Effect of standing baffle on the structure of flow in a rectangular open channel

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Effect of a standing baffle on the spatial and temporal structure of flow in a rectangular open channel has been investigated experimentally by 3D Acoustic Doppler Velocimeter. The flow is observed to be fully developed in the upstream of the baffle and far from the inlet. The presence of baffle causes the spatial structure of flow deviates from uniformity whereas before baffle the flow is fully developed. This effect is reflected in mean streamwise velocity profiles as well as turbulent intensity distribution. By applying a special smoothing method and analyzing the space-averaged power spectra an obvious peak structure is observed in upstream region of baffle whereas in downstream of baffle this peak structure is decreased. Moreover, pattern of flow near the inlet has been investigated. Results showed that due to high inlet velocity a jet of flow is observed near the bed of channel. Accordingly a recirculation zone has been formed upstream of baffle near the inlet.

Keywords: Baffle, power spectrum, turbulence intensity, spatial and temporal structure, ADV

1 INTRODUCTION

Understanding of flows over obstacles is important due to their relevance to many practical and theoretical problems. For example, separated flows produced by an abrupt change in geometry are of great importance in many engineering applications [1]. Also use of baffles or deflectors in settling tanks to improve the flow field has been investigated by several researchers such as Lyn and Rodi who conducted turbulence measurements in a model settling tank and observed the effect of different deflectors [2]. Also Wu and Rajaratnam have investigated the effect of baffles on submerged flows [3]. In this paper due to the lack of quantitative studies and also importance of baffle's application an Acoustic Doppler Velocimeter is used to investigate the structure of flow as well as effect of a standing baffle on spatial and temporal structure of flow in a rectangular open channel quantitatively.

2 EXPERIMENTALS

2.1 Experimental System

A specially designed unit at Fluid Mechanics Laboratory of the Mechanical Engineering Department at Sharif University of Technology (Iran) has been used to demonstrate the hydraulic characteristics and performance of a rectangular sedimentation open channel. A schematic diagram of the experimental setup is presented in Figure 1.
Water from the laboratory main supply was directed by a pump to a cylindrical storage tank and from this tank was pumped to the constant head tank and then was fed to the channel via a flow meter. Experiments were conducted in a glass sided rectangular open channel $8m \times 0.2m \times 0.4m$ in length, width and height(x,y, and z, with x=0 at upstream end, y=0 in center of channel, and z=0 at the bed), respectively, with a smooth bottom. A rectangular feeding slot with the height of h_0=0.11 m extending throughout the full width of the channel at the bottom, provided the inlet gate. The depth of water was controlled by a sharp-edged weir of height of 32 cm, located at the downstream end of the channel. The baffle is located at x=4m and is extended across the full width of the channel. The height of baffle is 8 cm.

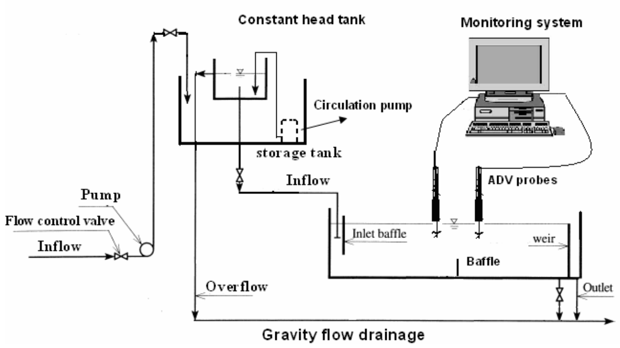

Figure 1: Schematic diagram of experimental setup

2.2 Experimental procedures

The velocities were measured on the central longitudinal plane by a 3D Acoustic Doppler Velocimeter (ADV) which makes it possible to observe the flow field at each point. This device is based on the principles of Doppler shift of a wave reflected from particles suspended in the fluid flow. Data are available at an output rate of 25 Hz. The 3-D velocity range is 2.5 m/s, and the velocity output has no zero-offset. The small sampling volume (0.25 cm^3) is located away from the sensor to provide undisturbed measurements and therefore is able to make accurate velocity measurements. Another advantage of ADV is that the probes of ADV were previously calibrated by the Nortek Company and the measurements have a relatively high accuracy of 0.1 mm/s. [4]. The data acquisition took 30–40 sec. at each measuring point. Figure 2 illustrates the details of the channel and measured sections. Measurements have been done at 6 stations (sections) along the channel. Because of having only two ADV probes the simultaneous measurement of only two sections at the same time was possible. Therefore measurement at each pair of sections (0.5m, 1.5m), (2.5m, 3.5m) and (4.5m, 5.5m) have been done simultaneously. Also tracer particles were added to water for measurements.

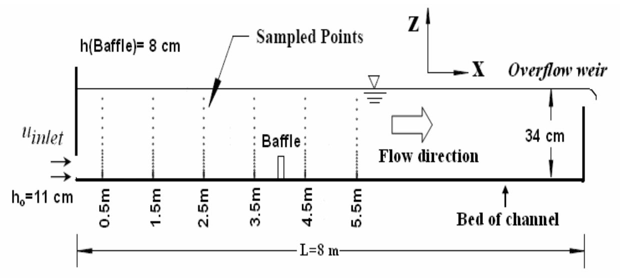

Figure 2: Schematic of channel and measurement sections along the channel

2.3 Conditions of Experiments

The flow conditions as well as the values of non-dimentional parameters such as Reynolds(Re) and Froud(Fr) numbers having the following definitions are represented in Tab.1. Q is the inlet flow rate.

$$\mathrm{Re} = \frac{U_0 h_o}{\nu} \tag{1}$$

$$Fr = \frac{U_0}{\sqrt{g h_o}} \tag{2}$$

In equations 1 and 2, h_0 is the opening height of the inlet gate, ν is the kinematic viscosity of the fluid (Water) at T=20^o C and U_o is the inlet bulk velocity.

Table 1: Flow conditions in neutral experiments

Q (lit/min)	h_0 (cm)	Re (inlet)	Fr (inlet)
35.5	11	2946	0.0259

3 RESULTS AND DISCUSSION

The instantaneous velocity has three components in Cartesian coordinate system $U(t)$, $V(t)$, $W(t)$ in streamwise, transversal and vertical direction respectively. A typical example of velocity time series obtained at a specific point is shown in Figure 3.

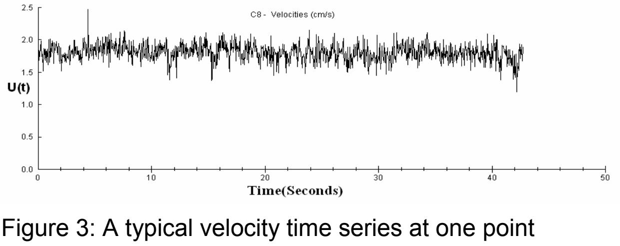

Figure 3: A typical velocity time series at one point

3.1 Spatial structure

3.1.1 Mean Velocities

The high accuracy and the inherent property of zero-drift free velocity measurements make the ADV suitable for accurate measurements of mean flow even at positions close to the boundary (z=0.75cm)[5]. In Figure.4 streamwise mean velocity profiles at various streamwise positions are shown. The horizontal axis represents the streamwise velocity (u) which has been made non-dimensional by average velocity based on flow rate. Also vertical axis represents the height relative to the depth of water (H=34 cm). It must be noted since a downward-looking ADV probe has been used, the acquisition of data could not cover the free surface because the probe of ADV would be out of water and consequently the variation of sound velocity in air and water would lead to poor quality data.

As shown in the Figure 4, at x=0.5 m which is very close to inlet an obvious jet flow is observed near the bed of channel. Negative velocities at the higher part of the profile indicate the existence of a recirculation region due to high velocity gradient between different layers of fluid. But at x=1.5 m the velocity profile is almost uniform over depth of channel. This is reasonable because this section is far away from inlet and is not under the strong influence of inlet. At x=2.5m and x=3.5m which are located much downstream of inlet region the flow is developed because no difference of mean velocity profile along the streamwise direction appears between x=2.5m to x=3.5m. Additionally, as it is observed downstream of the baffle(x=4.5m) the flow pattern deviates from uniformity. It can be inferred that due to decrease in cross sectional area as a result of presence of baffle at x=4m velocity profile has a maximum value at x=4.5m.

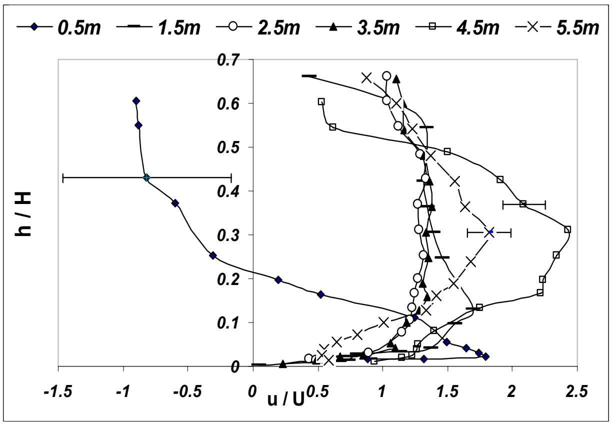

Figure 4: Variation of streamwise velocity profiles along the baffled channel (The error bars represent the dispersion of velocities at some typical points)

At x=5.5m which is located at much downstream of baffle the maximum value of the velocity profile has been decreased compared to the corresponding one at x=4.5m. Also the value of velocity near the free surface at section x=5.5m is higher than the corresponding one at x=4.5m. This indicates the strong effect of baffle at x=4.5m which is very close to baffle and also indicates that flow at much downstream of baffle(x=5.5m) tends to get more uniform although the effect of baffle is still felt.

3.1.2 Turbulence intensities

The Root-Mean-Square (RMS) of the velocity fluctuations denotes the standard deviation of the samples taken by the ADV and its value relative to mean velocity is equal to the turbulent intensity for the respective velocity component.

3.1.2.1 Effect of inlet

In Figure 5 the value of turbulence intensities near the inlet compared to the next section. At x=0.5m (very close to inlet) the absolute value of turbulent intensity is very high and varies strongly over height.

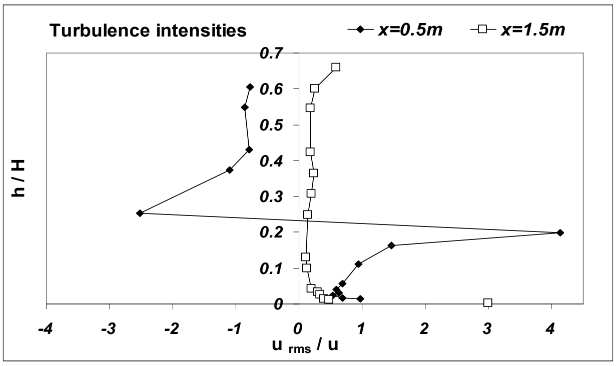

Figure 5: Comparison of turbulence intensities profiles at x=0.5m and x=1.5m from inlet

Downstream of the inlet and upstream of baffle the value and the variation of turbulent intensity over height is decreased considerably. Therefore it is concluded that at x=0.5m the pattern of flow is under the strong influence of inlet flow. The negative turbulent intensity in the upper part of the channel indicates the existence of a recirculation region.

3.1.2.2 Effect of baffle

As shown in Figure 6 before the baffle the variation of turbulent intensity is almost the same over depth

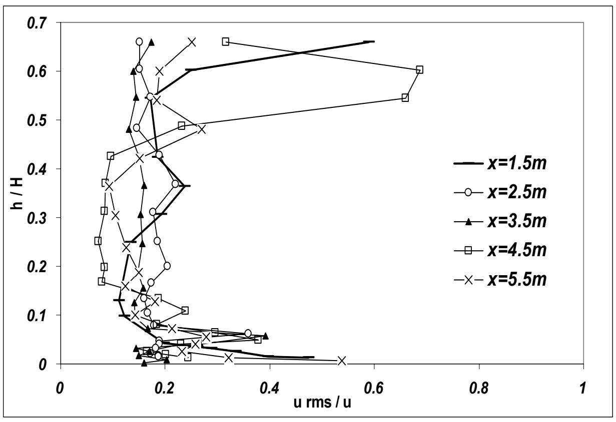

Figure 6: Turbulent intensities along the channel

of channel and flow is calm but downstream of baffle the variation of turbulent intensity over the depth is strong and its value has been increased in the upper part of profiles. These observations indicate the deviation of the spatial structure of flow from uniformity and strong variation of turbulent intensity over depth after baffle due to presence of baffle.

3.2 Temporal structure

3.2.1 Power spectrums

Discrete Fourier Transform (DFT) has been used and a program has been written to extract and analyze the power spectrum from streamwise velocity time series.

3.2.2. Methodology

Usually the power spectrum obtained from raw data of velocity time series contains some noises. Therefore to eliminate the noises to some degree and fare observation of peak structures a special method has been used for smoothing the power spectrum. We denote $u[n]$ as velocity time series at each point in which n $\in \{1,2,3,...,N\}$ and N is the number of samples. In this method $u[n]$ has been divided into two time series u_1 and u_2 as follows:

$u_1[n]$: n $\in \{1,3,...,N-1\}$, $u_2[n]$: n $\in \{2,4,...,N\}$

The DFT has been applied separately to each of the subdivided time series to extract their power spectra and then ensemble average of the results has been calculated over frequency to obtain the smoothed power spectrum at each point. In Figure 7 the effect of smoothing is clearly observed for a typical point.

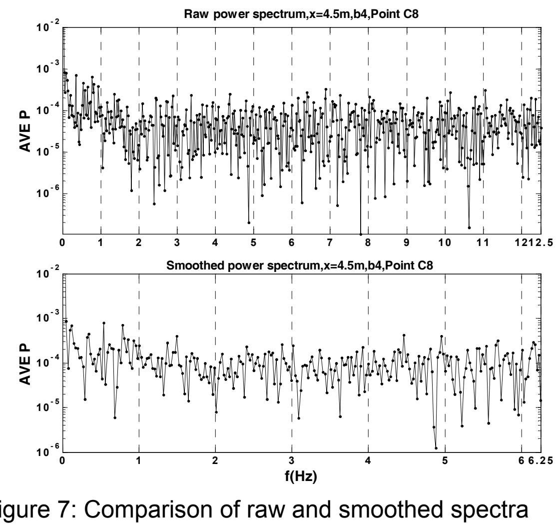

Figure 7: Comparison of raw and smoothed spectra

It is notable that the maximum frequency of the smoothed power spectrum is a quarter of the sampling frequency (25 Hz) that is 6.25 Hz. Although there are special characteristics observed to be space-dependent in the power spectra we focus our attention on space averages of the power spectrum. In fact by taking the space average of power spectra the peak structure could be observed apparently. Comparison of space averaged power spectra over different ranges in space showed that we are dealing with a local phenomenon and as a result space averaging has been represented in Figures (8, 9 and 10) for three points namely (b6, b7, b8) for upstream sections and (c6, c7, c8) for downstream sections of baffle having the height in the range of 8 cm $\leq$ h $\leq$ 12 cm. In these figures the horizontal axis is frequency and vertical axis is the amplitude of space averaged power spectrum.

3.2.3 Effect of baffle on power spectra

In order to observe the effect of baffle the space averaged power spectra over the first half of frequency domain are illustrated in Figures 8 and 9 for upstream and downstream of baffle respectively.

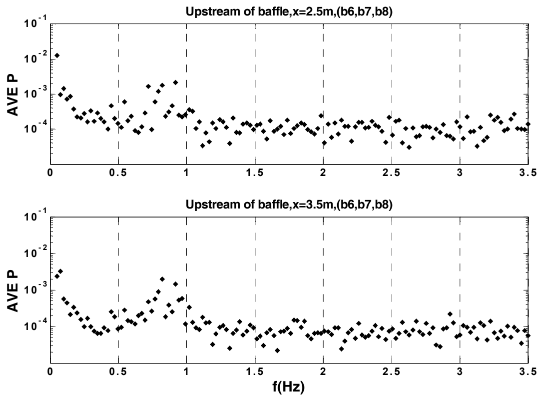

Figure 8: Upstream of baffle(x=2.5m, x=3.5m)

Upstream of baffle a clear peak structure is observed. This peak structure is a natural characteristic of the system because it is observed at x=2.5m and x=3.5m. On the other hand, in downstream of baffle the amplitude of the peak structure has been decreased.

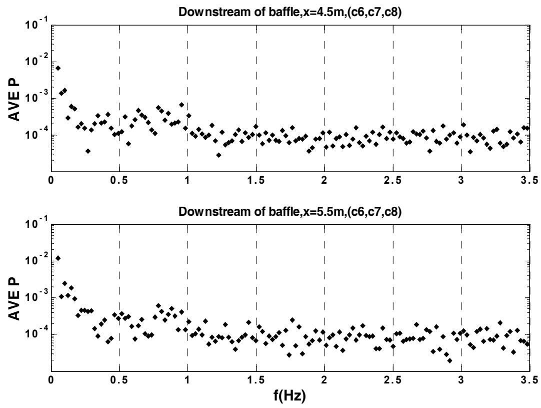

Figure 9: Downstream of baffle(x=4.5m, x=5.5m)

Comparison of the effect of baffle on the power spectra before and after baffle in Figure 10 indicates the destruction of the peak structure due to presence of baffle. As a result clear effect of baffle on temporal structure of flow has been observed by spectral analysis and a special smoothing method.

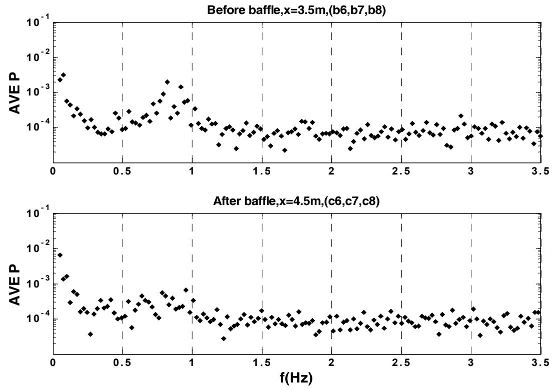

Figure 10: Power spectra before and after baffle

4 CONCLUSIONS

The effect of a standing baffle on spatial and temporal structure of flow in a rectangular open channel has been investigated experimentally using a 3D ADV. Based on the results of this experimental investigation following conclusions can be made:

1. The flow was observed to be fully developed in the upstream of baffle and far from the inlet.

2. Comparison of streamwise velocity profiles and turbulent kinetic energy along the channel shows that existence of baffle causes the flow pattern deviates from uniformity.

3. Importantly, by analyzing and comparing space averaged power spectra it has been found that in the upstream of baffle a clear peak structure is observed whereas in the downstream of baffle the peak structure has been destroyed. This indicates that presence of baffle has caused the inherent periodicity in the temporal structure of flow to be destroyed in the downstream of baffle.

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