EXPERIMENTAL INVESTIGATION ON ARTIFICIAL CONTROL AGAINST PERIODICALLY DEFLECTED FLOW IN SUBMERGED HYDRAULIC JUMP

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ABSTRACT

If a submerged hydraulic jump has a large submergence, a high velocity flow below a sluice gate is located near the bottom. When the main flow lifts to the water surface from the channel bottom, at a certain condition, the main flow is periodically deflected. In this case, it might be difficult for swimming fishes to migrate upstream through the hydraulic structure, even if the fish passage is installed at the downstream of the structure. Because, most of swimming fishes might lose their upstream migration route by the formation of the periodically deflected flow. In this study, the installation of diagonal baffle blocks at the downstream of a sluice gate was proposed in order to disappear a periodically deflected flow in submerged hydraulic jump. The velocities and flow condition in the improved submerged jump were investigated experimentally. It has been confirmed that the main flow is concentrated into center part by installing diagonal baffle blocks properly at both side below sluice gate, and the periodically deflected flow can be changed to a stabilized flow. The artificially controlled flow has been characterized by the time averaged velocity vectors and the distribution of turbulent intensity. The velocity distribution at vertical section yields that the main flow is controlled by the installation of baffle blocks. Also, the change of velocity with time series shows that the fluctuation of the main flow can be reduced by the disappearance of the periodically deflected flow.

Keywords: Submerged hydraulic jump, Artificial control, Periodical deflected flow, Diagonal baffle blocks, Upstream migration route

1. INTRODUCTION

In order to stabilize the upstream water level against the change of downstream water level, a submerged hydraulic jump is formed below a sluice gate. If a submergence of the jump becomes higher, a high velocity flow is located near the bottom. When the main flow lifts to the water surface from the channel bottom, it has been observed at a certain condition that the main flow is periodically deflected (Yasuda and Tomita, 2015). In this case, most of swimming fishes might lose their upstream migration route by the formation of the periodically deflected flow, even if the fish passage is installed at the downstream of sluice gate.

The submerged hydraulic jump was investigated by many researchers (*e.g.*, Ohtsu et al., 1990, Rajaratnam, 1965, Wu and Rajaratnam, 1995). Their results were presented on the basis of time averaged quantities. In order to improve the energy dissipator due to the formation of submerged jump, the installation of either baffle, sill, or blocks in the submerged jump was investigated (*e.g.*, Habibzadeh et al., 2011, Habibzadeh et al., 2012, Hager and Li, 1992). But, the flow condition of submerged jump has not been discussed during normal stages from the point of aquatic habitat.

This paper presents the proposal of the optimal installation of diagonal baffle blocks at the downstream of a sluice gate in order to disappear periodically deflected flow in submerged hydraulic jump during normal stages. The optimal installation of diagonal baffle blocks was discussed on the basis of the observation of flow condition. The flow condition of submerged jump with the installation of baffle blocks was compared with that without the installation. The velocity vectors at downstream of sluice gate and the maximum velocity decay were shown. Also, the distribution of the turbulent intensity and the change of velocity with time series were shown. The optimal installation of baffle blocks in submerged jump may help the upstream migration of swimming fishes through the fish passage.

2. EXPERIMENTAL SETUP AND METHOD OF INSTALL BAFFLE BLOCKS

Experiments were conducted in horizontal rectangular channel with 15 m long, 0.80 m wide, and 0.60 m height. In order to install baffle blocks in the channel, three boards with 1.80 m long, 0.796 m wide, and 22 mm thickness were settled on the channel. The baffle blocks were installed on the board and the location of blocks was shown in Figure 1. The experimental conditions were summarized in Table 1. Here, R is the *Reynolds* number ($R = q/v$; q is discharge per unit width, v is coefficient of kinematic viscosity), F_0 is the *Froude* number at *vena contracta* ($F_0 = q/(h_0^{3/2}g^{1/2})$; g is acceleration due to gravity).

In Figure 1 (a), h_0 is the *vena contracta* depth, h_3 is the backup depth downstream of the gate, h_4 is tailwater depth, a is the opening sluice gate height, h_b is the baffle height, and θ is baffle tilt angle. In Figure 1 (b), B is width of the channel, x_b is the baffle location from gate, w_b is the baffle width, and φ is baffle installation angle. The coordinate axes of x, y, and z were defined as the downstream direction from the gate, the transverse direction from the center of the channel, and the vertical direction from the channel bottom, respectively.

F_0 and h_4/h_0 were set to the conditions in which a periodically deflected flow was formed (Yasuda and Tomita, 2015). The angle of baffle block installation φ was settled as either 45° or 135°, and the tilt angle of baffle block θ was settled as either 30° or 45° to do the main flow concentrated into center part and lifted to the water surface from channel bottom.

The water surface profile were recorded by using a point gauge with 0.1 mm reading. The velocity in the submerged jumps were recorded by using a two-dimensional electromagnetic current meter produced by KENEK CO. LTD. In the current meter, I and L type probes were used to measure the velocities u, v, and w with x, y, and z components. The velocities were recorded with sampling time 120 s and sampling frequency 20 Hz. The velocities at $y/(B/2) = 0.00$, 0.38, and 0.75 were measured at $x/h_0 = 8.96$, 17.9, 22.4, 27.0, 31.3, 35.8, 40.3, 44.8, and 49.3. Also, the discharge was measured by using a wide rectangular sharp edged weir located downstream end of channel. The flow conditions were recorded by a digital camera.
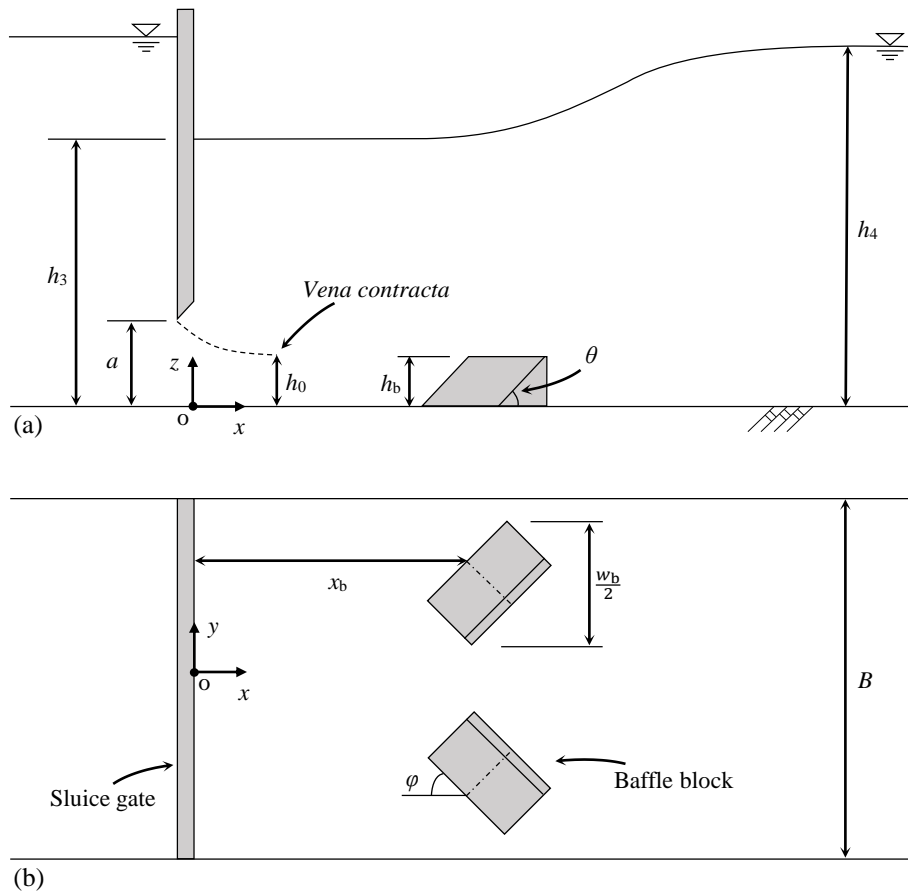

Figure 1. Definition sketch of submerged hydraulic jump with installation of baffle blocks: (a) side view, (b) plan view

Table 1. Experimental conditions.

$R \times 10^4$	F_0	h_4/h_0	h_3/h_0	h_b/h_0	w_b/B	x_b/h_0	φ	θ
9.08-10.4	2.08	6.29	5.68	0.75	0.30	13.4	45°, 135°	30°, 45°

3. FLOW CONDITION IN SUBMERGED JUMP WITH BAFFLE BLOCKS

Photo 1 shows the flow condition of submerged jump with or without the installation of baffle blocks. In Photo 1, the submerged jump was formed under the condition shown in Table 1, and the main flow in the submerged jump was visualized by a rope flutter.

If the baffle blocks are not installed below a sluice gate, a periodically deflected flow is formed. As shown in Photo 1 (a), the main flow is periodically deflected when the main flow lifts to the water surface from the channel bottom. While, by installing baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$, a high velocity flow below a sluice gate is deflected along a plate of baffle blocks. Also, the main flow is concentrated into center part and lifts to the water surface from channel bottom (Photo 1 (b)). Also, turbulences in the concentrated main flow might be reduced by comparing with the periodically deflected flow. If the baffle blocks are installed under the condition of $\varphi=45°$ and $\theta=30°$, a high velocity flow below a sluice gate is also deflected along a plate of baffle blocks. As shown in Photo 1 (c), the main flow spreads toward to side wall. In this case, a periodically deflected flow cannot be disappeared, and a similar flow condition is formed as in the case of Photo 1 (a). Therefore, the installation of baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$ is significant for the disappearance of periodically deflected flow.
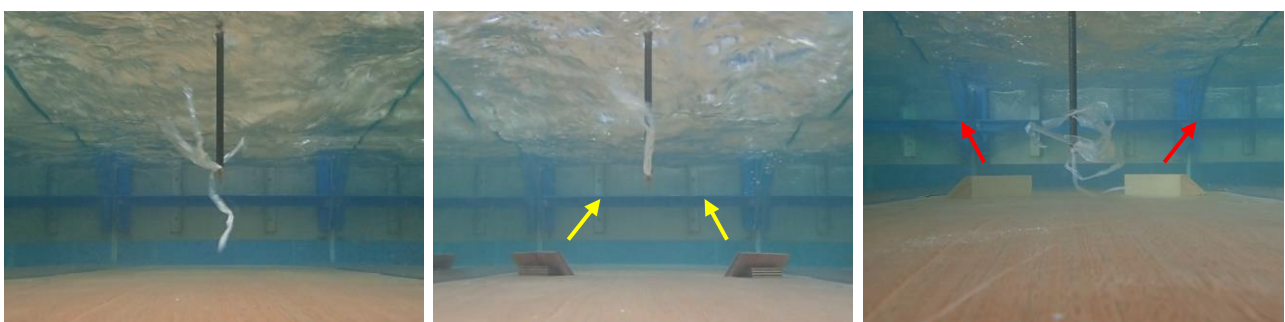
4. MEAN VELOCITY FIELDS IN SUBMERGED JUMPS

4.1 Mean velocity vectors in submerged jumps

Figure 2 shows mean velocity vectors at the center plane of channel ($y/(B/2) = 0.00$) under three different conditions shown in Table 1. Here, V_0 is the average velocity at the *vena contracta*. In this case, the components of velocity vectors u/V_0 and w/V_0 were measured for different locations of x/h_0 and z/h_0.

As shown in Figure 2 (a), by installing baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$, the main flow lifts to water surface from channel bottom in short distance. This might be caused by the deflection due to the baffle blocks. In the formation of the periodically deflected flow shown in Photo 1 (a), the velocity profile at vertical section is changed rapidly in approximately $x/h_0 = 40$ (Figure 2 (b)). Because, the main flow is periodically deflected when the main flow becomes to lift to the water surface from the channel bottom. In the case of the installation of baffle blocks under the condition of $\varphi=45°$ and $\theta=30°$, as shown in Figure 2 (c), velocity vectors are similar to those shown in Figure 2 (b).

Figure 3 shows mean velocity vectors at plane view on near the bottom ($z/h_0=0.75$) and underwater ($z/h_0=3.00$). In this case, the components of velocity vectors u/V_0 and v/V_0 were measured for different locations of x/h_0 and $y/(B/2)$.

As shown in Figure 3 (a), by installing baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$, the main flow can be concentrated into center part. Because, the main flow is artificial controlled by the formation of a deflected flow along a plate of installed baffle blocks. However, in case of the periodically deflected flow, the mean velocity near the side wall is higher than at center part of channel (Figure 3 (b)). Because the mean averaged velocity flow along both sides might be concentrated by the formation of periodically deflected flow.
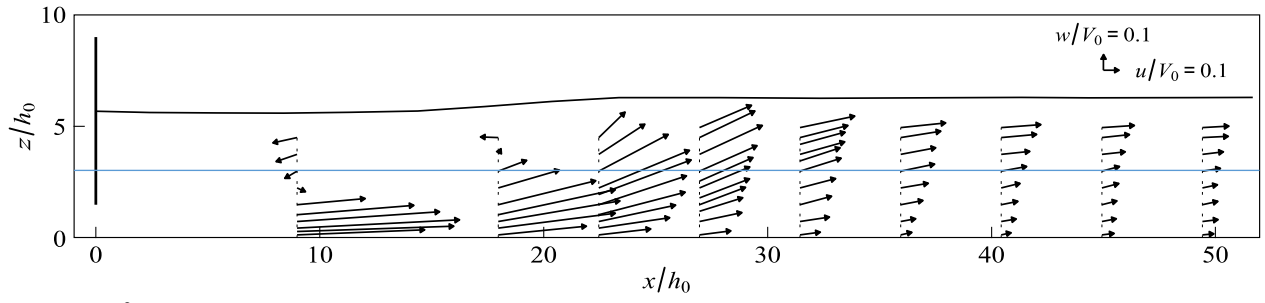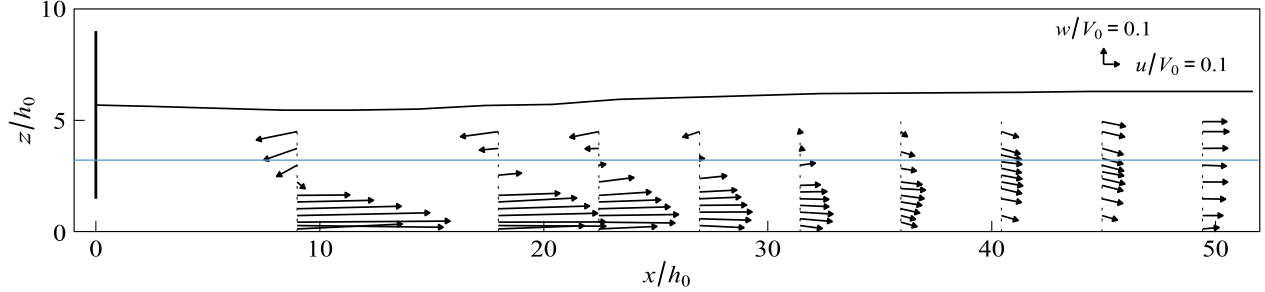

(a) Without baffle blocks   (b) $\varphi=135°$, $\theta=45°$ (c) $\varphi=45°$, $\theta=30°$
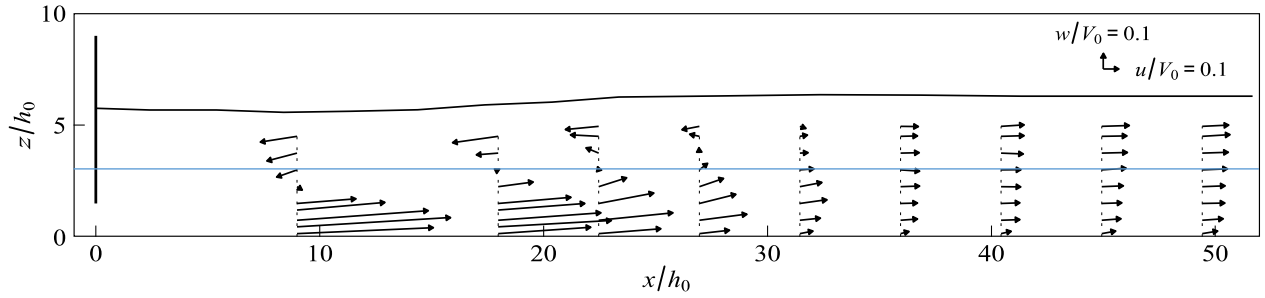
Photo 1. Flow condition in submerged jump under the condition shown in Table 1.

(a) $\varphi=135°$, $\theta=45°$

(b) Without baffle blocks

(c) $\varphi=45°$, $\theta=30°$

Figure 2. Mean velocity vectors in submerged jumps at center plane (y/(B/2) = 0.00).

4.2 Maximum velocity decays in submerged jumps

Figure 4 shows a streamwise decay of maximum velocity decided in velocity profile at each vertical section. The data were plotted under three different conditions shown in Table 1. Here, u_{max} is the maximum velocity at each section, V_4 is the average velocity at the tail water. The non-dimensional parameters $(u_{max}-V_4)/V_0$ at $y/(B/2)=0.00$, 0.38, and 0.75 were arranged.

As shown in Figure 4, the maximum velocity decays within the range of $0 < x/h_o < 40$, and the length for the maximum velocity decay accomplished by the jump formation in not significantly affected by the installation of baffle blocks. In this case, the maximum velocity is varied with $y/(B/2)$ in the range of $15 < x/h_o < 40$. When the main flow becomes to lift to the water surface, the mean velocity might be different transversely. As shown in Figure 3, the plane velocity vectors is affected by the installation of baffle blocks.

5. TURBULENT CHARACTERISTICS IN SUBMERGED JUMPS

5.1 Turbulent intensity distribution in submerged jumps

Figure 5 shows turbulent intensity distributions at the center plane of channel ($y/(B/2) = 0.00$) and near the side wall of channel ($y/(B/2) = 0.75$) under three different conditions shown in Table 1. Here, u'_{rms} is turbulent intensity of streamwise component velocity u, and also is represented as root mean square.

As shown in Figure 5 (a), by installing baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$, the turbulent intensity can be reduced at center plane of channel. Also, as the velocity near the side wall ($y/(B/2) = 0.75$) is smaller than that at the center part of channel, the turbulent intensity is smaller than that without baffle blocks (Figure 5 (b)).

In the case of the installation of baffle blocks under the condition of $\varphi=45°$ and $\theta=30°$, as a periodically deflected flow cannot be disappeared, the turbulent intensity is larger than that for the condition of $\varphi=135°$ and $\theta=45°$. In the range of $x/h_o < 30$, the turbulent intensity at $y/(B/2) = 0.00$ is a similar to that without baffle blocks. Also, for the range of $35 < x/h_o < 50$, as the main flow spreads toward to side wall by the installation of the baffle blocks, the turbulent intensity at $y/(B/2) = 0.75$ is a similar to that without baffle blocks.

5.2 Change of velocity with time series in submerged jumps

Figure 6 shows the change of velocity with time series about transverse component velocity v at x/h_0=27.0, $y/(B/2) = 0.00$, $z/h_0 = 3.00$ (see Figure 2).

In the case of the installation of baffle blocks under the condition of φ=135° and θ=45°, the main flow lifts to the water surface. While, in the case of the flow condition without the installation of baffle blocks, as shown in Figure 2 (b), the boundary between reverse flow and streamwise flow is located at x/h_0=27.0 and $z/h_0 = 3.00$. As shown in Figure 6 (a), as the main flow does not spread transversely, the change of the velocity with time series is limited, even if a high frequency occurs.

i) $z/h_0 = 0.75$

ii) $z/h_0 = 3.00$
(a) φ=135°, θ=45°

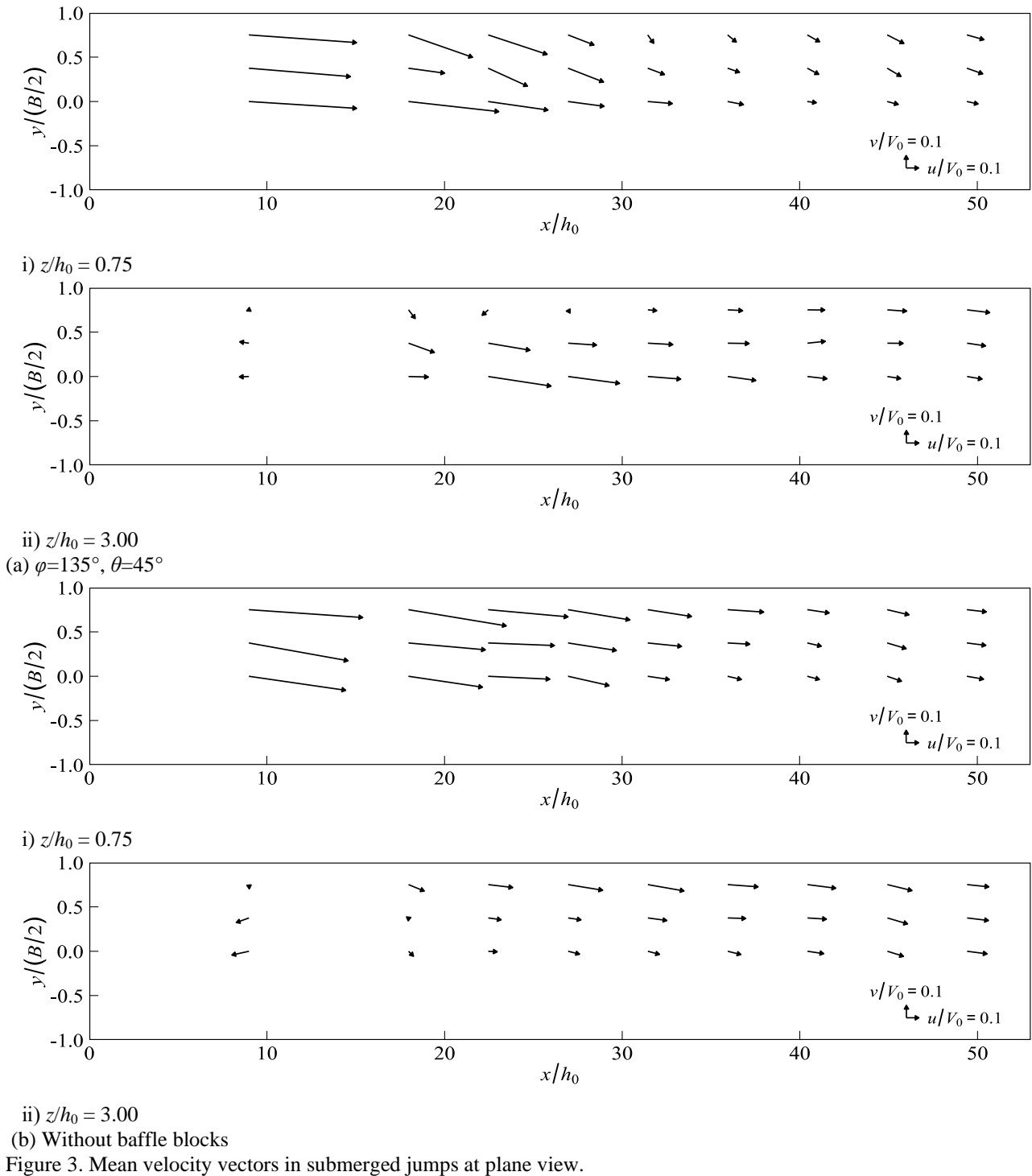i) $z/h_0 = 0.75$

ii) $z/h_0 = 3.00$
(b) Without baffle blocks
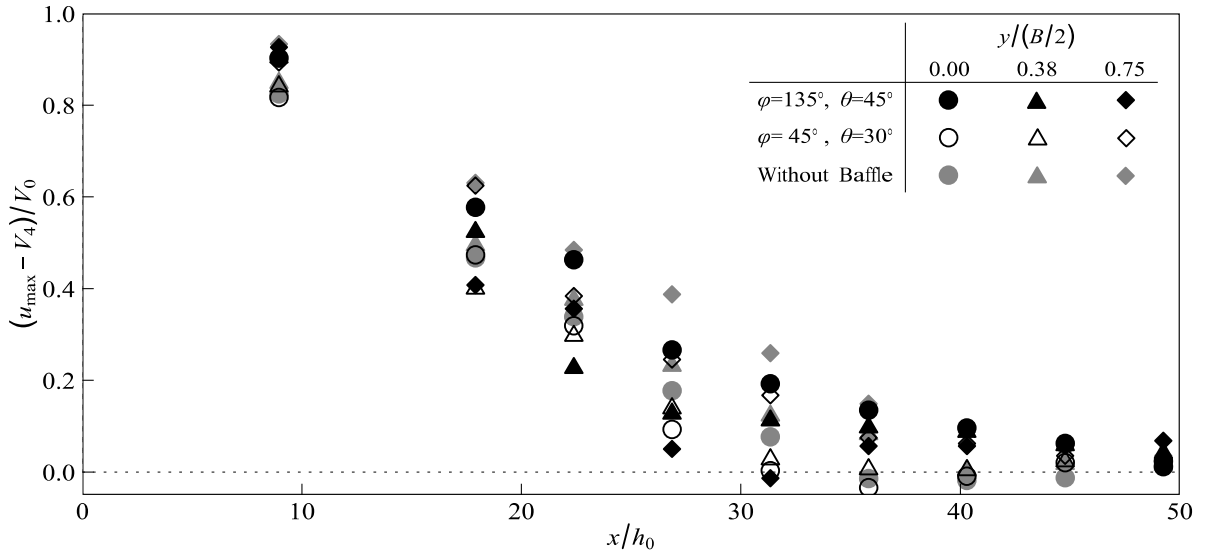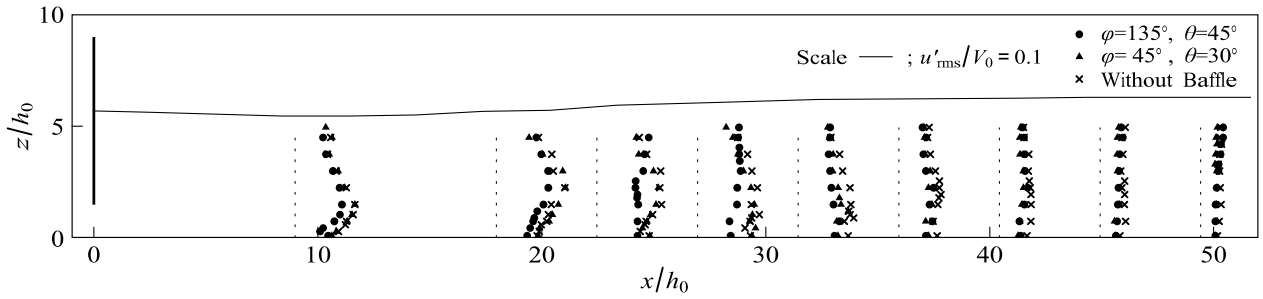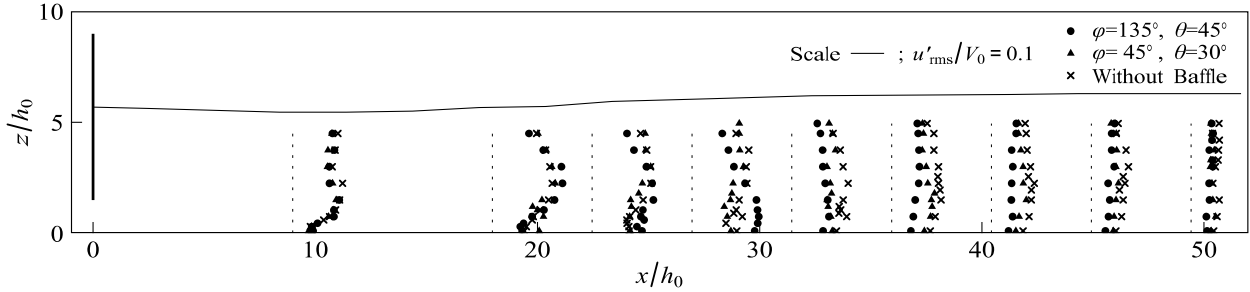Figure 3. Mean velocity vectors in submerged jumps at plane view.

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Figure 4. Maximum velocity decay in submerged jumps.

(a) Center plane; $y/(B/2) = 0.00$

(b) Side plane; $y/(B/2) = 0.75$

Figure 5. Turbulent intensity distribution in submerged jumps.

In the case of the flow condition without the installation of baffle blocks, as a periodically deflected flow is formed, the change of the velocity with time series is large, even if the mean velocity is shown as the boundary between reverse and streamwise flows (Figure 6 (b)). Further, a high frequency occurs in low frequency.

In the case of the installation of baffle blocks under the condition of $\varphi=45°$ and $\theta=30°$, as shown in Figure 6 (c), the change of velocity with time series is a similar to that for the flow condition without the installation of baffle blocks. Because, a periodically deflected flow cannot be disappeared, even if the baffle blocks is installed.

5.3 Results of spectral analysis

Figure 7 shows the results based on spectral analysis for the velocity v measured at the location indicated in section 5.2. As shown in the change of the velocity with time series (Figure 6), high frequencies exist in low frequencies for three different cases shown in Table 1. In the case of the installation of the baffle blocks under the condition of $\varphi = 135°$ and $\theta = 45°$, as shown in Figure 7, the value of Fourier spectrum is lower than that for the flow condition without baffle blocks in the range of $0.05<f<1$. Accordingly, the frequency for $0.05<f<1$ might be characterized for the formation of periodically deflected flow.

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(a) $\varphi=135°$, $\theta=45°$

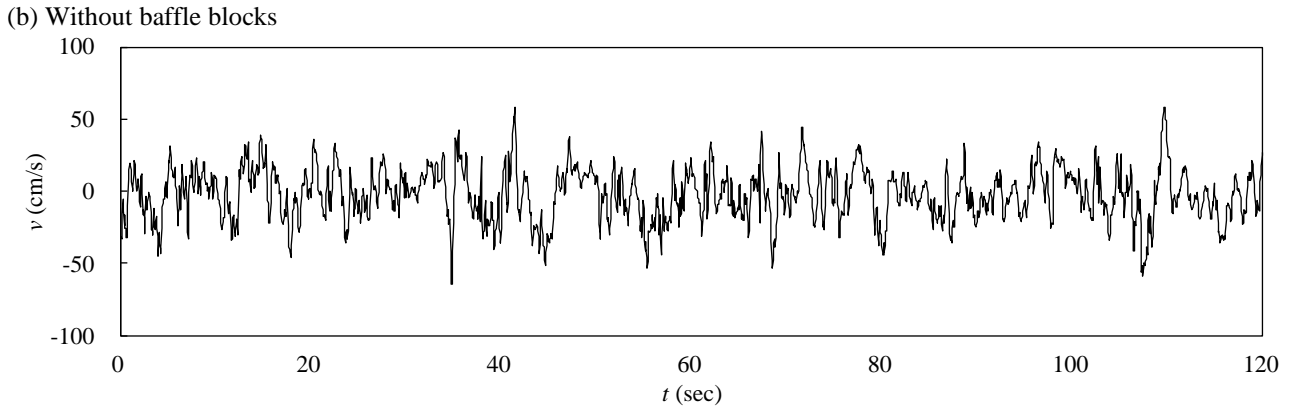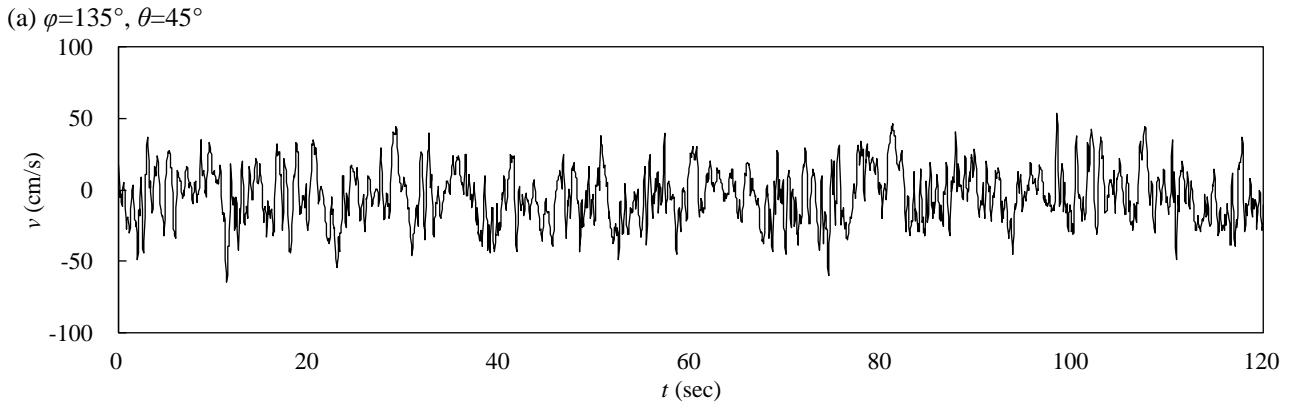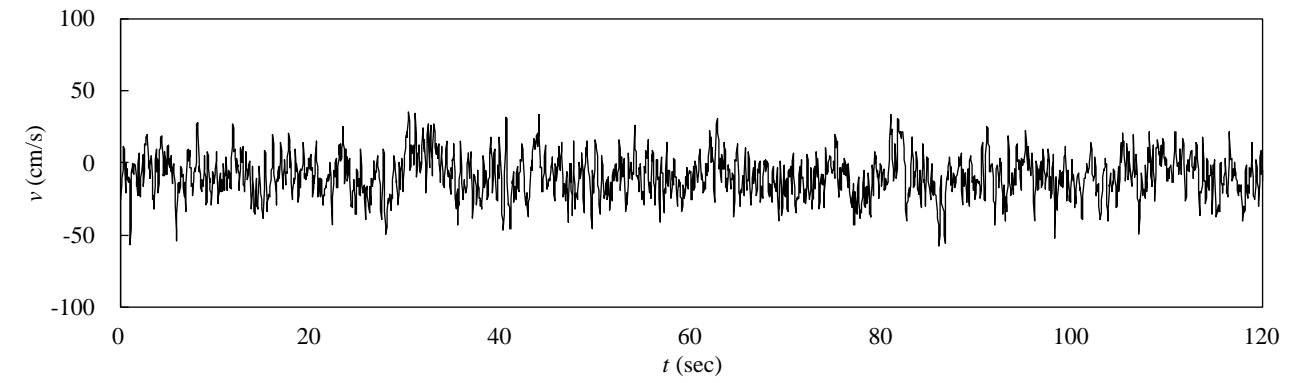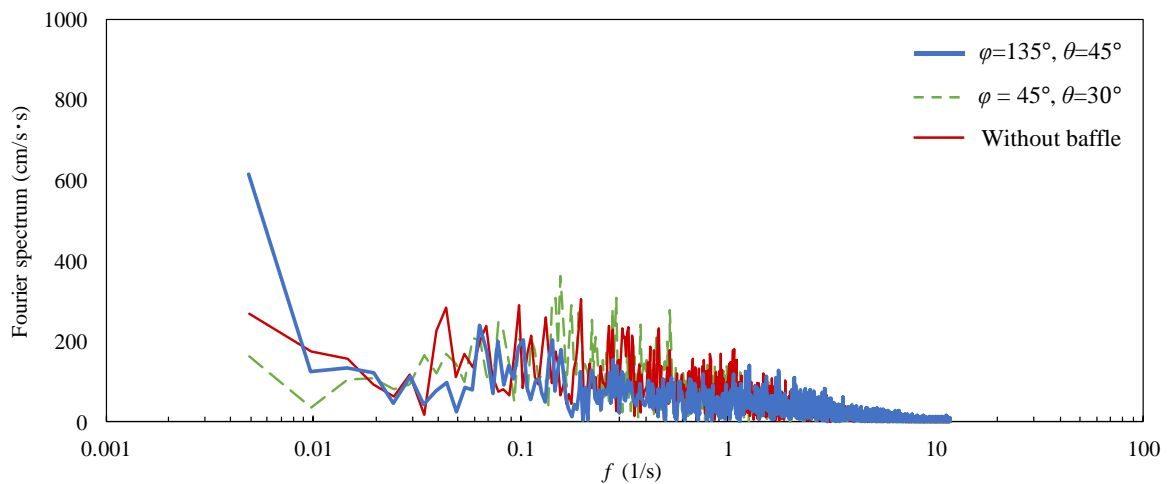(b) Without baffle blocks

(c) $\varphi=45°$, $\theta=30°$

Figure 6. Change of velocity with time series in submerged jumps at $x/h_0=27.0$, $y/(B/2) = 0.00$, $z/h_0 = 3.00$.

Figure 7. Results of spectral analysis at $x/h_0=27.0$, $y/(B/2) = 0.00$, $z/h_0 = 3.00$.

6. CONCLUSIONS

The optimal installation of the baffle blocks in submerged hydraulic jump during normal stage is effective for artificial control of the main flow. The method for the installation of baffle blocks is significant to change the periodically deflected flow to a stabilized flow.

Experimental results yield that the main flow is concentrated into center part of channel and lifts to the water surface from channel bottom by installing baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$. Also, the periodically deflected flow is disappeared, and the turbulent intensity can be reduced. Because, the main flow can be artificial controlled by the formation of a deflected flow along a plate of installed baffle blocks under the condition of $\varphi=135°$ and $\theta=45°$. However, in the case of the installation of baffle blocks under the condition of $\varphi=45°$ and $\theta=30°$, a periodically deflected flow cannot be disappeared, and the flow condition is similar to that without baffle blocks.

Accordingly, the optimal installation of diagonal baffle blocks in submerged jump during normal stages may help the upstream migration of swimming fishes through the fish passage by the disappation of periodically deflected flow in submerged jump. For a wide range of condition, systematical investigation on the improvement of periodically deflected flow in submerged jump might be required, and the optimal installation of diagonal baffle blocks should be studied. Also, turbulent characteristics in submerged hydraulic jump with baffle blocks should be investigated systematically for the preservation of aquatic habitat.

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