II - 299 **Investigation of 3-D Vortical Structures in a Compound Channel**

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1. Introduction

In compound channels, most of the work on the effect of the interaction of low– and high–speed regions is restricted to the determination of the velocity distribution, shear stress over the bed and along the interface plane, and finally, capacity of the compound channel. Various techniques of flow visualization have already been used to picture the flow and to show the actual state of the vortex in real time by taking sequential photographs of the flow. However these techniques are restricted to qualitative analysis whose advantages over quantitative analysis are limited by limited pictured sections and large time intervals between each loop of photography as well as between sections.

In this work, we have used multi-section flow visualization technique to overcome these problems. Investigation of the behavior of a typical vortical structure, individually or in a group of vortices, such as generation, evolution, deformation and interaction which helps us to picture the mechanism of continuous momentum, mass and energy exchange between the main channel and the flood plain, is the objective of this study.

2. Experimental Condition and Procedure

The present experiments were carried out in a free surface water channel. The working section dimensions of the channel were 30.0 m, 0.7 m and 0.12 m in length, width and depth, respectively. At the channel inlet, a bell-mouth and multi-hole steel screens were installed to shape the flow. An inclination of 1/1000 was given to channel to provide the uniformity of flow at the testing area. The coordinate system is right-handed with origin located on the bed at the edge of flood plain. As is the convention in hydraulics, x, y are horizontal directions and z is vertical one; and u, v, and w are velocity components in the x, y, and z directions, respectively. The height of the flood plain was 60 mm and its width was 400 mm which is equal to half of the channel width. The mean streamwise velocity over the compound cross section $U_m = 15.2$ cm/s, was chosen as a reference velocity. The photography system is shown in Fig. 1. From four pictured sections a three-dimensional velocity field was obtained. For more information reader is referred to Kawanisi et al.[1].

3. Results

Mean Flow

Here, we have investigated 15 frames of instantaneous velocity fields. Later they were used to calculate the mean characteristics of flow. In this work Figs. 2 and 3 are obtained by the use of time-space-average method. Fig. 2 shows iso-velocity lines of the mean velocity in the main flow direction in the background and vector field of v and w components of velocity mapped on the contour lines in front. In this figure in the main channel two main secondary flows can be observed. At the junction point toward the water surface, which makes a surface with an angle of 45° to the horizontal direction, upward flow can be seen. This surface is called the interface plane. It can be seen that the main part of upward flow is inclined toward the main channel.

In the flood plain two secondary currents can be observed, one being beside the main channel with a counter-clockwise sense of rotation which is almost restricted to $-1.5 < y/H < 0.2$. Next to this at $y/H < -1.5$ another smaller secondary current flow can be observed with the same sense of rotation. Almost identical secondary flow patterns were observed by others namely Naot and Rodi[2] and Tominaga and Nezu[3] using different approaches: numerical and experimental.

Fig. 3 shows the iso-lines of the rate of momentum transport by the secondary currents, calculating $\overline{\overline{V}}\frac{\partial\overline{\overline{U}}}{\partial y} + \overline{\overline{W}}\frac{\partial\overline{\overline{U}}}{\partial z}$ on grid points, where $=$ refers to time-space-average values. As can be seen, the highest rate of momentum exchange is taken place near the junction point along the interface plane. Low and high momentum flows over the junction border, mainly along the interface plane, exchange momentum with each other and each one takes on the characteristics of a momentum balanced flow. Along the interface plane they go up toward the water surface. At this region they have two alternatives: rotating over the flood plane or turning back to the main channel.

A schematic illustration of this phenomenum is given in Fig. 4. As can be seen, low and high momentum flow from the flood plain and main channel enter into the mixing region. The output result will be high momentum flow for the flood plain part and low momentum for the main channel. Recalling Fig. 2 it is obvious that high momentum flow in the flood plain bulges the isovel-lines at $y/H = -0.8$ downward while in the main channel the low momentum flow extends the low-speed region. This reveals the fact that, as has also been mentioned by other researchers like Knight and Hamed[4], momentum exchange is taken place perpendicular to the interface plane as well as next to the junction border in the main channel.

Instantaneous Flow

Fig. 5 (a) shows a top view of vorticity vector field at $z/H = 1.5$. In this figure at $x/H = 1.2$ a vortical structure which extends from the flood-plain to the main channel can be observed. A sudden change in its direction at $y/H = 0.5$ can be observed where it is likely the junction of the vortex limbs. Since this elevation $(z/H = 1.5)$ is comparatively close to the flood plain bed the ordinary boundary shear-layer vortical structures are dominant. Another view of this vortical structure in the lower elevation at $z/H = 0.83$ (Fig. 5 (b)) helps us to follow the vortical structure in the main channel. In this figure, the directions of vorticity components near the flood plain are changed to the opposite direction. In another top view closer to bed at $z/H = 0.5$ (Fig. 5 (c)), the direction of vortical structures is changed again to the $+y$-direction . In an attempt to compare the magnitude of vorticity components at $z/H = 1.5$ and 0.5 one can see that vortical structures in the flood plain are not as strong as those in the main channel.

The low momentum flow transferred from the flood plain to the main channel provokes a higher velocity gradient in the main channel which causes vortical structures stretched along the x-axis. This effect can be seen dramatically in Fig. 5 (c) at $1 < x/H < 2$ and $0.5 < y/H < 1.0$. It is clear that the vertical size of vortical structure in the flood plain is larger than the one in the main channel.

An end view of vorticity is given in Fig. 6. In this figure, the vortical structure in the flood plain rises first at $y/H = -0.2$ and soon after entering in the main channel at $y/H = 0.4$ it goes downward with a maximum approach to the junction border at $z/H = 0.75$ then it continues going down. Here at $y/H = 0.4$ in the upper part of the main channel (along the flood plain) a very complicated flow at the head part of the vortex can be seen. As it goes down the flow, this vortical structure is inclined to the junction border and at $z/H = 0.7$, where $\omega_y = 0$, the maximum approach to the junction border occurs and after that, with positive ω_y, it goes down the flow; at $z/H = 0.6$ a sudden inclination toward the main channel can be observed.

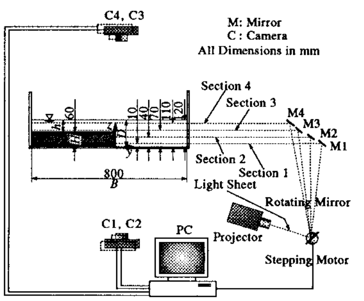

Fig. 1 Schematic sketch of channel cross-section and experimental setup.

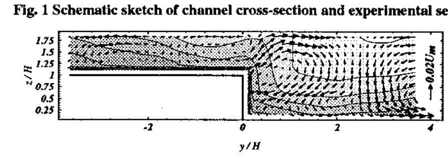

Fig. 2 Time-space-average values of u component of velocity (contour-lines) and v and w components of velocity (vectors).

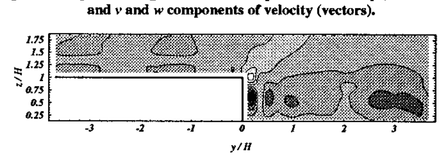

Fig. 3 The rate of momentum transfer between the main channel and flood plain corresponded to Fig.2.

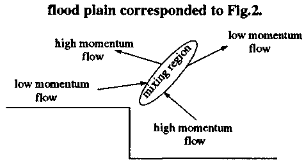

Fig. 4 A schematic sketch of the mechanism of momentum transfer in a compound channel.

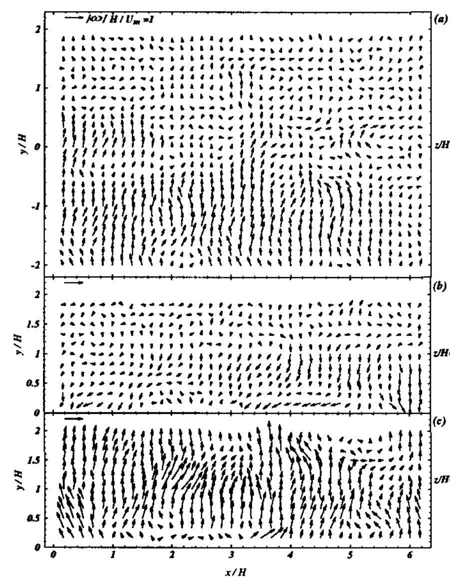

Fig.5 Top views of instantaneous vorticity in different elevations; the track of a typical vortical structure is marked while it is contributing in the turbulent transfer over the flood plain and main channel.

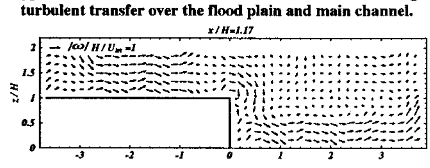

Fig.6 An end view of instantaneous vorticity vectors; a continued vortical structure can be observed over the flood plain and main channel.

References

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