STUDY ON FLOW CHARACTERISTICS IN THE CAVITY OF STRAIGHT OPEN CHANNEL SIDE WALL

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ABSTRACT

An embayment in real rivers are depressions on the banks of the river, and they serve as habitats and breeding areas for creatures and plants. Therefore, it is necessary to know the internal flow conditions to manage them. In this study, we set up the side wall cavity in the experimental channel and examined the characteristics of the internal flow using PTV and visualization method. As a result of PTV, it was found that a large-scale circulation flow was formed inside the cavity, and a remarkable shear layer was formed at the boundary between the cavity and the main stream. From the results of the visualization experiments, it was suggested that a characteristic vortex structure was found at the boundary between the cavity and main stream, and that it played an important role in the formation of the shear layer and the circulation

Keywords: side-cavity zone, shear layer, vortex structure, circulation flow, PTV, flow visualization

1. INTRODUCTION

In Japan, the creation of rivers is being promoted in consideration of the river environment under substantial river control measures. A embayment is connected to the main stream of a river, and is a topography that looks like a pond surrounded by river structures. It provides a stable habitat for aquatic organisms such as fish, and is a place where various vegetation breeds. In order to preserve the environment inside the wand, it is necessary to understand the flow structure inside the embayment. Various experiments on the wand flow have been conducted. Regarding the velocity distribution characteristics of the flow field, a remarkable circulating flow was formed and a remarkable shear layer and a large turbulent region were formed at the boundary with the main flow. It is clear that However, the findings were obtained only in the horizontal section where the measurement section was limited to a half-water depth, and did not capture the entire flow field, so it could not be said that it captured the essence of the flow structure of the wand. Sufficient knowledge has not been obtained about the coherent structure, which is a factor that governs flow.

Based on the above, in this study, in order to understand the essence of open channel flow with a cavity on the side wall, we performed detailed flow velocity measurement in the flow field and focused on the coherent structure formed there, and clarified its characteristics, and create a conceptual model of the flow.

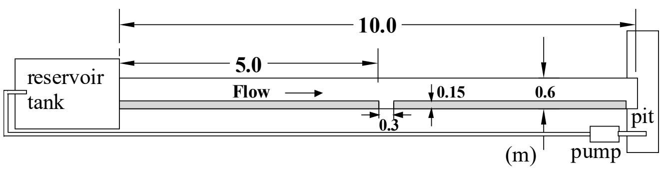


Figure 1. Outline of the test channel

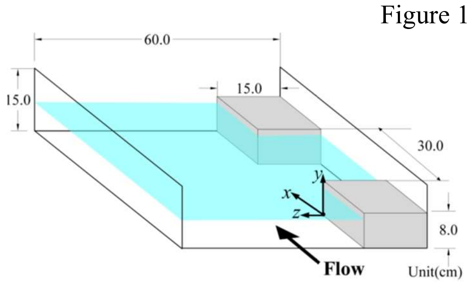


Figure. 2. Outline of water channel recess

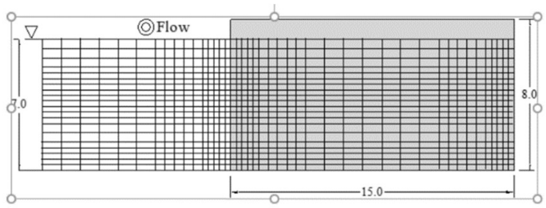


Figure 3. PTV measurement cross section position

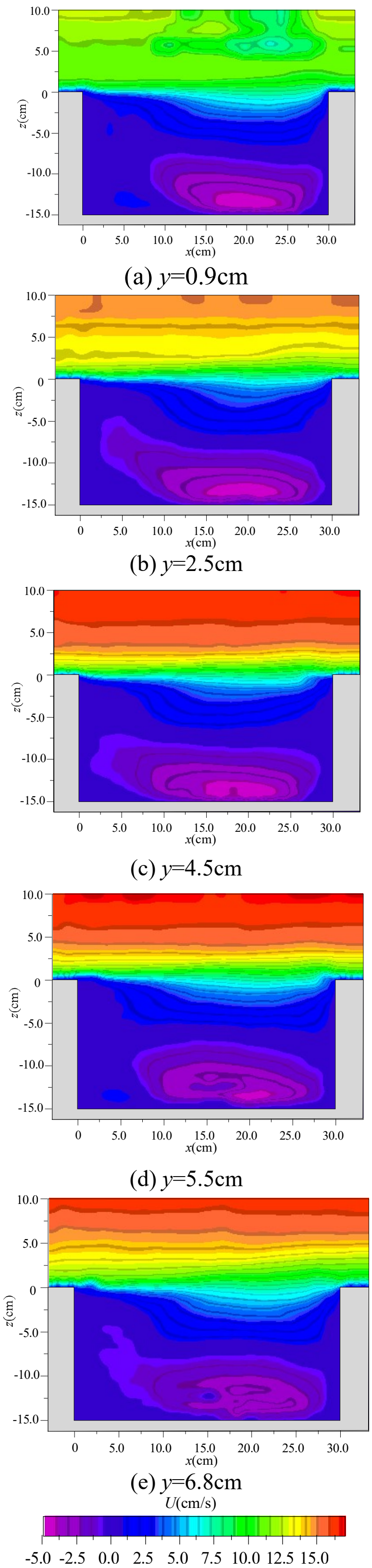


Figure 4. Average primary velocity distribution (U)

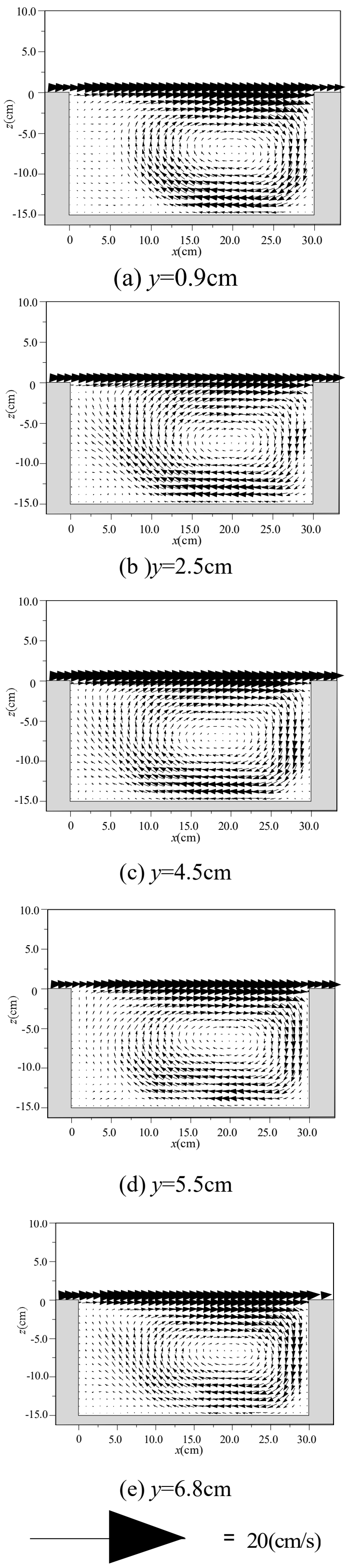


Fig 5. Flow velocity vector distribution (U, W)

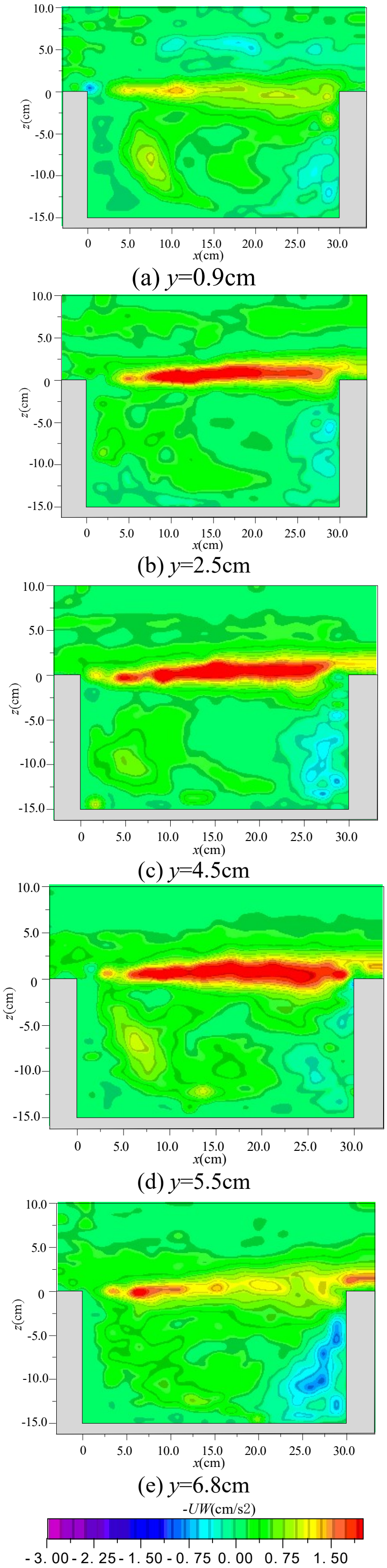
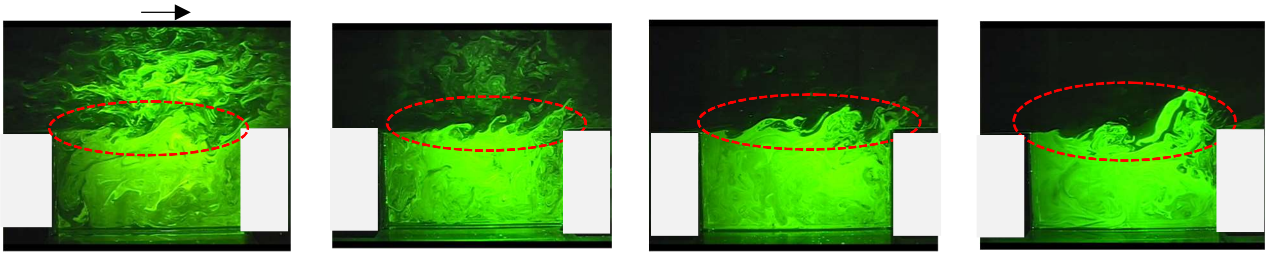


Fig 6. Reynolds stress distribution ($-uw$)

For this purpose, the following three tasks are performed. 1st. Clarify the detailed three-dimensional flow velocity characteristics of the flow field. 2nd. Clarify the spatiotemporal characteristics of the tissue structure formed in the flow field. 3rd. Clarify the correlation between the behavior of the coherent structure and the flow velocity distribution. 4th. Create a conceptual model of the flow field.

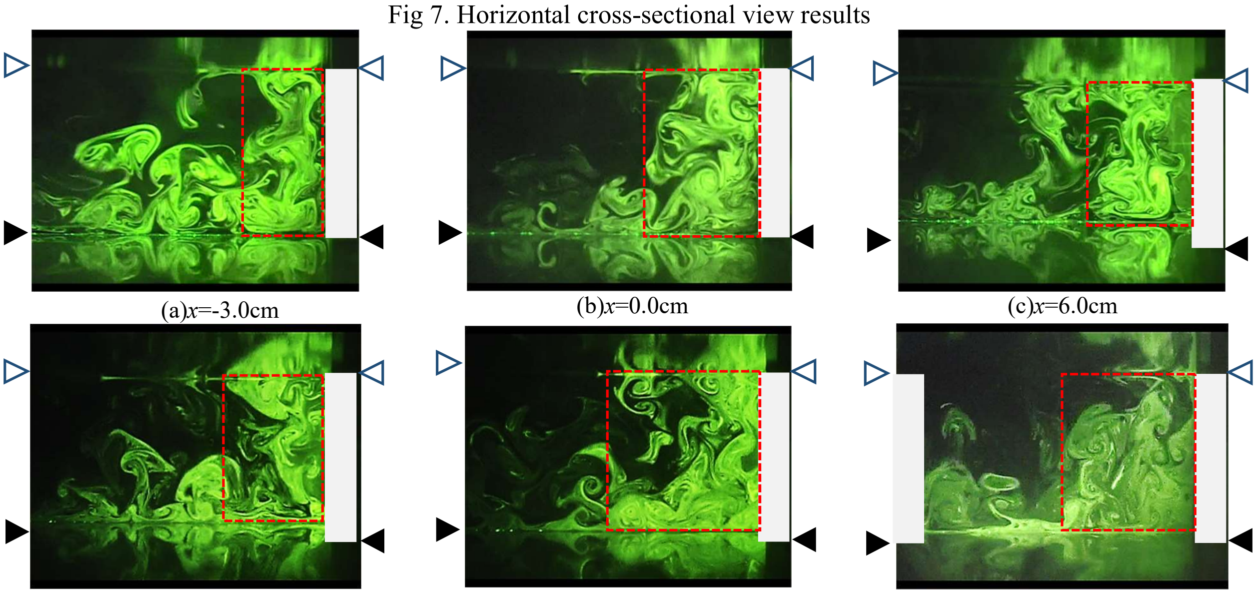
2. EXPERIMENTAL EQUIPMENT AND EXPERIMENTAL METHOD

In this study, a straight open channel made of total acrylic resin with a length of 10m, a width of 60cm and a height of 15cm is used. A 15 cm wide, 6 cm high and 1 m long board made of PVC resin was laid on the right



(a)y=1.0cm (b)y=3.0cm (c)y=5.0cm (d)y=6.8cm

Fig 7. Horizontal cross-sectional view results



(a)x=-3.0cm (b)x=0.0cm (c)x=6.0cm

(d)x=12.0cm (e)x=25.0cm (f)x=30.0cm

▷ ◁ Water surface ▶ ◀ Wall surface

Figure 8. Results of cross-sectional view

bank side of the canal, and a 30 cm long space was provided at 5 m from the upstream to serve as a cavity flow. Figure 1 shows an overview of the experimental channel, and Figure 2 shows an overview of the channel cavity. PTV (Particle Tracking Velocimetry) using fine particles (Rilsan powder with an average particle size of 100μm and a specific gravity of 1.04) was adopted for flow velocity measurement. A 4K digital video camera (Sony PXW-Z150) was used to capture the particle flow image. The size of the captured image is 3840 x 2160 pixels. The particle flow image was captured in a computer every 1/30 second for 60 seconds (1800 images), and the instantaneous velocity was calculated using the software FLowPTV (Library Co., Ltd.) which adopted the density pattern tracking algorithm. The average velocity distribution and turbulence distribution were obtained by statistically processing the obtained instantaneous velocity. The fluorescent dye injection method was adopted for visualization of the internal flow.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figures 4 to 6 show the PTV measurement results. From the mean primary velocity distribution (U) in Figure 4, the inside of the cavity is relatively slow. In the vicinity of it, a reverse flow area is confirmed. A remarkable shear layer is formed at the boundary with the high-speed region. In the flow velocity vector (U, W) in Figure5, it was presumed that a clockwise circulating flow was formed near the downstream in the side wall cavity. In the velocity vector of y = 5.5cm and y = 6.8cm, the formation of anti-clockwise circulating flow was confirmed at the corner of the upstream side wall in the side wall cavity. In the Reynolds stress distribution (-uw) in Fig. 6, it was confirmed that the boundary between the side wall cavity and the main stream had a positive region, and a negative region was formed at the downstream corner of the cavity. From the above, it was clarified that a strong shear stress region was formed at the boundary of the main stream due to the formation of a remarkable shear layer.

Figure 7 shows the visualization results when viewed in a horizontal cross section, and Figure 8 shows the visualization results when viewed in a cross section. In Figure 7, as indicated by the red dashed line, a vortex structure with a vertical axis of rotation was observed at the boundary with the main stream, and its scale was observed to increase in the downstream direction. It is also clear that the overall scale increases with approaching the water surface. Furthermore, it was observed that this vortex structure transported the fluid from the main stream side to the inside of the cavity by the vortex motion in the clockwise direction, and thus formed a circulating flow clockwise in the cavity. In addition, a small vortex structure around the anti-

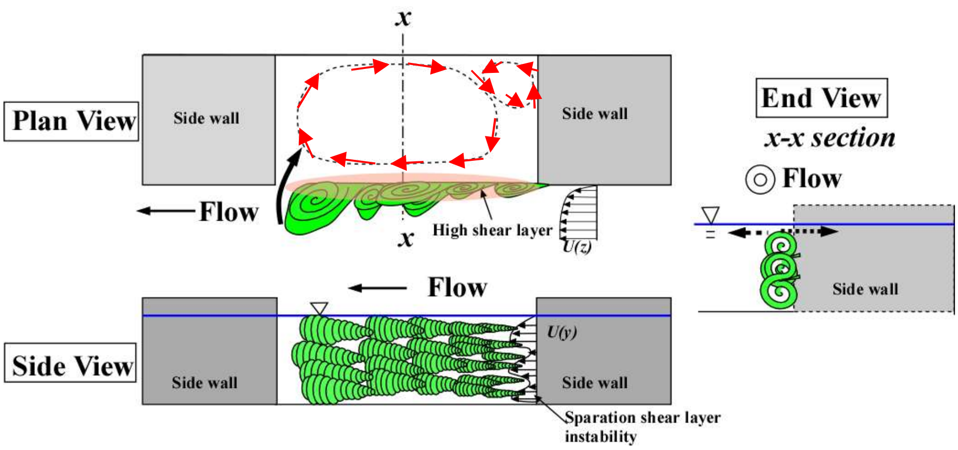


Fig 9. Conceptual model of flow in open channel cavity

clockwise direction was observed in the upstream corner near the water surface. In Figure 8, the cross-section of the longitudinal vortex structure was observed at the boundary between the mainstream and the cavity on the side wall, as indicated by the red dashed line. It was observed that this vortex structure transports fluid from the main stream to the cavity or vice versa due to the vortex motion. This longitudinal vortex structure corresponds to the vortex shape observed in horizontal cross section. Furthermore, it was observed that this longitudinal vortex structure became larger in the downstream direction. This longitudinal vortex structure is presumed to be the longitudinal vortex structure caused by the instability of the shear layer separated from the side wall of the main stream.

3.1 Conceptual model of flow in cavity

Figure 9 shows a conceptual model of the flow of the open channel cavity. In this flow, two shear layers, a vertical shear layer $\partial u/\partial y$ and a horizontal shear layer $\partial u/\partial z$, are formed at the downstream end of the open channel side wall. The coexistence of these two shear layers is a necessary condition for the formation of a longitudinal vortex structure. (Watanabe et al,2006). As a result, a vertical vortex structure group is formed downstream. This longitudinal vortex structure develops downstream and plays an important role in transverse fluid transport at the boundary area between the cavity and the main stream. This longitudinal vortex structure forms a region with strong turbulence intensity and high Reynolds stress in the boundary region. Fluid transport from the main stream to the cavity generates a circulating flow in the clockwise direction and a secondary circulating flow in the anti-clockwise direction inside the cavity.

4. CONCLUSIONS

The flow characteristics and coherent structure in an open channel flow with a cavity on the side wall were studied using a detailed flow velocity measurement with a PTV and a flow visualization method. The main conclusions of this study are as follows.

(1) The cavity in the open channel becomes a relatively low-speed region, and a circulating flow in the clockwise direction is formed inside the cavity. As the water gets closer to the water surface, a small circulating flow forms in the anti-clock wise direction.
(2) A remarkable shear layer was formed at the boundary between the open channel and the depression, and it was revealed that the turbulence strength (u_{rms}, w_{rms}) and Reynolds stress ($-uw$) were high.
(3) A longitudinal vertical structure group is formed in the boundary area between the main stream and the cavity due to the coexistence of two shear layers. It was guessed that this longitudinal vortex structure group formed a large-scale circulating flow inside the cavity due to the generation of strong turbulence and the fluid transport from the main stream to the cavity due to the fluid motion.

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