Application of Specific Energy in Open Channels to Various Forms of Channel Constriction

RATNA MUSA[1]*, TRIFFANDY M.W[2], AMALIA RUSALDY[3]
[1]Civil Engineering Program, Muslim University of Indonesia, South Sulawesi, INDONESIA
[2]Great Hall of the Pompengan Jenneberang River Region, South Sulawesi, INDONESIA
[3]Department of Civil and Environmental Engineering, Gadjah Mada University, Yogyakarta, INDONESIA

Abstract: - Planning of water structures such as dams, irrigation canals, and other water structures requires a description of these buildings' hydraulic flow phenomenon. Each flow condition, moderate, and after passing through each building has its characteristics or tendencies. The aim of the study was to analyze the flow characteristics through several channel constrictions (sudden, transition, and radius) and verify the relationship between the results of laboratory tests with other research results. Understanding the flow characteristics in a narrow channel can be used to consider the design of channel engineering, especially irrigation canals. The results of the analysis show that the flow of water through the constriction undergoes a specific energy change. The maximum specific energy occurs at the sudden constriction type of 0.1339 m. The predicted results correlated moderately with experimental data from this and other studies. The application of specific energy for channel narrowing with upstream Es = downstream Es with Q = 0.0025 m^3/s, then the maximum downstream water level elevation occurs in the form of a sudden narrowing of 0.1200 m. This value deviates from the results of laboratory tests with an elevation of 0.1310 m by 8%. This is due to setting and measurement errors during laboratory tests.

Key-Words: Channel narrowing, Flow velocity, Froud Numbers, Specific Energy

Received: April 21, 2021. Revised: January 22, 2022. Accepted: February 24, 2022. Published: March 26, 2022.

1 Introduction

An open channel is a free-flowing water channel. Open channels can be distinguished into two types, namely artificial and natural. Open channels are found both on irrigation channels, technical, semi-technical, and natural channels in non-prismatic conditions. In a channel with a non-prismatic drainage channel, water flow changes such as altitude, velocity, channel width, water discharge, and other flow behavior. Some of the causes of the non-prismatic cross-section are the connection of two cross-sections, other buildings such as bridge pillars, or other causes that alter the channel's cross-section. Flow analysis of non-prismatic channels requires precision due to changes in flow characteristics. One example is channel narrowing, which causes altitude, velocity, and energy in the flow to change. The flow of energy affects the channel's smooth flow, which can disrupt water flow distribution that can harm. This fact needs attention. The discussion of the flow in the case of channel narrowing in this paper tries to disentangle the problem through measurement and testing on an open channel in the presence of constriction. Referring to the law of continuity, when the flow of water flows on a narrow section of the channel, it can increase the flow rate and energy. The narrowing of the channel cross-section becomes one of the factors to increase the flow and energy velocity. From previous research, [1] project is to establish general design criteria for optimal hydraulic conditions to avoid sediment depositions in the tunnel and keep the resulting abrasion damages at a minimum. In [2] propose a depth-discharge relationship and energy-loss coefficient for a subcritical, equal-width, right-angled dividing flow over a horizontal bed in a narrow aspect ratio channel. [3] Used abrupt type of narrowing by using several different channel widths; hence previous research has been used as a benchmark in this study, which used three types of narrowing types constriction, transition constriction type, and the narrowing Radius of the same channel width. This study focuses on analyzing changes in flow characteristics due to channel narrowing (sudden, transition, and radius). We argue that applying it to the inspection model should solve the following two problems: (1) How to know the flow characteristics of different types of constriction, and (2) How to apply specific energy in determining the downstream water level (after constriction) with the assumption that upstream Es = downstream Es, then this result is verified by laboratory test results with other research results.

The results of previous research that are (Analysis of Changes in the Effect Flow Rate on the Open Channel) [4] produces a difference in energy loss at the beginning of the narrowing, and after the narrowing, the change in energy before and after the narrowing is commonly called the specific energy loss. We tried to refine the results by designing open channels on a uniform flow, assuming the specific energy of the upstream part is equal to the specific energy of the downstream part to determine the depth of water downstream resulting from the narrowing of the channel.

2 Problem Formulation

2.1 Research Methodology and Procedure

According to the generation type of assumptions, we divided the existing work into three narrowing.

2.1.1 Research Methodology

The research method is a scientific way to get data with a specific purpose and usefulness. The natural channel cross-section is generally very irregular, usually varying from parabolic to trapezoidal forms. The term channel section is perpendicular to the flow direction, while the vertical channel section is the vertical cross-section through the lowest or lowest point of the cross-section. Therefore, the horizontal channel of the cross-section is always a vertical cross-section (Figure 1):

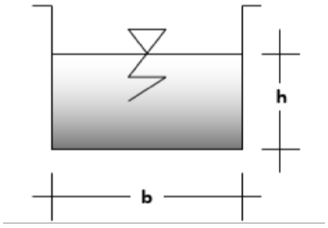


Fig. 1: Cross-section of rectangular channels

Wide (A) = b x h (1)

Wet Round (P) = b + 2h (2)

Hydraulic Radius (R) = A/P = b x h / (b+2h) (3)

With b = channel base width (m) and h = high water level (m).

The material used is water. The tools used are a set of open channel models with a bottom of a channel and a wall made of fiber, ruler, current meter FL 03, stopwatch, pumping ball, 90° constrictions, 45° constrictions, and Radius constriction. The cross-section in abrupt type refinement are presented in Figure 2 and Figure 3. Also, Figure 4 presents the cross-section on the narrowing of the Radius

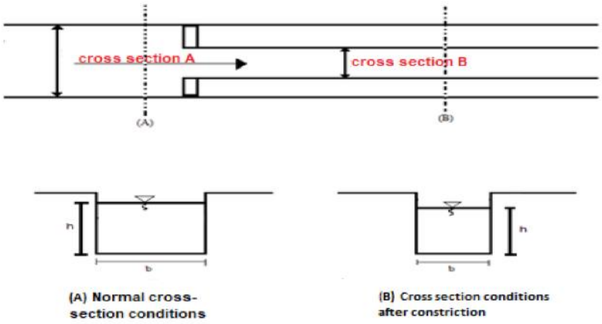


Fig. 2: Cross-section in abrupt type refinement. [4]

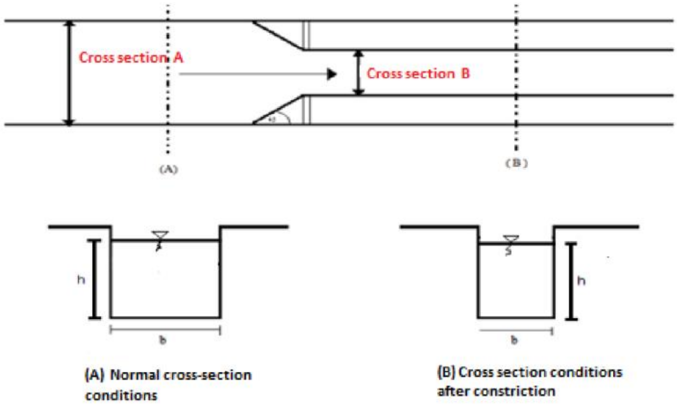


Fig. 3: Cross-section on Transitional type refinement. [4]

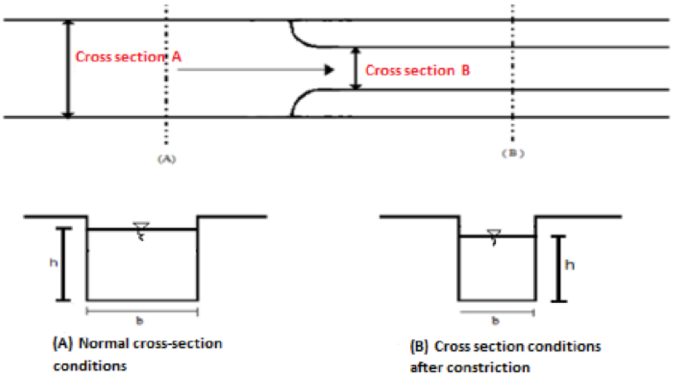


Fig. 4: Cross-section on the narrowing of the Radius. [4]

2.1.2 Research Procedures

a. Laboratory Testing

(1) prepare tools and materials, (2) regulate flow rate, (3) calibrate tools and flow rate, (4) Setting the discharge with Q = 0.0025 m^3/s (one of the variations of the discharge used for each type of narrowing), (5) measuring the water level before and after constriction, (6) measuring the flow velocity assuming the average flow velocity in the vertical direction is measured only at a few points and then calculated with mathematical results. Measurements were carried out using the one-point and two-point methods. The one-point method of

measurement is carried out at a depth of 0.2 h or 0.6 h (h = Depth), at 0.6 h it is carried out when the flow depth is between 2.5-7.5cm (V = 0.6 h). And the two-point method was carried out at a depth of 0.2 h and 0.8 h. The average flow velocity is obtained by the formula (V= 0.5(0.2h+0.8h)), (7) calculate the Froude number, (8) calculate the Specific Energy for each type of narrowing, (9) compare the results of the three forms of narrowing type (h and Es) which is greater than the results of the three forms of narrowing type.

b. Application of Specific Energy in Irrigation Channel Design

(1) determine the discharge (according to the variation of the discharge used in laboratory testing), (2) determine the channel width before and after narrowing (according to laboratory tests) for each type of narrowing, (3) determine the elevation of the upstream water table according to the results of laboratory tests (h_1), (4) calculate the discharge per unit width (q) before and after constriction for each type of narrowing, (5) calculate the Froude number, (6) calculate the specific energy upstream, (7) calculate the water level in the downstream assuming upstream Es = downstream Es, (8) compare the water level elevation (h2) laboratory tests with other tests, (9) describe the results of the analysis obtained.

2.2 Our Contribution

This paper present analyses the flow changes due to the narrowing of the open channel. From previous research, Cristian Auel et al. [1] discusses Turbulence Characteristics in Supercritical Open Channel Flows: Effects of Froude Number and Aspect Ratio, Chieh Hsu et al. [2] discussing Subcritical 90° Equal-Width Open-Channel Dividing Flow, and Jhonson et al. [3] used abrupt type of narrowing by using several different channel widths, hence previous research has been used as a benchmark in this study which used three types: sudden narrowing type, transitional narrowing type, and radius narrowing type with the same channel width. Understanding the flow characteristics of a narrowed channel is used to consider canals' technical design, especially irrigation channels.

2.3 Open Channels

Channels that drain water with a free surface are called open channels. Open channels can occur considerably, ranging from ground-level flows during rain until continuous water flow in the prismatic channel. Channels are classified into two types: natural existing and artificial channels. Natural channels include all water channels naturally occurring on earth, from small gutters in the mountains, small rivers, and large rivers to river mouths. Artificial channels are human-made channels for specific purposes and interests. Nature's hydraulic properties are very uncertain. Artificial channels have a regular cross-section and are easier to analyse than natural channels. Artificial channels include roadside drainage, irrigation canals to irrigate rice fields, sewers, drains to carry water to hydroelectric power, drinking water supply channels, floodway. In some ways, it can be assumed that the approach is sufficiently consistent with actual observations. Thus, the flow requirements of this channel are acceptable for the completion of theoretical hydraulics analysis.

2.4 System Classification

The open channel flow can be classified into several types and described in various ways as follows. The flow-through constriction can be supercritical or subcritical. Critical depth can be formulated by Rangga Raju [5].

2.4.1 Steady Flow And Unsteady Flow

A flow in an open channel is steady when variables of flow (such as velocity V, pressure P, mass density ρ, flow face A, debit Q) and so on, across the point of the liquid, do not change with time. The flow is said to be unstable (unsteady) if the flow variable at each point changes with time. Most open channel problems generally require only research on flow behavior in steady-state. The equation expresses debit Q on a channel cross-section for any flow:

$$Q=VA \tag{4}$$

With V = average velocity and A = The cross-sectional area is perpendicular to the flow direction.

Most steady-flow problems, based on consideration, are assumed to remain along a large section of the channel, in other words, a steady flow of continuous steady flow, from equation (4):

2.4.2 Critical and Supercritical Flow

The Stream is critical if the Froude number (F) is equal to one (1), whereas the subcritical flow is sometimes called (*tranquil flow*) when F < 1 and supercritical or (*rapid flow*) when F > 1. The flow velocity ratio with the force of gravity (per unit volume) is known as the Froude number and can be formulated as follows [6] so that F can be written as Boris.A [7], Ven Te Chow [8], Osman Akan [9]:

$$F = \frac{Q}{\sqrt{g(A^3/T)}} = \frac{Q}{\sqrt{g(y^3b^3/b)}} = \frac{Q}{\sqrt{gy^3}} = \frac{q}{\sqrt{gy^3}} \tag{5}$$

With T = width of the water face, q = debit per unit channel width

The specific energy diagram is presented in Figure 5.

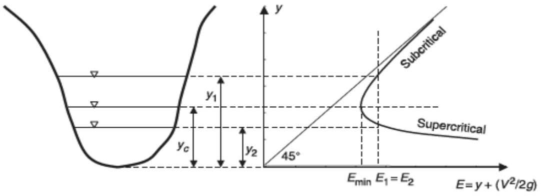


Fig. 5: Specific energy diagram [9]

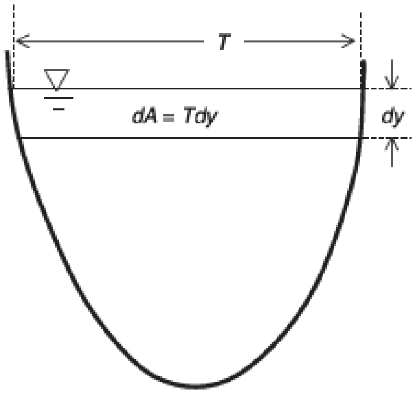


Fig. 6: Expression for top width T [9]

A channel changes its width from B_1 to B_2 assuming that the channel bottom is constant. Since steady flow Q is constant, due to changes in channel width, the equation for the unit discharge q can be written:

$Q = B_1.q_1 = B_2.\ q_2$ (6)

Because $B_1 > B_2$ then $q_1 < q_2$. Equation (6) states that the flow condition that occurs has a constant flow rate (steady flow) but the unit of discharge (q) changes due to changes in channel width from B_1 to B_2. The specific image of the energy can be seen in Figure 6.

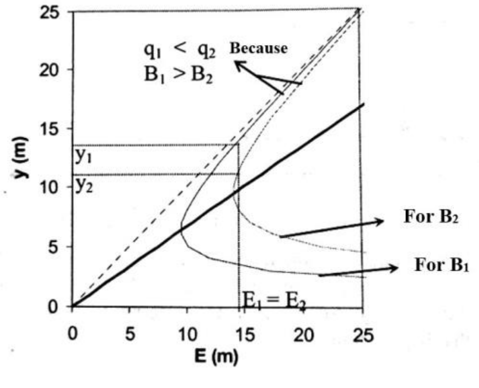


Fig. 7: E and y relationships for channel width changes [10]

For the example above $E_1 = E_2$, and from Figure 7 $y_1 > y_2$. Equation 6 can be written as

$Q = B_1.\ y_1.v_1 = B_2.\ y_2.\ v_2$ (7)

Because $B_1 > B_2$ and $y_1 > y_2$, then to fulfill the above equation the magnitude of $v_2 > v_1$

2.4.3 The Flow is Changing Gradually

The specific energy is equal to the sum of the water depth and the high velocity. On a channel basis, it is assumed to have a sloping slope or no slope. Z is the base height above the selected reference line, H is the flow depth, and the energy correction factor (α) is equal to one. The specific energy of the Stream at each particular cross-section is calculated as the total energy at that cross-section by using the bottom of the channel as a reference, Budi Santoso [11] For small slopes, $\Theta = 0$. Then the amount of energy at the channel cross-section is:

$$H = Z_a + d + \frac{V^2}{2g} \quad (8)$$

This equation applies to streams aligned or changed irregularly. That is Bernoulli's energy equation Hunter Rouse and Simon Ince [12]. The criteria of flow in a critical state of a stream have been defined as a condition in which the Froude number is equal to one. A more general definition is the flow state in which the specific energy for a given discharge is minimum, Paul Boss [13]. The following definition can elaborate on a criterion for critical flow. The amount of specific energy can be formulated as follows [8], [10] for flat channels ($\theta = 90^o = 0$)

$$E = h + \frac{V^2}{2g} \quad (9)$$

With E = Specific Energy

Associated Q = A x v then the Specific Energy becomes [14], [15]:

$$E = h + \frac{Q^2}{2g\ A^2}, \quad (10)$$

$$q = \frac{Q}{B} \quad (11)$$

$$E = h + \frac{Q^2}{2gy^2} \quad (12)$$

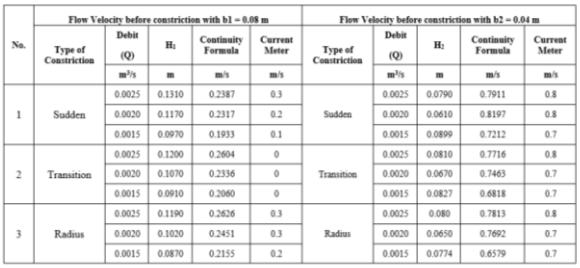
3 Result dan Discussion

3.1 Results

3.1.1 Change in Flow Speed

Analysis of changes in flow speed can be seen in Table 1:

Table 1. Change of Flow Velocity Result



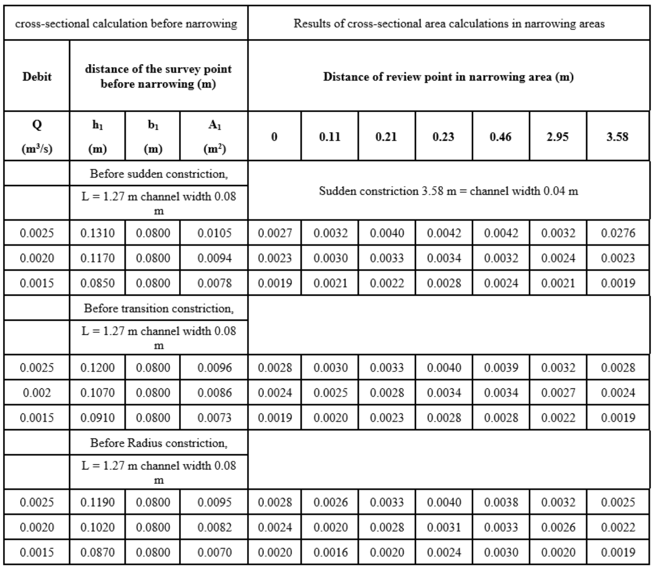
No.	Flow Velocity before constriction with b1 = 0.08 m					Flow Velocity before constriction with b2 = 0.04 m				
	Type of Constriction	Debit (Q)	H_1	Continuity Formula	Current Meter	Type of Constriction	Debit (Q)	H_2	Continuity Formula	Current Meter
		m³/s	m	m/s	m/s		m³/s	m	m/s	m/s
1	Sudden	0.0025	0.1310	0.2387	0.3	Sudden	0.0025	0.0790	0.7911	0.8
		0.0020	0.1170	0.2317	0.2		0.0020	0.0610	0.8197	0.8
		0.0015	0.0970	0.1933	0.1		0.0015	0.0899	0.7212	0.7
2	Transition	0.0025	0.1200	0.2604	0	Transition	0.0025	0.0810	0.7716	0.8
		0.0020	0.1070	0.2336	0		0.0020	0.0670	0.7463	0.7
		0.0015	0.0910	0.2060	0		0.0015	0.0827	0.6818	0.7
3	Radius	0.0025	0.1190	0.2626	0.3	Radius	0.0025	0.080	0.7813	0.8
		0.0020	0.1020	0.2451	0.3		0.0020	0.0650	0.7692	0.7
		0.0015	0.0870	0.2155	0.2		0.0015	0.0774	0.6579	0.7

From the result of Table 1, flow velocity before constriction with b1 = 0.08 m occurs before the narrowing using the comparison of the continuity formula and the Current meter in the form of sudden narrowing and the Radius not experiencing a significant change in flow rate. The transition narrowing form has a significant change where the current meter's velocity is 0.0 m/s, and the continuity formula is 0.2 m/s. In comparison, the velocity that occurs before the narrowing shows that the constriction area's velocity for the three forms of narrowing does not experience a significant change where the current meter velocity and the continuity formula are almost the same.

3.1.2 Wide Cross-Section

The cross-sectional area for each point can be seen on Table 2:

Table 2. Broad cross-sectional results

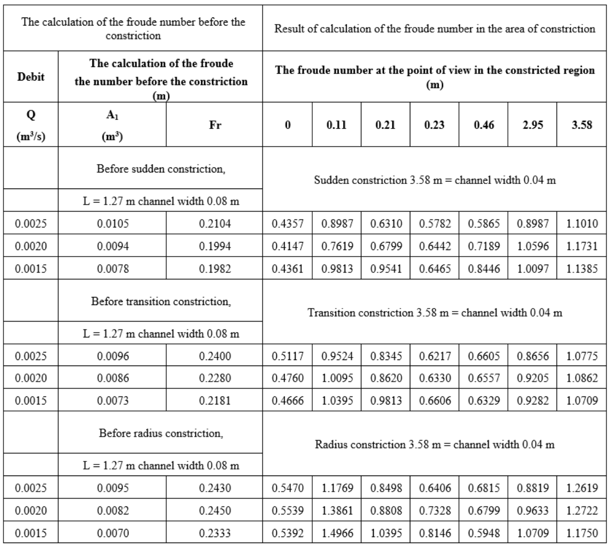


cross-sectional calculation before narrowing				Results of cross-sectional area calculations in narrowing areas						
Debit	distance of the survey point before narrowing (m)			Distance of review point in narrowing area (m)						
Q (m³/s)	h_1 (m)	b_1 (m)	A_1 (m²)	0	0.11	0.21	0.23	0.46	2.95	3.58
	Before sudden constriction,			Sudden constriction 3.58 m = channel width 0.04 m						
	L = 1.27 m channel width 0.08 m									
0.0025	0.1310	0.0800	0.0105	0.0027	0.0032	0.0040	0.0042	0.0042	0.0032	0.0276
0.0020	0.1170	0.0800	0.0094	0.0023	0.0030	0.0033	0.0034	0.0032	0.0024	0.0023
0.0015	0.0850	0.0800	0.0078	0.0019	0.0021	0.0022	0.0028	0.0024	0.0021	0.0019
	Before transition constriction,									
	L = 1.27 m channel width 0.08 m									
0.0025	0.1200	0.0800	0.0096	0.0028	0.0030	0.0033	0.0040	0.0039	0.0032	0.0028
0.002	0.1070	0.0800	0.0086	0.0024	0.0025	0.0028	0.0034	0.0034	0.0027	0.0024
0.0015	0.0910	0.0800	0.0073	0.0019	0.0020	0.0023	0.0028	0.0028	0.0022	0.0019
	Before Radius constriction,									
	L = 1.27 m channel width 0.08 m									
0.0025	0.1190	0.0800	0.0095	0.0028	0.0026	0.0033	0.0040	0.0038	0.0032	0.0025
0.0020	0.1020	0.0800	0.0082	0.0024	0.0020	0.0028	0.0031	0.0033	0.0026	0.0022
0.0015	0.0870	0.0800	0.0070	0.0020	0.0016	0.0020	0.0024	0.0030	0.0020	0.0019

3.1.3 Froude Number

The calculation of Froude numbers can be seen in Table 3:

Table 3. The Froude Number Result



The calculation of the froude number before the constriction			Result of calculation of the froude number in the area of constriction						
Debit	The calculation of the froude the number before the constriction (m)		The froude number at the point of view in the constricted region (m)						
Q (m³/s)	A_1 (m³)	Fr	0	0.11	0.21	0.23	0.46	2.95	3.58
	Before sudden constriction,		Sudden constriction 3.58 m = channel width 0.04 m						
	L = 1.27 m channel width 0.08 m								
0.0025	0.0105	0.2104	0.4357	0.8987	0.6310	0.5782	0.5865	0.8987	1.1010
0.0020	0.0094	0.1994	0.4147	0.7619	0.6799	0.6442	0.7189	1.0596	1.1731
0.0015	0.0078	0.1982	0.4361	0.9813	0.9541	0.6465	0.8446	1.0097	1.1385
	Before transition constriction,		Transition constriction 3.58 m = channel width 0.04 m						
	L = 1.27 m channel width 0.08 m								
0.0025	0.0096	0.2400	0.5117	0.9524	0.8345	0.6217	0.6605	0.8656	1.0775
0.0020	0.0086	0.2280	0.4760	1.0095	0.8620	0.6330	0.6557	0.9205	1.0862
0.0015	0.0073	0.2181	0.4666	1.0395	0.9813	0.6606	0.6329	0.9282	1.0709
	Before radius constriction,		Radius constriction 3.58 m = channel width 0.04 m						
	L = 1.27 m channel width 0.08 m								
0.0025	0.0095	0.2430	0.5470	1.1769	0.8498	0.6406	0.6815	0.8819	1.2619
0.0020	0.0082	0.2450	0.5539	1.3861	0.8808	0.7328	0.6799	0.9633	1.2722
0.0015	0.0070	0.2333	0.5392	1.4966	1.0395	0.8146	0.5948	1.0709	1.1750

From the results of Table 2 and Table 3, it appears that the flow that occurs before the narrowing is a subcritical flow and flows. That occurs in the area of sudden narrowing for a point distance review of 0.0 m, 0.11 m, 0.21 m, 0.23 m, and 0.46 m experiencing subcritical flow. For a point distance review of 2.95 m experiences flow critical and for an overview, the point distance of 3.58 m experiences supercritical flow. In the transition narrowing area for the review, point distances of 0.0 m, 0.21 m, 0.23 m, and 0.46 m experience subcritical flow, a point-distance view of 0.11 m and 3.58 m experience critical flow. In the confinement area, Radius for point distance review of 0.0 m, 0.21 m, 0.23 m, 0.46, and 2.95 m experienced subcritical flow. For point distance review 0.11 m and 3.58 m experienced supercritical flow.

3.1.4 Specific Energy

The results of specific energy calculations can be seen in Table 4

Table 4. The Specific Energy Result

Result of specific energy calculation before constriction				Result of specific energy calculation in the area of constriction						
Debit	**Specific energy at the point before the constriction (m)**			**specific energy at the point of view in the area of constriction (m)**						
Q (m^3/s)	**H_1 (m)**	**A_1 (m^2)**	**E (m)**	**0**	**0.11**	**0.21**	**0.23**	**0.46**	**2.95**	**3.58**
	Before sudden constriction, L = 1.27 m channel width 0.08 m			Sudden constriction 3.58 m = channel width 0.04 m						
0.0025	0.1310	0.0105	0.1339	0.1338	0.1109	0.1199	0.1237	0.1231	0.1109	0.1108
0.0020	0.1170	0.0086	0.1193	0.1192	0.0981	0.1010	0.1026	0.0994	0.0952	0.0962
0.0015	0.0970	0.0078	0.0989	0.0988	0.0785	0.0786	0.0846	0.0799	0.0785	0.0791
	Before transition constriction, L = 1.27 m channel width 0.08 m			Transition constriction 3.58 m = channel width 0.04 m						
0.0025	0.1200	0.0096	0.1235	0.1233	0.1105	0.1119	0.1205	0.1182	0.1113	0.1106
0.0020	0.1070	0.0086	0.1098	0.1097	0.0951	0.0960	0.1032	0.1021	0.0954	0.0954
0.0015	0.0910	0.0073	0.0932	0.0931	0.0786	0.0785	0.0841	0.0852	0.0787	0.0787
	Before Radius constriction, L = 1.27 m channel width 0.08 m			Radius constriction 3.58 m = channel width 0.04 m						
0.0025	0.1190	0.0095	0.1225	0.1224	0.1117	0.1116	0.1193	0.1171	0.1111	0.1132
0.0020	0.1020	0.0082	0.1051	0.1050	0.1000	0.0958	0.0989	0.1010	0.0952	0.0977
0.0015	0.0870	0.0070	0.0894	0.0893	0.0848	0.0786	0.0799	0.0871	0.0787	0.0794

From the results of Table 4 before the narrowing, it appears that the maximum specific energy in the form of sudden constriction (0.1339 m), moving (0.1235 m), and Radius (0.1225 m) is due to crushing in the narrowing.

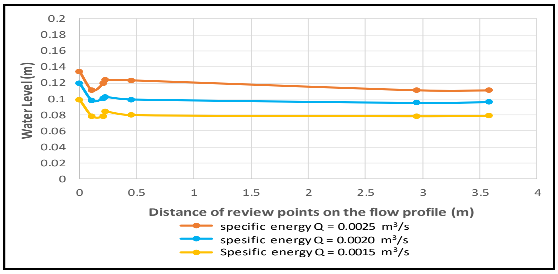


Fig. 8: Specific Energy and water level with a sudden constriction with a discharge of 0.0025 m^3/s, 0.0020 m^3/s, and 0.0015 m^3/s.

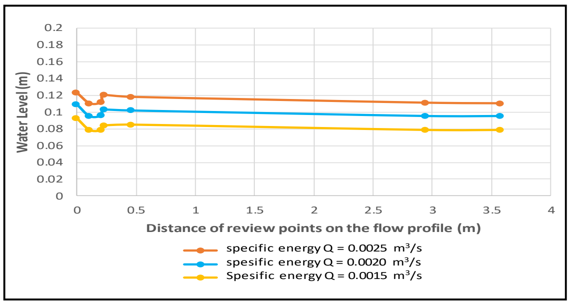


Fig. 9: Specific Energy and water level with a transition with a discharge of 0.0025 m^3/s, 0.0020 m^3/s, and 0.0015 m^3/s.

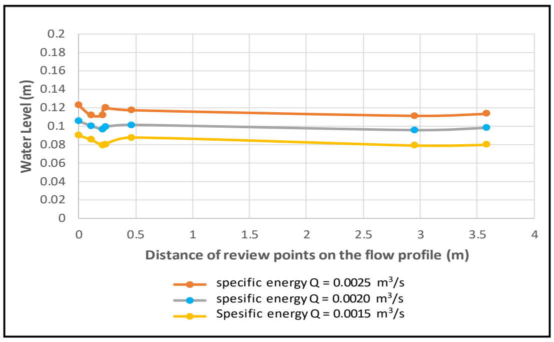


Fig. 10: Specific Energy and water level with a radius type with a discharge of 0.0025 m^3/s, 0.0020 m^3/s, and 0.0015 m^3/s.

From Table 3 and Figure 8, Figure 9 and Figure 10 show that maximum specific energy occurs at sudden constriction.

3.1.5 Application of Specific Energy

It is known that a rectangular channel is almost horizontal with a width of 0.08 m and flows a discharge of 0.0025 m^3/s. its width is reduced to 0.04 m. and Es (upstream) = Es (downstream) or $E_1 = E_2$. determine what is the water level downstream if the water level upstream of the narrowing of the channel bottom is known.

Table 5. Calculation of Energy Principle

Result of specific energy calculation before constriction					Result of specific energy calculation in the area of constriction			
Debit	**Specific energy at the point before the constriction**				**specific energy at the point of view in the area of constriction**			
Q (m^3/s)	**h_1 (m)**	**q_1 (m^3/s)**	**Fr_1**	**E_1 (m)**	**q_2 (m^3/s)**	**Fr_2**	**E_2 (m)**	**h_2 (m)**
	Before sudden constriction, L = 1.27 m channel width 0.08 m				Sudden constriction 3.58 m = channel width 0.04 m			
0.0025	0.1310	0.0312	0.2104	0.1339	0.0625	0.4795	0.1339	0.1200
	0.0210		3.3051	0.1339		20.3537	0.1339	0.0480
	Before transition constriction, L = 1.27 m channel width 0.08 m				Transition constriction 3.58 m = channel width 0.04 m			
0.0025	0.1200	0.0312	0.2400	0.1235	0.0625	0.5815	0.1235	0.1056
	0.0220		3.0802	0.1235		31.8823	0.1235	0.0520
	Before radius constriction, L = 1.27 m channel width 0.08 m				Radius constriction 3.58 m = channel width 0.04 m			
0.0025	0.1190	0.0312	0.2431	0.1225	0.0625	0.5932	0.1225	0.1042
	0.0230		2.8604	0.1225		26.8735	0.1225	0.0540

In Figure 11, Figure 12 and Figure 13 below, we can see the specific energy difference in the three form of narrowing, namely sudden narrowing, transition narrowing, and Radius narrowing with a fixed discharge (Q) of 0.0025 m^3/sec

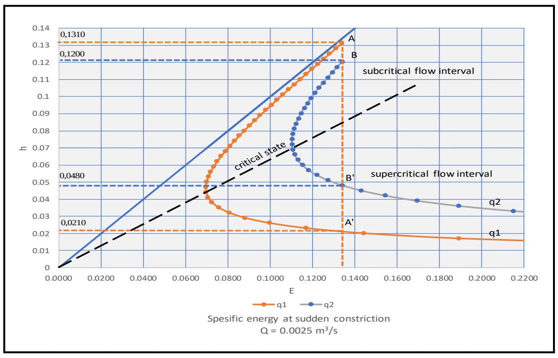


Fig. 11: Specific energy at sudden constriction with Q = 0.0025 m^3/s

Figure 11 shows that the depth (h) at points A-A' and B-B' has the same specific energy of 0.1339 m. Prior to construction a depth of 0.1310 m is a subcritical flow and a depth of 0.0210 m is a supercritical flow for the same discharge of 0.0312 m^3/s. in the constriction area to a depth of 0.1200 m is a subcritical flow and a depth of 0.0480 m is a supercritical flow with the same discharge 0.0625 m^3/s.

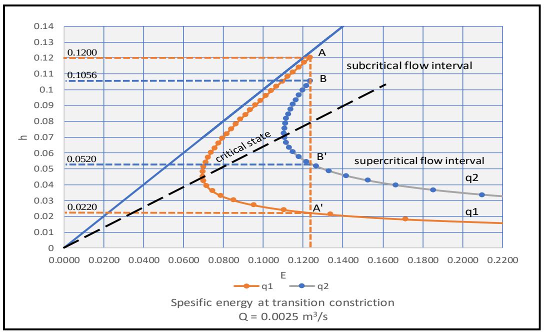


Fig. 12: Specific energy at transition constriction with Q = 0.0025 m^3/s

Figure 12 shows that the depth (h) at points A-A' and B-B' has the same specific energy of 0.1235 m. Before narrowing the depth of 0.1200 m is a subcritical flow and a depth of 0.0220 m is a supercritical flow for the same discharge of 0.0312 m3/s. in the constriction area for a depth of 0.1056 m is a subcritical flow and a depth of 0.0520 m is a supercritical flow with the same discharge of 0.0625 m3/s.

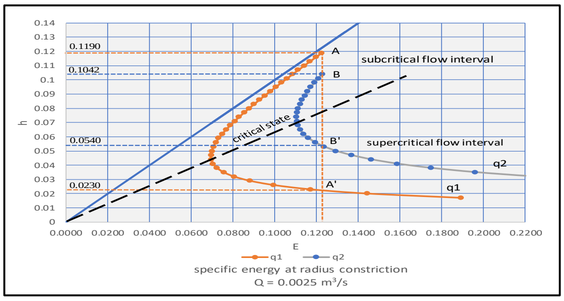


Fig. 13: Specific energy at radius constriction with Q = 0.0025 m^3/s

Figure 13 shows that the depth (h) at points A-A' and B-B' has the same specific energy of 0.1225 m. Before narrowing the depth of 0.1190 m is a subcritical flow and a depth of 0.0230 m is a supercritical flow for the same discharge of 0.0312 m3/s. in the narrowing area for a depth of 0.1042 m is a subcritical flow and a depth of 0.0540 m is a supercritical flow with the same discharge of 0.0625 m3/s.

3.2 Discussion

Based on Table 5 and Figure 11, Figure 12 and Figure 13, if q increases from q upstream to q downstream, then:

a) in the flow of supercross the water level must rise, while in the subcritical flow, the water level must go down
b) At the time of criticism, then the narrowing becomes maximum. If it is narrowed again, then the water level upstream (A) changes to add Es.
c) if the narrowing equals or exceeds the narrowing of the criticism, then downstream (B) narrowing will occur the flow of criticism so that the depth of the downstream channel (B) is H criticism
d) if the narrowing exceeds the narrowing of the criticism, then the water level next to the upper (A) narrowing will change.
e) The downstream water level of the three narrowing forms studied It appears that the maximum water level occurs in the sudden narrowing form of 0.1200 m.
f) Comparison of water level downstream between laboratory tests (0.1310 m) and analytical results (0.1200 m) with a difference of 8%. This indicates the presence of storage that may be caused by measurements during laboratory tests.

4 Conclusion

Based on the research that has been done, it can be concluded that the flow of water through the constriction undergoes specific energy changes. The maximum specific energy occurs at the sudden constriction type of 0.1339 m. The predicted results correlated moderately with experimental data from this and other studies. The application of specific energy for channel narrowing with upstream Es = downstream Es with Q = 0.0025 m^3/s, then the maximum downstream water level elevation occurs in the form of a sudden narrowing of 0.1200 m. This value deviates from the results of laboratory tests with an elevation of 0.1310 m by 8%. This is due to setting and measurement errors during laboratory tests.

5 Suggestions

Further research used a larger channel change model so that measurement and flow behavior are more comfortable to observe and adding several variables or objects that are not included in this study, for example, sedimentation measurements.

Acknowledgments:
This work was supported by the Hydrological Laboratory of Civil Engineering Program, Muslim University of Indonesia, South Sulawesi, Indonesia.

References:

[1] Yang, S. Q. (2010). Depth-averaged shear stress and velocity in open-channel flows. Journal of Hydraulic Engineering, 136(11), 952-958.

[2] Hsu, C. C., Tang, C. J., Lee, W. J., & Shieh, M. Y. (2002). Subcritical 90 equal-width open-channel dividing flow. Journal of Hydraulic Engineering, 128(7), 716-720.

[3] Harianja, J. A., & Gunawan, S. (2007). Overview of Specific Energy Due to Constriction of Open Channels. Scientific Magazine UKRIM, Edition 1/th, 30-46.

[4] Musa, R., & Rusaldy, R. A. (2020). Analysis of Changes in the Effect Flow Rate on the Open Channel. In the International Seminar of Science and Applied Technology (ISSAT 2020).

[5] Raju, K. R., & Pangaribuan, Y. P. (1986). Flow Through Open Channel. Erlangga, Jakarta.

[6] Th.Rehbock, (1991). Zur Frage des Bruckenstaues (On the problem of ponding due to bridge constructions), Zentralblatt der Bauverwaltung, Berlin, 39(37), pp.197-200.

[7] Bakhmetev, B. A. (1932). Hydraulics of open channels. McGraw-Hill Book Company, Inc, New York.

[8] Chow, V. T. (1959). Open-channel hydraulics. McGraw-Hill civil engineering series.

[9] Akan, A. O. (2006). Hydraulic structures. Open Channel Hydraulics, 200-265.

[10] Kodatie Robert, J. (2009). Applied Hydraulics Flow in open lines and pipes. Revised Edition, Publisher Andi. Yogyakarta.

[11] Santoso, B. (1988). Hidrolika II. UGM publishing bureau, Yogyakarta.

[12] Rouse, H., & Ince, S. (1957). History of Hydraulics, Iowa Institute of Hydraulic Research. State University of Iowa, Ames, Iowa, 269.

[13] Paul Boss, (1991). Berechnung der wasserspiegellage beim wechsel des fliesszustandes (Computation of Water Surface with Change of the Flow Type), Springer-Verlag Berlin, pp.20 and 52.

[14] Jaeger, C. (1956). Engineering fluid mechanics (No. 627 J34).

[15] Bresse, J.A.C. (1860). Applied mechanics course by M. Bresse: Hydraulics (Vol. 2). Mallet-Bachelor.

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Ratna Musa has has organized this paper and submitted and also executed the experiments of Section 4 .

Triffandy M.W was responsible for the Statistics and proofreading this article .

Amalia Rusaldy was responsible for the analyses .

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself
No funding was received for conducting this study.

Conflicts of Interest

The authors have no conflicts of interest to declare .