THE APPLICATION OF CONCRETE BLOCKS AS SLOPING ENERGY DISSIPATOR WITH LARGE ROUGH ELEMENTS

NOBUYOSHI SUGANUMA
Engineer, AIZAWA Concrete Corporation, Asahikawa Branch, 1-978-4 Taisetsudori, Asahikawa City, Hokkaido, Japan, n.suganuma@aizawa-group.co.jp

YOUICHI YASUDA
Professor, Department of Civil Engineering, College of Science and Technology, Nihon University, 1-8 Kanda Surugadai, Chiyodaku, Tokyo, Japan, yasuda.youichi@nihon-u.ac.jp

KEITO MASUI
Master Student, Department of Civil Engineering, Graduate School of Science and Technology, Nihon University, 1-8 Kanda Surugadai, Chiyodaku, Tokyo, Japan, cske19006@g.nihon-u.ac.jp

ABSTRACT

Recently, the experimental investigation on sloping energy dissipator with stacked boulders revealed that a surface jet flow with three dimensional might be effective for both energy dissipator and prevention of river bed. The formation of surface jet flow is characterized by a lift of the main flow to center part of water surface from the bottom, and a high velocity flow might be dissipated by the formation of the main flow with a strong turbulence. From the point of environmental problems, the reuse of installed concrete blocks below apron must be considered. This study presents the possibility of sloping energy dissipator with concrete projective blocks by using a scale model. The experiments yielded that the formation of surface jet flow was confirmed by installing the blocks in 1/15 slope, even if the tailwater level was same level as in the case of the limited jump below abrupt drop structure. Furthermore, the hydraulic condition required to form the surface jet flow was discussed. The velocity decay and the location of the main flow, and vertical distributions of turbulent intensity revealed that the formation of the surface jet flow might be effective for both protection of river bed and energy dissipator. The sloping energy dissipator with concrete projective blocks was compared with that with stacked boulders, and the application might be decided from gravel and rock sizes in the sediment transport.

Keywords: Energy dissipator, Concrete blocks, Surface jet flow, Drop structure, Mainstream position

1. INTRODUCTION

Generally, a plunging flow is formed below drop hydraulic structure as a stability of jump position. The hydraulic jump is a phenomenon well known as useful method of energy dissipation (Ministry of Land Infrastructure and Transport, 2012; Hager, 1992; and Yasuda, 2017). If the toe of jump is not plunging, it must be required to keep jump length and approach length of supercritical flow on concrete apron. In this case, the total length of energy dissipator might be longer, and the total cost might not be economically adequate. Further, concrete blocks were installed below concrete apron as river-bed protection work (Kanda et al. (1995)), but concrete blocks might be flushed away by the formation of local scour. After floods, flushed blocks must be used as recycle resources. In order to stabilize the jump position, a plunging flow is formed. But, a high velocity near the bottom continues far downstream, and the formation of plunging flow might cause local scouring and degradation of river bed.

The transition from supercritical to subcritical flows at an abrupt drop was investigated systematically by Ohtsu and Yasuda (1991), and various types of flow conditions was classified by approaching Froude number, relative drop height, and relative downstream depth. Further, low and high drops was defined on the basis of different flow pattern. The hydraulic condition required to form a plunging flow was clarified, and maximum plunging condition was shown as upper limit of the formation of plunging flow. Also, limited jump was shown as lower limit of the formation of plunging flow.

Recently, the jump formation below low drop structure was investigated by Yasuda and Shinozaki (2018, 2019). If the relative drop height becomes lower, a high velocity flow near the bottom continues far downstream in the jump formation, even if the downstream face of drop is varied (stepped chute with 1/3 slope, sloping chute with 1/3, ogee crest shape, and abrupt drop). The experimental results yield that the jump formation below low drop structure might not help for an energy dissipator by considering river-bed protection below stilling basin. The main flow during flood stages should be lift to the water surface, and the surface jet flow might be significant.

A sloping energy dissipator with stacked boulders below low drop structure was proposed by Yasuda and Masui (2019). The dissipator has gentle slope (i.e., 1/10 to 1/20 slopes). The hydraulic condition for the formation of surface jet flow was discussed.

This paper presents the application of concrete blocks with protrusion type to the sloping energy dissipator. The experimental investigation yields that the formation of plunging flow can be disappeared by installing the concrete blocks with protrusion type on 1/15 slope for different discharges. Also, it has been confirmed that the surface jet flow is formed without the formation of plunging flow. The velocity fields at the downstream of concrete blocks were measured, and the velocity measurement supported that the velocity near the bottom could be reduced by the formation of the surface jet flow.

2. EXPERIMENTAL SETUP

Experiments were conducted in rectangular horizontal channel with 15 m long, 0.80 m wide, and 0.60 m height. Physical scale model was used, and Froude similarity was applied for the experimental investigation. In the channel, drop model with 0.796 m wide, 0.10 drop and 1.00 m long was installed. The water resistant board with 0.796 m wide, 1.8 m long, and 0.032 m or 0.021 m thickness was used in order to adjust the difference level at the upstream and downstream of drop.

As shown in Photo 1, concrete blocks with protrusion type were installed in 1.34 m length for the sloping portion of 1/15 slope. The concrete block produced by AIZAWA Concrete LTD. with 0.038 m height, 0.10 m length, and 0.10 m wide (Photo 2) was used as 1/15 scale model.

The downstream end of concrete blocks was adjusted at abrupt rise to connect smoothly at the downstream of the bottom by installing two boards with 0.796 m wide, 0.032 m height, and 1.8 m long (Photo 3). In order to investigate the effect of installation of concrete blocks on sloping energy dissipator, free over type and supercritical flow type were tested. The supercritical flow type was settled by installing trapezoidal weir model with 0.12 m height, 0.796 m wide, 0.10 m top length, and 0.12 m bottom length (Photo 4).

The velocity profile at each vertical section was recorded by using a two-dimensional electromagnetic current meter with I type probe (0.004 m diameter) of KENEK CO. LTD to measure both the streamwise x and the transverse y directions (sampling time 30 s, sampling frequency 20 Hz). The discharge was measured by using wide rectangular sharp edged weir located at downstream end of channel.

The experimental condition is shown in Table 1. Then, *i is* slope of installed concrete block defined as h_m/L(h_m= Height difference, L= horizontal installation length of installed concrete blocks). The inflow condition above the drop was settled by Froude number F_1 and relative drop height h_m/h_1. Here, h_1 is the inflow depth defined in the flow passing over the drop (located in 3.5 times of h_1 upstream from drop), s is the drop model height, and F_1 is the inflow Froude number defined as $V_1/(gh_1)^{1/2}$; V_1 is average velocity. If the inflow Froude number is unity, a free over flow type was assumed. The relative drop height h_m/h_1 (=h_m/d_c; d_c is critical depth) was settled as 0.79. If the flow above the drop is supercritical (F_1 > 1.00), the relative drop height h_m/h_1 was settled as 1.32. The flow conditions were recorded by a digital camera. In addition, the downstream depth is expressed as averaged depth measured in gradually varied flow region (200 cm < x < 300 cm).

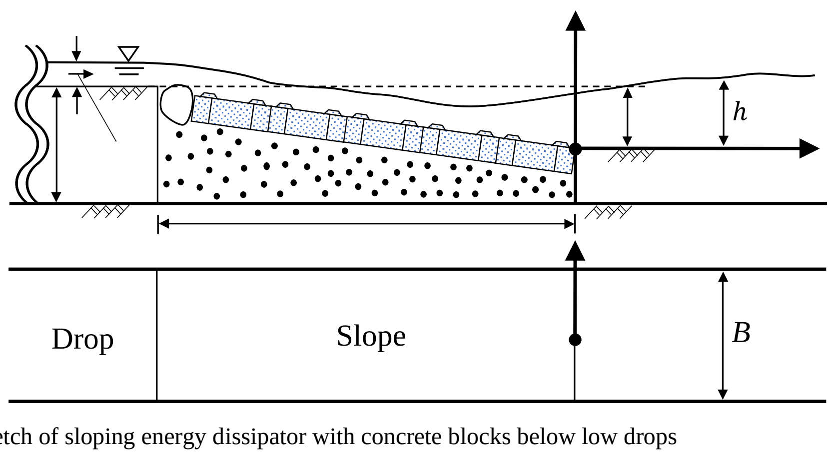


Figure 1. Definition sketch of sloping energy dissipator with concrete blocks below low drops

Photo 1. Installations of drop model, concrete blocks, and boards for abrupt rise in rectangular channel.

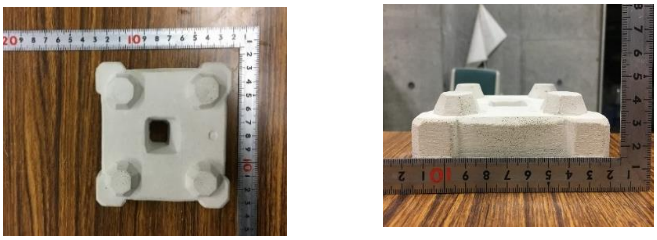


Photo 2. Concrete block model with protrusion type.

Photo 3. Installation of concrete blocks.

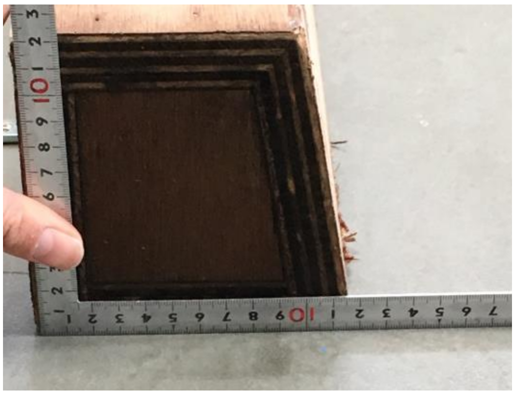


Photo 4. Trapezoidal weir model.

Table 1. Experimental conditions.

Concrete Blocks with protrusion type	h_m/h_1	F_1	i (= h_m/L)	$Re\times 10^4$	h_d/h_1
	0.79	1.00	1/15	8.65-9.56	1.44,1.81,2.17
	1.32	2.16	1/15	10.7	2.78,3.33,3.96

3. INSTALLATION OF SLOPING ENERGY DISSIPATOR WITH CONCRETE BLOCKS

Recently, the sloping apron with stacked boulders was proposed in order to prevent from degradation of river bed during flood stages as an energy dissipator (Yasuda and Masui (2019)). The lifting of main flow into the water surface during flood stages is significant for the prevention of river bed below drop structure. If the drop structure is consisted as an abrupt drop, there is the range of the tailwater level in which a plunging flow is formed (Ohtsu and Yasuda (1991)). By installing sloping apron with the stacked boulders below drop structure, the surface jet flow is formed easily even if the tailwater level is the same as that for the formation of plunging flow under given relative drop height h_m/h_1 and inflow Froude number F_1. In this case, the sloping apron should be settled as i = 1/10 or 1/20 slope (Yasuda and Masui (2019)). Also, the shape resistance due to stacked boulders is important for both the reduction of high velocity on the slope and the production of strong turbulence on the stacked boulders. In order to form the surface jet flow, the approaching Froude number should be smaller, and it might be easy to disappear plunging flow.

In order to install the concrete blocks on the slope, the concrete blocks must be stabilized for different discharges, and the upstream end of installed blocks must be fixed by stacking boulders (Photo 1). By comparing with stacked boulders, as the degree of protrusion for concrete block is smaller than that for stacked boulders, the slope of the installation of concrete blocks should be settled as i = 1/15 slope in order to increase the flow resistance. Also, the block should be located to the plover as shown in Photo 3.

4. FLOW CONDITION ON SLOPING ENERGY DISSIPATOR WITH CONCRETE BLOCKS

The flow condition at the sloping apron with stacked boulders depends on inflow Froude number above the drop F_1, relative drop height h_m/h_1(in this case, $s = h_m$), slope of stacked boulders i, relative protruding height of stacked boulders ε/h_1, and relative downstream depth h_d/h_1 (Yasuda and Masui (2019)). If the concrete blocks are installed as the placement of plover on 1/15 slope, a surface jet flow is always formed for the change of the tailwater elevation. Photos 5 and 6 show the flow conditions of the surface jet flow for both cases of free over type and supercritical flow type.

4.1 Free over flow type

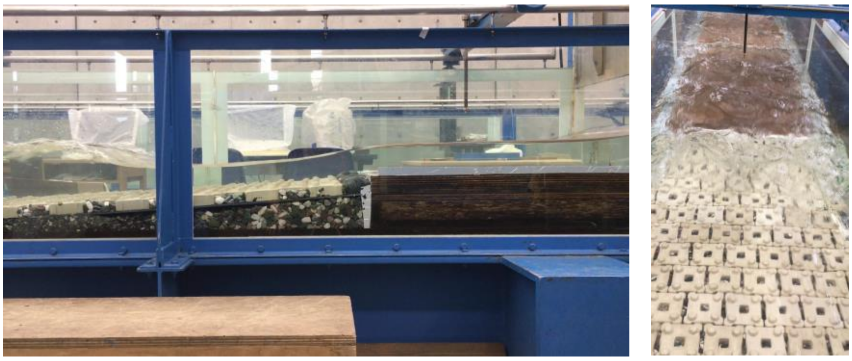
As shown in Photo 5, the main flow of the surface jet flow is located near the water surface, and the velocity of the main flow might be dissipated at downstream of the concrete blocks by the formation of strong turbulent flow with splashed water surface. In addition, if the transition from supercritical to subcritical flows is formed from the downstream end of the installed concrete blocks, a surface jet flow is formed. Because, a local Froude number $u_m/\sqrt{gh}$ (u_m is maximum velocity, h is flow depth) can be reduced to less than 1.9 at the downstream end of concrete blocks by the flow resistance due to the protrusion of concrete block.

4.2 Supercritical flow type

If the flow passing over the drop is supercritical ($F_1 > 1$) under the experimental condition shown in Table 1, a local Froude number $u_m/\sqrt{gh}$ can be reduced to less than 3.0 at the downstream end of concrete blocks. In this case, the jump with a surface roller is not formed, and a surface jet flow is formed as shown in Photo 6. Also, the concave coverture of streamline in the first wave is large, because the momentum of approaching flow is still larger than the free over type (Photo 5). If the tailwater level become to increase, the toe of the transition zone moves upstream.

5. WATER SURFACE PROFILES OF SURFACE JET FLOWS

Figures 2 and 3 show the water surface profiles for surface jet flows. As shown in these figures, the formation of undular surface does not continue far downstream, because a high velocity near the water surface might be dissipated in a short distance by a strong turbulent flow with splashed water surface. Also, the concave curvature of the undular surface for free over flow type (Figure 2) is smaller than that for supercritical flow type (Figure 3). This might be caused by the difference of approaching flow velocity. The undulation in the surface jet flow is consisted within four waves, and the formation of undulation might depend on the tailwater level (relative downstream depth h_d/h_1) under given relative drop height h_m/h_1, approaching Froude number F_1, and slope i.

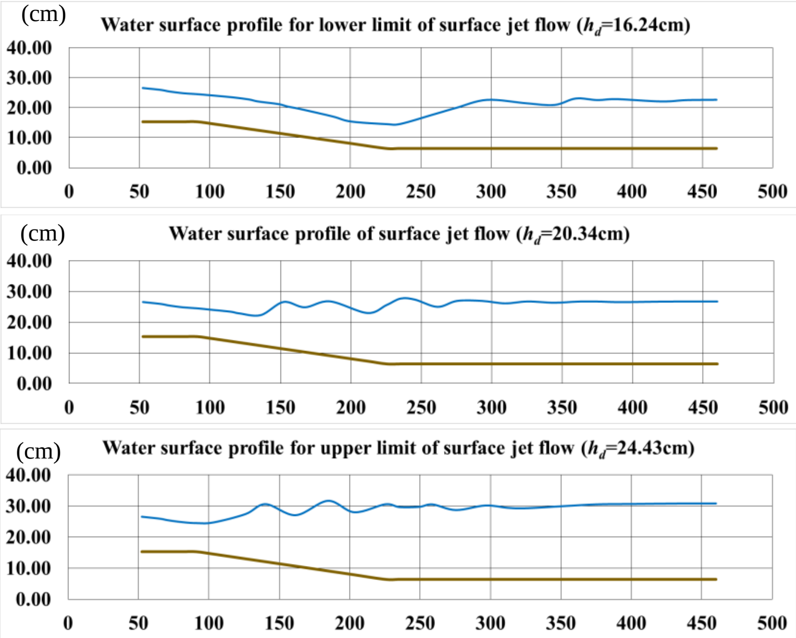


$F_1 = 1.0$, $h_m/h_1 = 0.79$, $i = 1/15$, $h_d/h_1 = 1.81$

Photo 5. Flow condition of surface jet flow under free over flow type.

$F_1 = 2.16$, $h_m/h_1 = 1.32$, $i = 1/15$, $h_d/h_1 = 3.33$

Photo 6. Flow condition of surface jet flow under supercritical flow type.

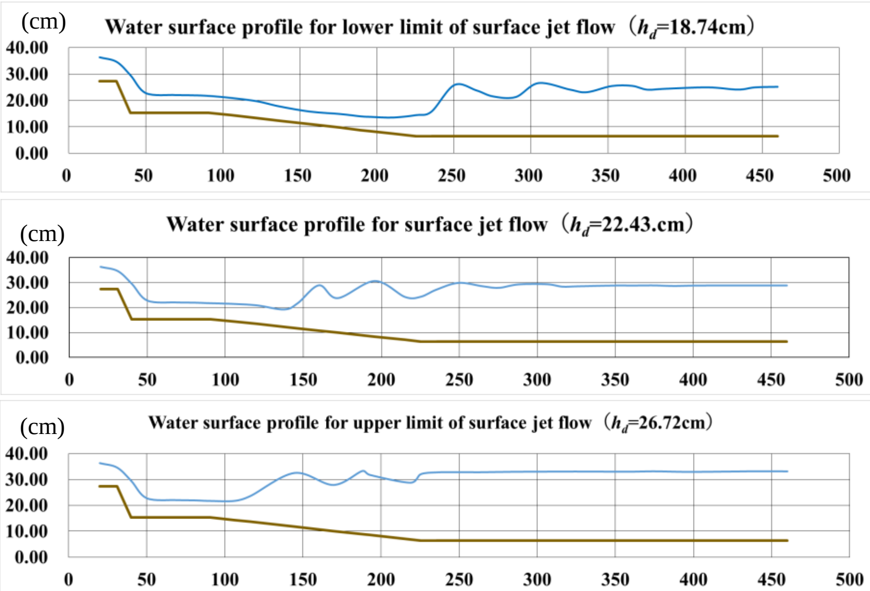


(a) h_d/h_1=1.44 (cm)

(b) h_d/h_1=1.80 (cm)

(c) h_d/h_1=2.17 (cm)

Figure 2. Water surface profiles for surface jet flows for F_1 = 1, h_m/h_1 = 0.79, i = 1/15 (Free over flow type).



(a) h_d/h_1=2.78 (cm)

(b) h_d/h_1=3.33 (cm)

(c) h_d/h_1=3.96 (cm)

Figure 3. Water surface profiles for surface jet flows for F_1 = 2.16, h_m/h_1 = 1.32, i = 1/15 (Supercritical flow type).

6. HYDRAULIC CONDITION FOR FORMATION OF SURFACE JET FLOWS

The hydraulic condition required to form plunging condition at an abrupt drop has been clarified by Ohtsu and Yasuda (1991). For F_1 = 1.0 and h_m/h_1 = 0.79, the surface jet flow is always formed. Accordingly, the formation of plunging flow can be disappeared by installing the concrete blocks on the slope of i (=h_m/L) = 1/15. For F_1 = 2.16 and h_m/h_1 = 1.32, the surface jet flow is formed, and the formation of the plunging flow cannot be observed. In order to predict the slope required to form the surface jet flow for different conditions, further investigation might be required.

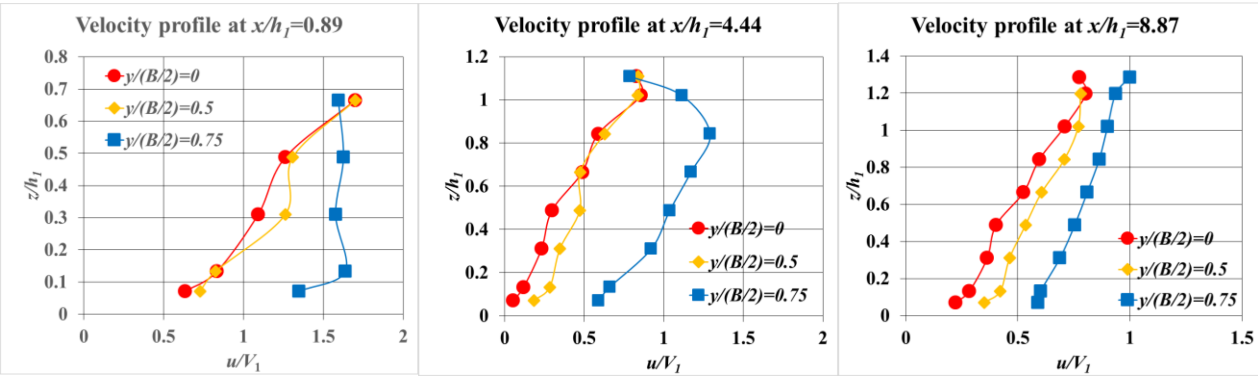
7. MEAN VELOCITY PROFILES IN SURFACE JET FLOWS

The mean velocity below concrete blocks was measured, and the velocity profile at each vertical section was arranged by equation (1).

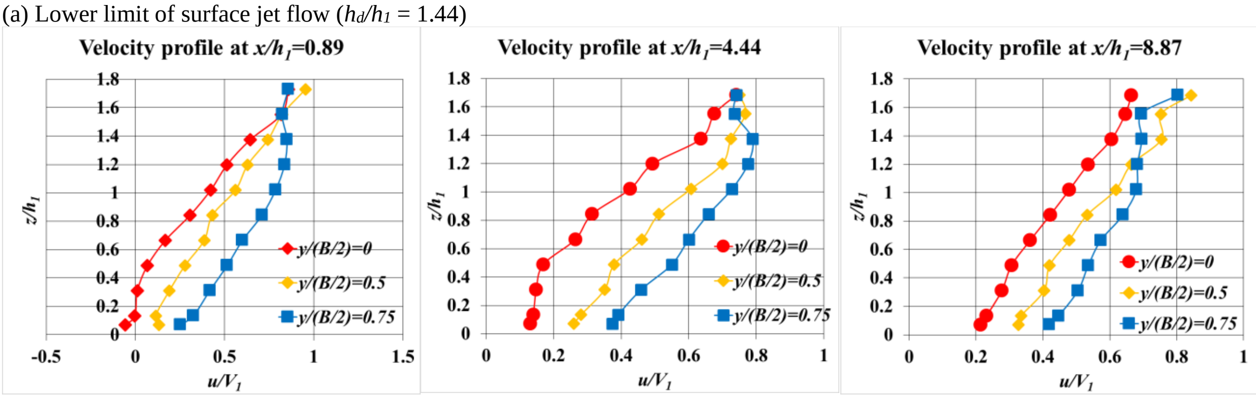
$$\frac{u}{} = f\left(\frac{}{},\frac{}{},F_1,\frac{m}{},i,\frac{d}{}\right) \tag{1}$$

Figure 4 shows the velocity profiles at downstream of the stacked boulders for F_1 = 1.00, h_m/h_1 = 0.79, and i = 1/15. For the formation of the surface jet flow, as shown in Figure 4, it has been confirmed that the main flow lifts into the water surface. Also, the velocity near the bottom is smaller than that near the water surface. But, for x/h_1 = 0.89 and h_d/h_1 = 1.44, the distribution of the mean velocity at $y/(B/2)$ = 0.75 is different from that at $y/(B/2)$ = 0 and 0.5. Also, the magnitude of the mean velocity at $y/(B/2)$ = 0.75 is larger than that at $y/(B/2)$ = 0 and 0.5. This might be caused by a high velocity flow along the side wall on the slope. As the concrete block was installed as staggered arrangement, a local flow resistance due to the protrusion of concrete block might be small near the side wall. At y = 0 cm, a reverse flow is formed near the bottom by the formation of stational wave.

Figure 5 shows the velocity profiles at downstream of the stacked boulders for F_1 = 2.16, h_m/h_1 = 1.32, and i = 1/15. At x/h_1 = 1.48, the velocity distribution at $y/(B/2)$ = 0.75 is slightly different from that at $y/(B/2)$ = 0 and 0.5. In this case, the effect of staggered arrangement on the flow along the side wall might be small.

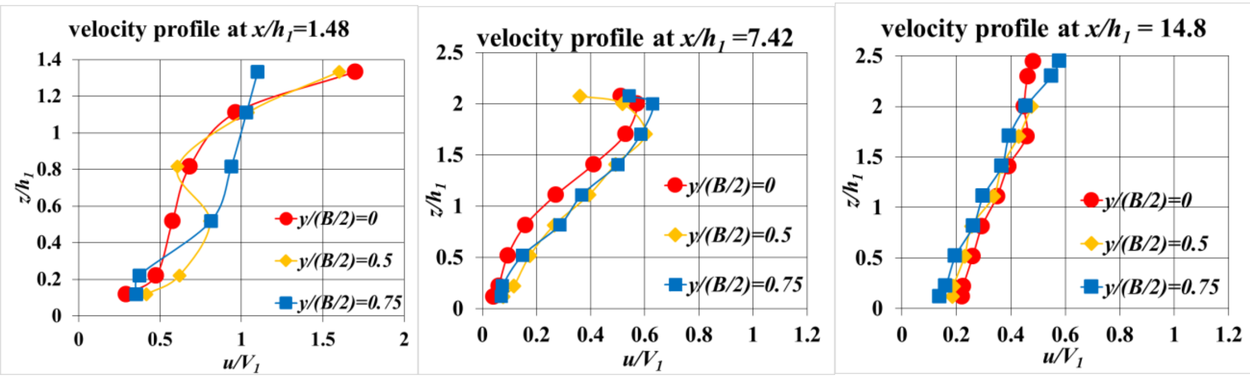


(a) Lower limit of surface jet flow (h_d/h_1 = 1.44)

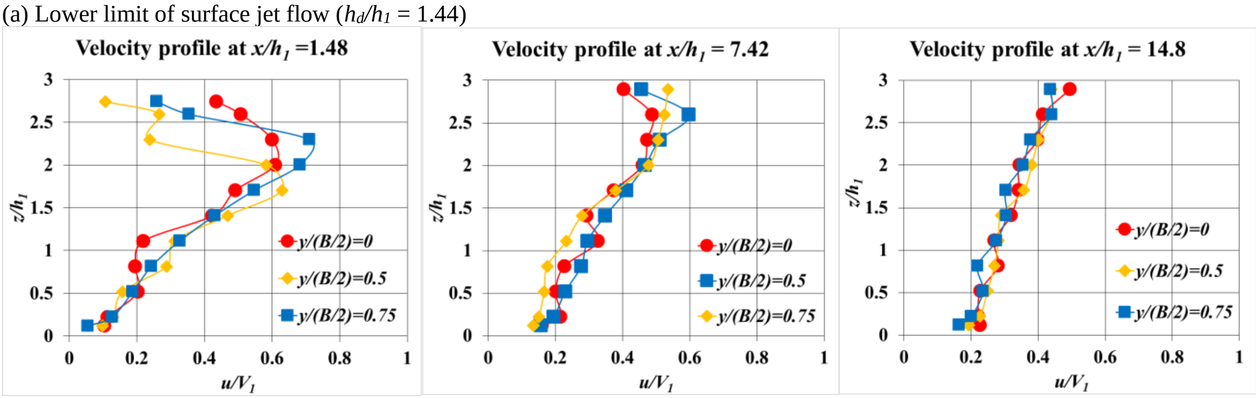


(b) Surface jet flow for h_d/h_1 = 1.80

Figure 4. Velocity profile for F_1=1, h_m/h_1 = 0.79, and i = 1/15.



(a) Lower limit of surface jet flow (h_d/h_1 = 1.44)



(b) Surface jet flow for h_d/h_1 = 1.80

Figure 5. Velocity profile for F_1 = 2.16, h_m/h_1 = 1.32, i = 1/15.

As shown in Figures 4 and 5, the velocity distribution for supercritical flow type differs from that for free over type. For free over flow type, the magnitude and distribution of the mean velocity affect *y/(B/2)* and x/h_1 under given h_m/h_1 and *i*. But, the effect of *y/(B/2)* on the magnitude and distribution of the mean velocity is small for supercritical flow type, because the momentum flux on the slope is large.

8. MAXIMUM MEAN VELOCITY DECAYS SURFACE JET FLOWS

In order to investigate the maximum mean velocity decay below the installation of concrete blocks for both free over flow type and supercritical flow type, the maximum mean velocity U_{max} was determined from the mean velocity profile at each vertical section, and the maximum mean velocity was arranged by equation (2).

$$\frac{U_{max}}{V_1} = f\left(\frac{x}{h_1}, F_1, i, \frac{h_m}{h_1}, \frac{h_d}{h_1}\right) \tag{2}$$

Figure 6 shows the maximum mean velocity decay of the surface jet flow under free over flow type. As the flow passing over the drop transits from critical to supercritical flows, and the velocity on the slope is accelerated. As shown in this figure, for the lower limit of surface jet flow, the maximum mean velocity decays within the range of $0 < x/h_1 < 8$. If the tailwater elevation is increased, the transition flow moves upstream, and the maximum mean velocity decays slightly at the downstream of the installation of concrete blocks.
In the case of supercritical flow type, as shown in Figure 7, the maximum mean velocity is more dissipated comparing with the case of free over type. Because, a strong turbulent flow is formed.

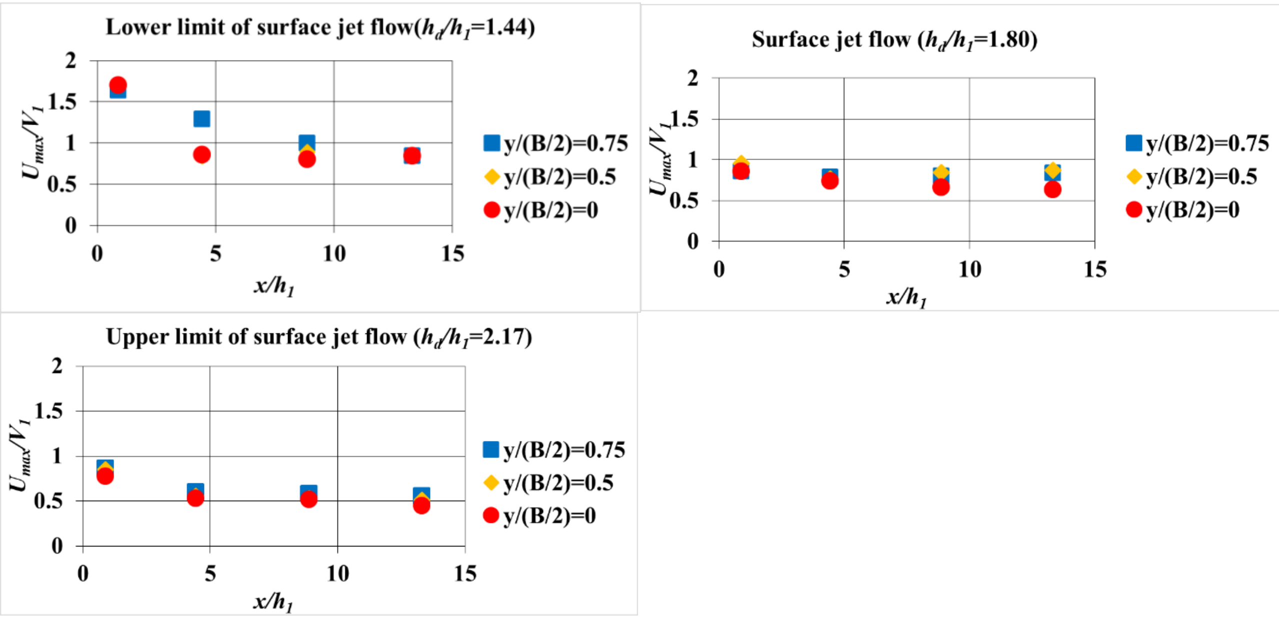


Figure 6. Maximum mean velocity decay for F_1=1, h_m/h_1 = 0.79, *i* = 1/15.

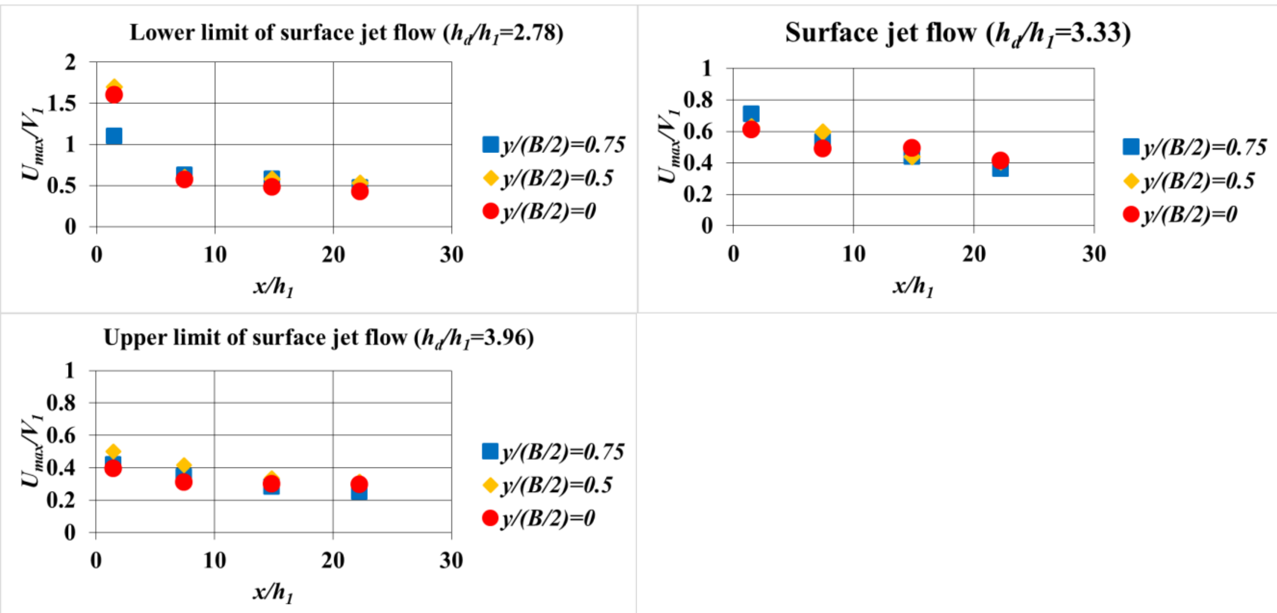


Figure 7. Maximum mean velocity decay for F_1 = 2.16, h_m/h_1 = 1.32, *i* = 1/15.

9. CONCLUSIONS

The application of concrete blocks with protrusion type to the sloping energy dissipator was presented. The installation of the sloping apron with concrete blocks below low drop structure is effective for the protection of river bed during flood stages if the slope of the installation is settled as 1/15 slope. The concrete block was installed as staggered arrangement. It might be easy to form surface jet flow by the flow resistance due to protrusion of concrete block for different discharges and tailwater elevations. The surface jet flow is always formed by considering the prediction for the hydraulic condition required to form plunging flow at an abrupt drop.

The method for the installation of concrete blocks with protrusion type is the most important, because the flow resistance due to the protrusion of concrete block is necessary to reduce the approaching high velocity. For the formation of the surface jet flow, it has been confirmed that the main flow lifts into the water surface. Also, the velocity near the bottom is smaller than that near the water surface. The velocity distribution below the installation of concrete block for supercritical flow type differs from that for free over type.

For the lower limit of surface jet flow, the maximum mean velocity decays in a short distance. In the case of supercritical flow type, the maximum mean velocity is more dissipated comparing with the case of free over type. Because, a strong turbulent flow is formed. If the tailwater elevation is increased, the transition flow moves upstream, and the maximum mean velocity decays slightly at the downstream of the installation of concrete blocks.

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