

where:

h - water level over mercu (m)

B - Rechbox width (m)

From the result of the Q analysis, there is designed to obtain h and the discharge curve, as presented in Table 1 and Fig. 4.

Table 1 Analysis of water level over Rechboxes customized to Q design (The authors)

No.	Water level over the spillway (h)		Discharge coefficient (K)	Discharge of Rechbox (Q)		
	(m)	(cm)		(m ³ /mint)	(m ³ /s)	(l/s)
1	0.067	6.7	108.706	1.508	0.025	25
2	0.076	7.6	108.237	1.800	0.030	30
3	0.084	8.4	107.850	2.101	0.035	35
4	0.092	9.2	107.531	2.401	0.0400	40
5	0.100	10.0	107.258	2.701	0.045	45
6	0.107	10.7	107.022	3.001	0.050	50
7	0.114	11.4	106.813	3.302	0.055	55
8	0.121	12.1	106.628	3.599	0.060	60

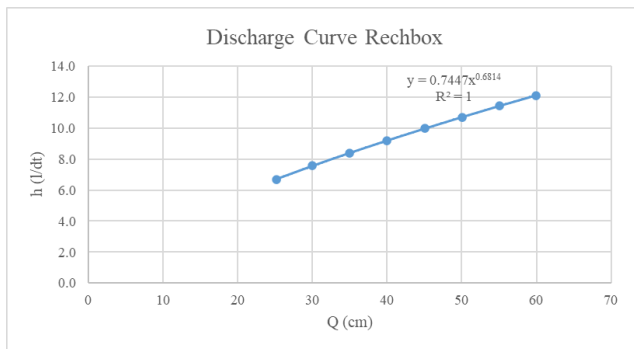


Fig. 4 Discharge curve Reachbox (The authors)

3.3. Test Scenario

The variables used are as follows:

- Discharge uses 8 variations: 25, 30, 35, 40, 45, 50, 55, and 60 l/s.
- Crest width uses 2 variations: 0.42 m and 0.33 m.
- Dimension of orifice uses 3 variations of diameter: 0.08, 0.06, and 0.04 m).
- Placement of orifice uses 3 variations: orifice in the bed channel, distance of orifice from the channel bed is 1/2 of diameter, distance of orifice from the channel bed is the same as the diameter.
- Number of orifice uses 3 variations: 1 orifice, 2 orifices, and 3 orifices.

Based on the variables and variations above, the obtained number of scenarios is 448 scenarios, consisting of 432 scenarios using orifices and 16 scenarios without orifices. A scenario without orifices is used to compare the analysis results using orifices. The physical model can realistically illustrate proportionality that can be achieved by combining a box-turnout structure. Therefore, it is necessary to perform some tests from several scenarios so that it can be found the proportional value that wants to be achieved or close to perfect as in the continuity equation.

Based on the conditional law that inflow is the same as outflow, or:

$$Q_{in} = Q_{out}; \text{ thus,} \tag{2}$$

$$Q_0 = Q_1 + Q_2 + Q_3 \tag{3}$$

Therefore, the test scenario in this research can be explained as follows (Fig. 5).

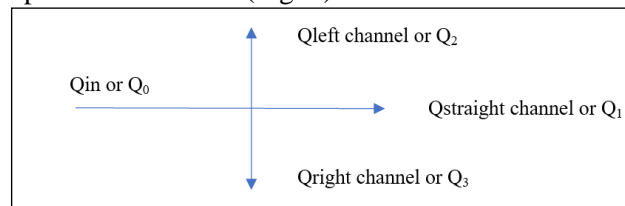


Fig. 5 Scheme model of flow discharge in a channel (The authors)

The proportionality test was performed by testing several scenarios as follows:

– Scenario

$$Q_0 = Q_1 + Q_2 + Q_3 \tag{4}$$

The outflow from 3 channels is the same ($Q_1 = Q_2 = Q_3$). This test will be carried out several times by customizing the form or size from the outlet so that a result that is close to the equation above.

– Validation

The development of a box-turn out structure combined with overflow and orifice-side form is also used in the equation in scenario-1, where the outflow from 3 channels are the same or $Q_1 = Q_2 = Q_3$. The development of the structure is useful for conducting the validation test of scenario 1, which is estimated to obtain a better proportional result. From the scenario test, the water level in the tertiary box, the water level upstream of the orifice, the water level downstream, the velocity in each channel, and the water level (h) Thomson in each channel will be obtained to obtain discharge in every channel. Figs. 6 and 7 present an illustration of the measurement point at the crest of 0.42, placement of an orifice in the bed with 1 orifice, and tested discharge of 60 l/s.

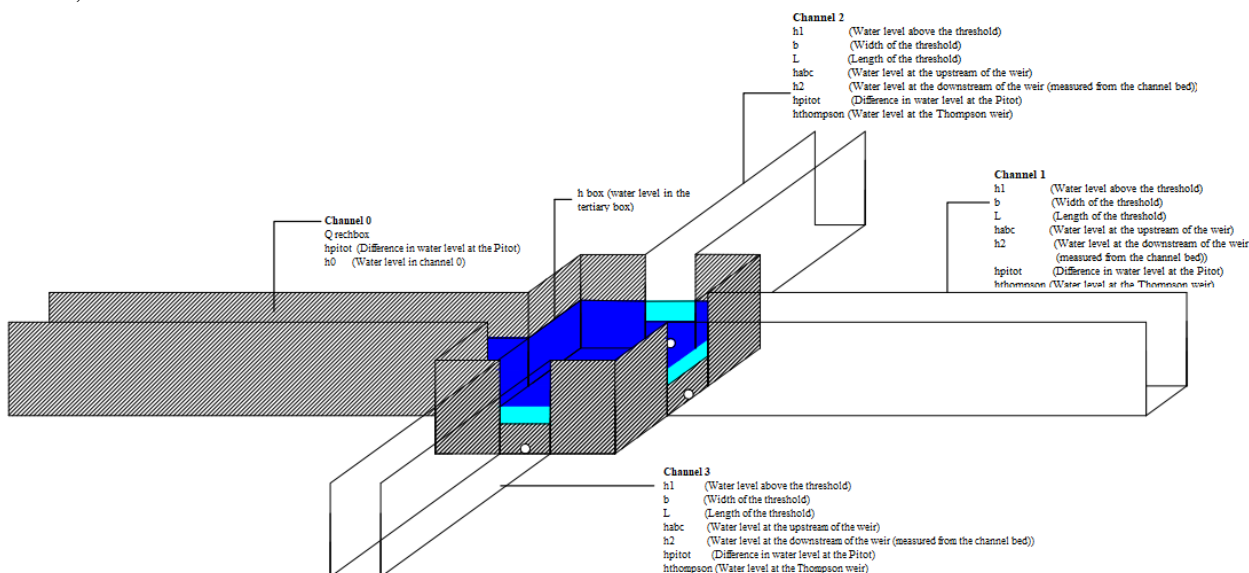


Fig. 6 Observation points of discharge and water level depth in the channel physical model (The authors)



Fig. 7 Details of observation points in the development of model tests (The authors' observation results, 2024)

This observation point has also happened for discharge scenarios that will be further tested. In this research, there are several flow conditions that can be observed: flow through a crest without orifice, flow through an orifice, and flow through a crest and orifice. Fig. 8 presents the flow through the crest, Fig. 9 presents the flow through the orifice, and Fig. 10 presents the flow through the crest and orifice.

• *Flow through crest*

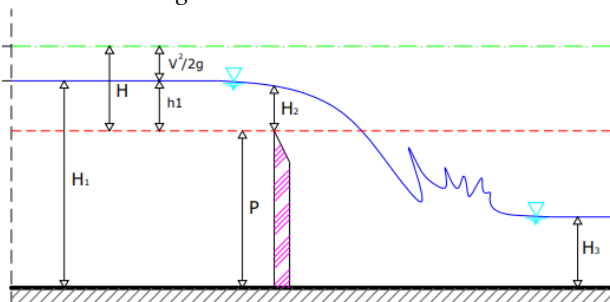


Fig. 8 Flow through the crest (The authors)

• *Flow through orifice*

When flowing through an orifice, the body will experience contraction, as shown by the flow contraction. Therefore, the flow through an orifice is not perpendicular but forms a certain angle caused by the velocity effect in the channel.

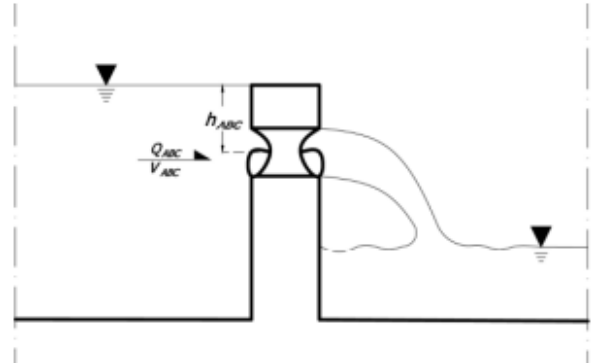


Fig. 9 Flow through the orifice (The authors)

• *Flow through the crest and orifice*

When the water level in the orifice downstream is going out, it is over the orifice to the upside, so the orifice is mentioned as submerged. The Fig. below shows the submerged hole for which the elevation of water level upstream and downstream of the hole axis is abc and h2.

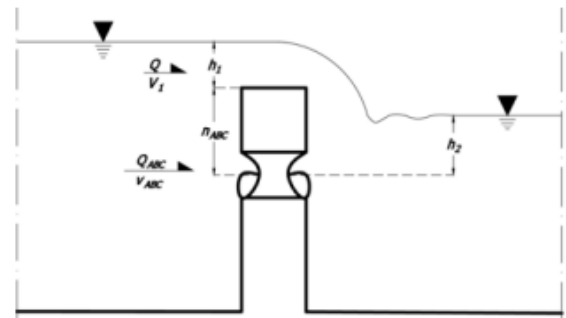


Fig. 10 Flow through the crest and orifice (The authors)

The aim of the hydraulic physical model test is to know the accuracy of discharge using orifices and to know the dimension and position of orifices to the accuracy of proportional discharge division.

3.4. Calibration and Verification

3.4.1. Calibration of the Thompson Discharge Measurer

The Thomson measurer structure is a very accurate and suitable tool for measuring small discharge between 5-7 l/s ($h_{max} = 30$ cm), and it is suitable for quarter channels or little channels in rice field blocks [11].

Calibration of the Thompson discharge measurer tool intends to obtain an accuracy of discharge measurement that is better than discharge measurement as the result of the theoretical equation for the Thompson measurer tool as follows:

$$Q = K.h^{5/2} \quad (5)$$

where:

Q - discharge of Thompson (m^3/s)

K - coefficients of Thompson discharge

h - water level over Thompson River (m)

From the calibration result, this result was obtained for Channel 1 (Fig. 11):

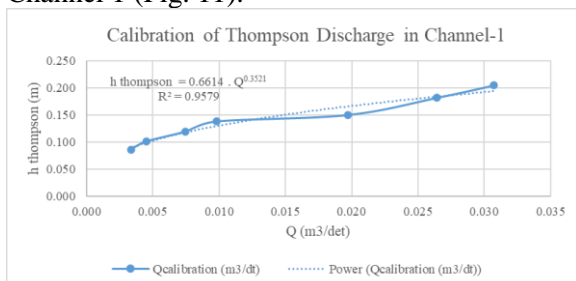


Fig. 11 Calibration of D-Thompson discharge in channel 1 (The authors' analysis results, 2024)

The discharge curve above is then regression to produce the formulation as follows:

$$h \text{ Thompson} = 0.725 \cdot Q^{0.3632} \quad (6)$$

Therefore, based on the above equation, the formula of Q can be determined as follows:

$$Q = \left(\frac{h \text{ thompson}}{0.725} \right)^{\frac{1}{0.3632}} \quad (7)$$

From the calibration result, it was obtained in channel-2 as (Fig. 12):

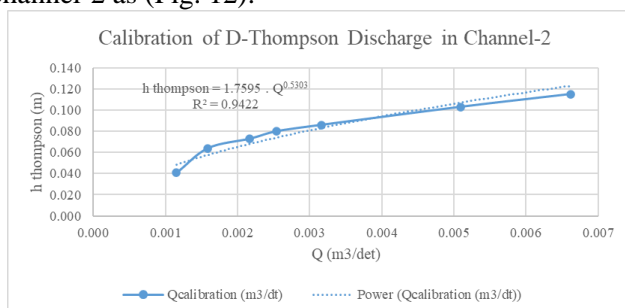


Fig. 12 Calibration of the D-Thompson discharge in channel 2 (The authors' analysis results, 2024)

The discharge curve above is then regression to produce the formulation as follows:

$$h \text{ Thompson} = 1.7986 \cdot Q^{0.5402} \quad (8)$$

Therefore, based on the above equation, the formula of Q can be determined as follows:

$$Q = \left(\frac{h \text{ thompson}}{1.7986} \right)^{\frac{1}{0.5402}} \quad (9)$$

From the calibration result, it was obtained in channel-3 as in Fig. 13.

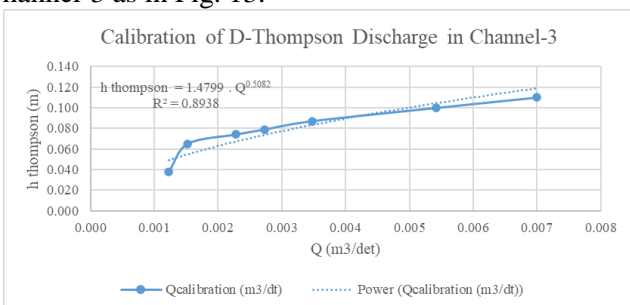


Fig. 13 Calibration of D-Thompson discharge in channel 3 (The

authors' analysis results, 2024)

The discharge curve above is then regression to produce the formulation as follows:

$$h \text{ Thompson} = 1.4,799; Q^{0.5082}$$

Therefore, based on the above equation, the formula of Q can be determined as follows:

$$Q = \left(\frac{h \text{ thompson}}{1,4799} \right)^{\frac{1}{0.5082}} \quad (10)$$

3.4.2. Calibration of the Pitot Velocity Measurement Tool

The calibration of the pitot measurement tool was intended to obtain the velocity coefficient value in accordance with the condition of the pitot tubes during treatment. The correction in coefficient (C_p) by the pitot equation is as follows:

$$V = C_p \cdot \sqrt{2 \cdot g \cdot \Delta h \text{ pitot}} \quad (11)$$

From the calibration results, it was determined that the average pitot velocity coefficient was 0.740.

3.4.3. Verification

Verification is a stage to prove that the parameter obtained in the model is correct. The control of discharge flows through a discharge measurer tool of Thompson which will gradually fulfill storage in the upstream of the crest. If the water level in storage is more than crest merck, water will overflow over crest with a certain height regarding the analysis result of the water level over crest. After measurement in the laboratory and obtaining data of the water level over the crest, the results are compared with the theoretical result. If the relative error is less than 10%, then it is accepted.

4. Conclusion

The increase in agricultural production is closely related to the condition and function of the irrigation network. One of the essential factors in an irrigation network is the tertiary box or turnout those functions for dividing water proportionally to the farmer. The tertiary box or turnout generally uses a block Scott gate as a measurer structure for controlling discharge into the turnout structure. From the construction side, block Scott is a simple construction; however, from the operation side, it is needed many times. To increase the efficiency of operating irrigation structures was carried out research through physical model tests by building orifices. An orifice is a ridge with circular openings on the broad side of the crest to ease and efficiently provide an irrigation water supply.

To increase the effectiveness of irrigation structure operation in irrigating agricultural areas, the development of a box-turn-out structure that combines overflow and orifices is very accurate to be carried out. The research on this model concept was carried out by building a physical model with a scale of 1:1 in the laboratory. The test was carried out with variations in

discharge, crest width, diameter, placement, and number of orifices. From this research, we obtain the relation curve for the dimension of the box-turn out a structure that combines with overflow and orifice for proportional discharge division, coefficient of crest discharge with orifice, and difference ratio limits of water level downstream and upstream so that does not cause submerged flow. This research suggests using supporting research tools with suitable accuracy for obtaining results with a higher reliability level.

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