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Kampus IPB Darmaga, Bogor 16680. Telp. 0251-8624691, Fax 0251-8623026,
E-mail: jtep@ipb.ac.id atau jurnaltep@yahoo.com. Website: ipb.ac.id/~jtep.

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Technical Paper

Hydraulical Approach in Designing of Proportional Division Structures in Traditional Irrigation Schemes

Pendekatan Hidrolik dalam Perancangan Struktur Pembagian Proporsional pada Skema Irigasi Tradisional

M. Hasan Yahya[1]

Abstract

To disribute water in equal and adequate ways among the farmers, farmers have been using a proportional division structure for years. The constrtuction of the structure is made of wood or stone with the notchs in rectangular form in part of its upper side. Its performance criterion estabilished by pertinient famers i.e. the notch width has to be proportional to the size of its command area. From hydraulic point of view, however, the unreliability of these structures can be occurred and it was estimated that their performance criteria not only depend on the notch width but also the other hydraulic design criteria. The objectives of this research are: (i) to comprehend the dependence of performance of a proportional division structure on hydraulic design criteria, (ii) to know relationships between the discharge of structure and the hydraulic design criteria. Result of experiment indicated that the performance of a proportional division structure not only depend on notch width but also the other hydraulic design criteria in common. In general, there were the relationships between discharge of a notch and the hydraulic design criteria including notch width, thickness and surface roughness of the structure, and deviation angle of channel where the structure to be located.

Keywords: *traditional Irrigation system, proportional devision structure, physical model, dimension analysis*

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Introduction

A traditional irrigation system, also known as farmer managed irrigation, performed with or without a financial aid of the goverment and fully manged by pertinient farmers. These irrigation schemes cover at least 1,036,613 ha or about 21 % of total irrigated areas in Indonesia (Ambler, 1992). The systems are facing to a number of difficult problem caused by changes in ecosystem (as consequence of deforestation), the status of water as natural resources (the priorities of water utilization established) and social economic condition in the area. One of difficult problems faced by irrigation system management of the management of is how to distribute water in equal and adequate ways among the farmers. The distribution water in unacceptable way by part of the farmers can lead to social conflict.

As an endeavor of overcoming the problem, the farmers has been using a proportional division structure for years, or may be for centuries, especially in the area with limited water supply. The performance criterion of this structure estabilished by the famers i.e. the notch width has to be proportional to the size of its command area. In its operation, the proportional division structure is set at such the branching of a channel that the vicinity of structure constitue a non aligment channel (corner or concave wall). So the branches of channel form an angle with main channel in a variety of deviation angle.

Field experience indicated that the realibility of farmer's designed and operated the devision structures were not always good enough. As consequence, the farmers must regularly modify the size of the notch which they established formerly. Oftentimes, it was also difficult to make a consensus among the involved famers in the case that a farmer has a large rice area or there was a social problem which was difficult to be solved.

From hydraulic point of view, however, the unreliability of these structures can be occurred and it was estimated that their performance criteria not only depend on the notch width but also the deviation angle (Subramanya, 1983), flow properties (Chow, 1986), and surface roughness (James, 1986). Moreover, the perfomance of the division structure

[1] Faculty Staff, Dept. of Agricultural Engineering, Syiah Kuala University, Darussalam Banda Aceh, Email: hasan_yhy@yahoo.co.id

has never been studied such a further that was estimated the perfomance also vary with the other hydraulic properties and hence can deviate from the formance base on above criterion.

According to Walker (1989) design process of an irrigation structure covers matching procedure between desirable water requirement for farmers in one hand and water supply capacity in the other hand. Therefor the limits of water supply to meet optimum irrigation adjustment must be evaluated. In addition, slope and size of channel, location and size of division structure must be determined. These natures of task need certain task requirements of human system. In this research, the design process restricted to hydraulic solution only with less attention on capability of operators and users to operate system in propper way.

The objectives of this reseach are : (i) to comprehend the dependence of performance a division structure on hydraulic design criteria, (ii) to know relationships between the discharge of structure and the hydraulic design criteria including flow properties, notch width, the thickness and surface roughness of the structure, and deviation angle of channel where the structur to be located.

The usefullness of this research are: (i) to provide the knowledge in designing the proportional division structure properly by using physical model, and (ii) can be the input in evaluating, operating, and developing the existing proportional division structure.

Proportional Division Structure

A proportional division structure in a farmer managed irrigaton system has a simple form in common, made of available material in the area such as wood stave, wood stem, stone, cement, or clay. Geometry of a typical division structure "Cowal" in West Java showed in Figure 1.

In its operation, a division structure set up at the branching of a channel so that its vicinity constitute a non linier alignment channel (corner, or concave wall) (Fig.2). These branchs could be formed with a variety of its deviation angle (Karnaen, *et al* and Sushila in Ambler, 1992).

The division structure could commonly be found in the area with the channel bed of a steep slope such as around the valley of a hill where hydraulic jump exist, so the downstrem water level can not influence the upstream water level. Usually, the

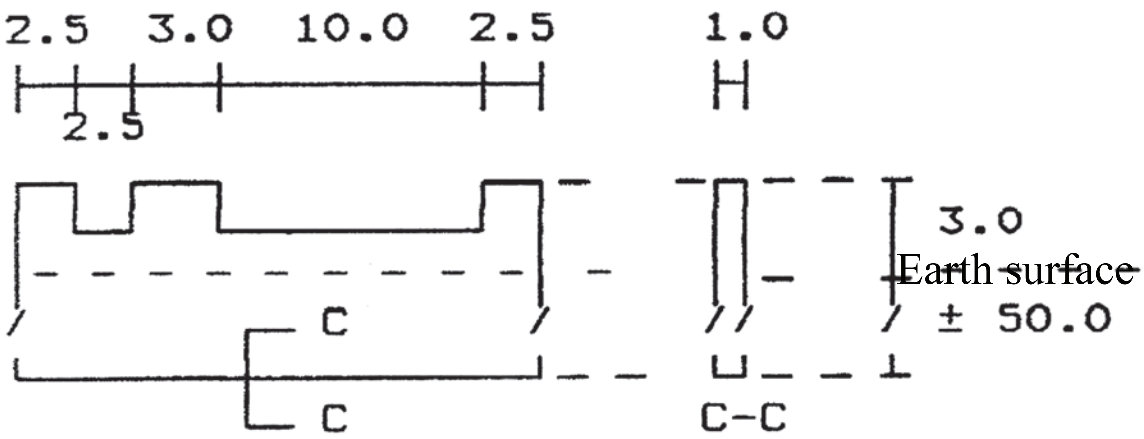

Figure 1. " Cowal " a typical proportional division structure in West Java (in cm): (a) longitodinal section and (b) cross section (Karnean *et al.* in Ambler, 1992)

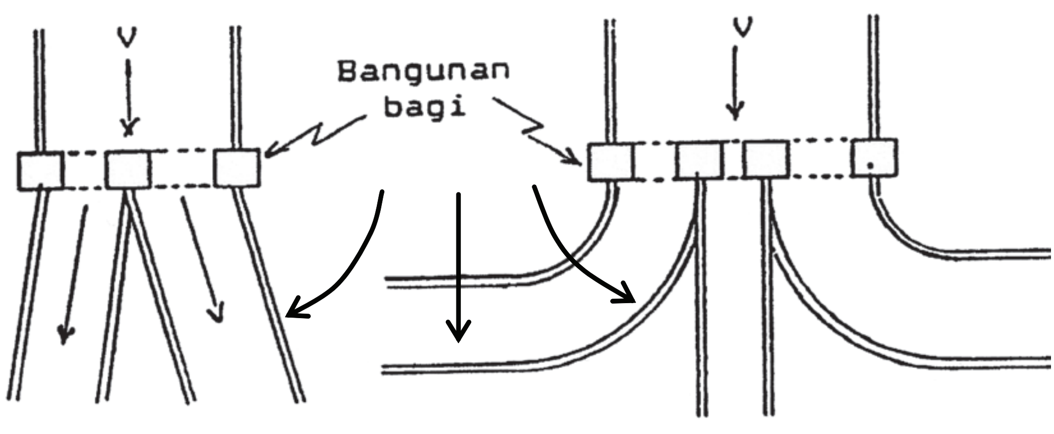

Figure 2. Setting a proportional division structure in a branching of channel: (a) at corner wall and (b) at concave wall (Karnaen, *et al* and Sushila in Ambler, 1992)

division structure is found in the area with limited water suply, conversely, in the area with sufficient water suply, this structure rarely used (Ambler, 1992).

According to James (1988) in order to function well, a division box should meet : (i) the approach channel is long and straight for at least 5 to 10 m upstream, so that flow approach the divisor in paralel path without cross currents; (ii) there is no backwater effect that would favor one side or the other; and (iii) the flow section of the structure is uniform roughness.

Mathematical Modelling

Discharge of a notch, which is constitue the function of hydraulic design criteria, can be written as follow :

$$Q_i = F(V_i, b_i, h_i, \tau_i, k_i, \theta_i, g, \rho, \mu, \sigma) \quad (8)$$

Result of dimension analysis of the above equation provides the equation in Pi term (Murphy, 1950; Munson et al., 1990) :

$$\frac{Q_i}{V_i b_i^2} = C\left(\frac{h_i}{b_i}, \frac{\tau_i}{b_i}, \frac{k_i}{b_i}, \frac{V_i^2}{gh_i}, \theta_i, \frac{\rho V_i b_i}{\mu}\right) \quad (9)$$

$$\pi_1 = C(\pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7) \quad (10)$$

In open chnnel, to obtain dynamic similarity, viscocity force can be ignored so that π_7 can be eliminated (Simon, 1986). In addition, in case there is no backwater effect, π_6 can also be eliminated. Threrefore equation 10 can be simplified as

$$\pi_1 = C(\pi_2, \pi_3, \pi_4, \pi_5) \quad (11)$$

Thereby, in accordance with Watkins (1976), several equations of design conditions can be obtained as follows :

$$h_i = n_i h_{iM} \quad (12)$$

$$\tau_i = n_i \tau_M \quad (13)$$

$$k_i = n_i k_M \quad (14)$$

$$V_i = n_i^{0.5} V_{iM} \quad (15)$$

$$l_i = n_i^{0.5} V_M \quad (16)$$

$$Q_i = n_i^{2.5} Q_{iM} \quad (17)$$

Based on equation (11), the peridiction equation in Pi term written as follow (Murphy, 1950):

$$\pi_1 = \frac{\pi_{2\overline{345}} \; \pi_{\overline{2}3\overline{45}} \; \pi_{\overline{23}4\overline{5}} \; \pi_{\overline{234}5}}{\pi_{\overline{2345}}} \quad (18)$$

If prediction discharge base on equation (18) rather distortion from theoritical formula, the right term of equation (17) must be multiplied by the pridiction factor δ (Murphy, 1950), so that the equation become:

$$Q_i = \delta n_i^{2.5} Q_{iM} \quad (19)$$

Hence, total discharge prediction of a proportional division structure of i notchs are

$$Q_i = \delta_1 n_1^{2.5} Q_{1M} + \delta_2 n_2^{2.5} Q_{2M} + \ldots + \delta n_i^{2.5} Q_M \quad (20)$$

The determination of prediction factor can be done as follow (in this case: $\pi_7 \neq \pi_{7M}$)

$$\pi_{7M} = a\pi_7 \quad (21)$$

$$\frac{\rho V_{iM} b_{iM}}{\mu} = \alpha \frac{\rho V_i b_i}{\mu}$$ where α = distortion factor.

$$\alpha = n_i^{-1.5};\ n_i = \frac{l_i}{l_{iM}};\ \delta = \frac{f(\pi_7)}{f(\alpha\pi_7)} = \frac{C\pi_7^m}{C\alpha^m \pi_7^m} = \alpha^{-m}$$

$$\delta = (1.5^{-1.5})^{-m} \quad (22)$$

Variabel m, which constitue gradient coefficient of linier equation in log, can be determined by experiment .

$$\log(Q/V_i b_i^2) = a + m \log((\rho V_i b_i)/\mu) \quad (23)$$

Values of log π_7 versus $\log \pi_1$ was plotted for each structure thickness as presented in Figure 3.

Expected discharge of notch i , E_i, based on design criteria established by famer can be computed as follow:

$$E_i = \frac{b_i}{b_1 + b_2 + \ldots + b_n} x(Q_1 + Q_2 + \ldots + Q_n) \quad (24)$$

i = number of notch 1,2, .., n
$Q_1, Q_2, \ldots, bn$ = width of notch 1, 2,…, n
$b_1, b_2, \ldots, bn$ = disharge of notch 1, 2, …, n.

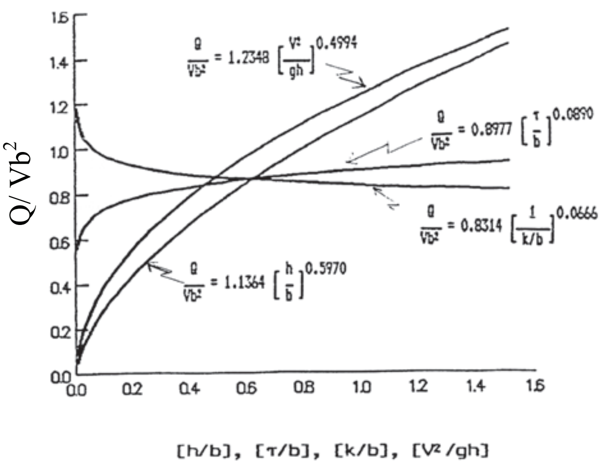

Figure 3. Diagram sketch in determination of variabel m

Tabel 1. Treatment composition and research variable of the model

No.	Treatment								Measurement		Research variables
	Flume	Div. struct.			Branc. chann.				Depth	Disch.	
	So	No.	k	τ (cm)	No.	θ_1 (degree)	θ_2	θ_3	y (cm)	Q (l/det)	
1.	s1, s2, s3	1D	k_o	1,0	1C	20	10	30	Y_{123}	Q_{123}	b, θ, s
2.	s1, s2, s3	1D	k_o	1,0	2C	20	10	30			
3.	s1, s2, s3	1D	k_o	1,0	3C	20	10	30			
4.	s1, s2, s3	2D	k_o	3,0	3C	20	10	30	Y_{123}	Q_{123}	b,θ, s,k
5.	s1, s2, s3	3D	k_1	3,0	3C	20	10	30			
6.	s1, s2, s3	4D	k_2	3,0	3C	20	10	30			
7.	s1, s2, s3	5D	k_1	1,0	3C	20	10	30	Y_{123}	Q_{123}	b, θ, s, τ
8.	s1, s2, s3	3D	k_1	3,0	3C	20	10	30			
9.	s1, s2, s3	6D	k_1	6,0	3C	20	10	30			

Tabel 2. Treatment composition and research variable of the prototype

No.	Treatment								Measurement		Research variables
	Flume	Div. struct.			Branc. chann.				Depth	Disch.	
	So*	No.	k	τ (cm)	No.	θ_1 (degree)	θ_2	θ_3	y (cm)	Q (l/det)	
1.	s1, s2, s3	1P	k_2	1,5	1C	50	30	20	Y_{123}	Q_{123}	b, θ, s,
2.	s1, s2, s3	1P	k_2	1,5	1C	50	30	20			
3.	s1, s2, s3	1P	k_2	1,5	1C	50	30	20			
4.	s1, s2, s3	2P	k_2	4,5	1C	50	30	20	Y_{123}	Q_{123}	b, θ, s,
5.	s1, s2, s3	2P	k_2	4,5	1C	50	30	20			
6.	s1, s2, s3	2P	k_2	4,5	1C	50	30	20			
7.	s1, s2, s3	5D	k_2	9,0	1C	50	30	20	Y_{123}	Q_{123}	b, θ, s,
8.	s1, s2, s3	3D	k_2	9,0	1C	50	30	20			
9.	s1, s2, s3	6D	k_2	9,0	1C	50	30	20			

Materials and Methods

Time and Place of The Research

This research was conducted, by experiment method, in Irrigation laboratory's Department of Agricultural Enginering, Faculty of Agriculture Technology, Gadjah Mada University, in 1995. The research was conducted under guidance of the thesis advisors. Results of researh, however, never been published yet in any journal, just a thesis as part of completing study at the the partment.

Materials and Equipments

Research materials and equipments include: proportional division structures, underground reservoir, flum (main channel), branched channel, benchwork, containers, centrifugal pump, wire screen, hook gauge, pitot tube, stopwatch, beaker glass, and pendulum balance.

Treatment Composition

Treatment composition presented in next Table 1 and Table 2.

Experimental Procedures

After all of the equipments installed (Appendix 5), water from reservoir was pumped into the container in steady state and uniform flow passing through wire screens (as energy dissipator), the porpotional division structure and then pass each of the notch into branch channels. Water depth and discharge for each treatment observed at location established

Table 3. Calculated and observed discharge of proportional division structure

	Parameter						Discharge					
				V for notch width:			Q_c for notch width:			Q_o for notch width:		
No.	h x10^2 (dm)	τ (dm)	k x10^2 (dm)	b1 v x10 (dm/s)	b2 v x10 (dm/s)	b3 v x10 (dm/s)	b1 (l/s)	b2 (l/s)	b3 (l/s)	b1 (l/s)	b2 (l/s)	b3 (l/s)
1.	25.25	0.1	0.20	3.60	3.81	3.56	0.31	0.51	0.61	0.34	0.48	0.56
2.	25.40	0.1	0.20	4.83	5.00	5.00	0.55	0.88	1.20	0.58	0.80	1.00
3.	34.40	0.1	0.55	3.44	3.79	3.61	0.27	0.49	0.60	0.32	0.47	0.56
4.	39.90	0.3	0.55	3.52	3.50	3.54	0.32	0.46	0.65	0.37	0.49	0.62
5.	24.03	0.3	0.55	3.73	3.60	3.47	0.34	0.47	0.59	0.39	0.49	0.59
6.	33.90	0.3	0.90	3.33	3.39	3.55	0.27	0.41	0.62	0.31	0.42	0.55
7.	37.00	0.6	0.55	3.33	3.05	3.31	0.30	0.37	0.60	0.32	0.39	0.53
8.	42.15	0.6	0.55	3.04	2.79	3.12	0.25	0.32	0.54	0.31	0.38	0.53
9.	18.77	0.6	0.90	3.67	3.50	3.53	0.31	0.42	0.58	0.33	0.42	0.53

Results snd Discussion

Flow Properties, Channel Deviation Angle, and Surface Roughness

Results of statistical analysis indicated that the performance criteria of proportional division structure is not affected significantly by either flow pro-perties (subcritical or supercritical flow) or the deviation angle up to 50 degrees There were the reability of structure because of no backwater effect, no cross current in upstream of structure. In accordance with suggestion by James (1988), if all condition above can be meet, then the performance of division structure can't be affected significantly by both flow properties and deviation angle (up to 50 degrees).

The division structure with surface roughness of grade k1 ≈ 0.00055 m and k2 ≈ 0.00090 m belong to criterion of hydrodinamically transition. It means the quantity of water reduced by a solid surface depend on Reynold number as well as relative roughness (Garde and Mirajgaoker, 1983). Base on the experiment indicated that the quantity of reduced water of a notch tend to be increased with decreased its notch width and conversely. It seems that the surface roughness can decreas of water to unproportional of notch width, hence for some extent can affected performance criteria of a proportional devision structure.

Relationships Between Discharge and Hydraulic Design Parameters

Results of data analysis by using equation (18), it was obtained relationships between discharge of a proportional division structure and hydraulic design criteria in the form of following mathematical equation:

$$Q = 1.1445 \frac{1}{k^{0.0666}} \left(\frac{h^{0.9638} \tau^{0.1437}}{b} \right)^{0.6194} \left(\frac{V^2}{gh} \right)^{0.4994} \left(Vb^2 \right) \quad (25)$$

From the equation indicated that the discharge not only depend on notch width (b) but also the others including roughness height (k), head over the crest (h), crest thickness (τ), and flow velocity (V). Results of computed discharge by using equation (25) and of observed discharge was presented in Table 3. It showed that the observed discharge can be approached closely by using the equation. Sensitivity and interrelation among them can be showed in Figure 4.

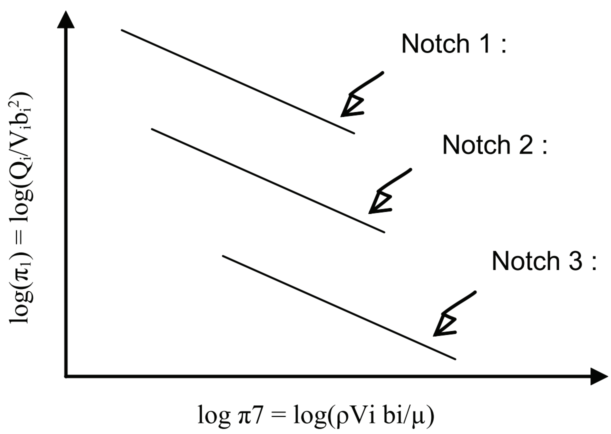

Figure 4. Sensitivity of hydraulic design parameters on performance of proportional divsion structure

Conclusions and Recommendations

Conclusion

1. There were the dependence of performance of the division structure on other hidraulic design criteria (beside notch width) in common However in the case there were no backwater effect and cross current in upstream vicinity of structure, the dependence on the other hydraulic design criteria was not significantly different.
2. There were relationships between discharge of a structure (the reflection of its performance) and hidraulics design criteria which can be.showed in mathematical equation.

Recommendation

To study the performance of proportional division structure so further, the research can be continued in the case there were a bacwater effect and cross current in upstrem of a proportional division structure.

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