# MEASUREMENT OF TURBULENCE CHARACTERISTICS BY USING PARTICLE TRACKING VELOCIMETRY

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**Abstract**: This study investigates the effects of sediment on the flow characteristics such as velocity distribution, friction velocity, turbulent intensities, Reynolds stress, etc. Particle tracking velocimetry (PTV) is used to measure the vertical flow field. Results show that flow over the high bed-load concentration region has larger values of mean velocity and friction velocity and smaller values of turbulence intensities, compared to those for flow over the low bed-load concentration region.

**Key Words**: PTV, velocity distribution, friction velocity, turbulent intensities, Reynolds stress

## 1. INTRODUCTION

Coherent structures in open channel flows can be classified into two categories: bursting phenomena and large scale vortical motion. The bursting phenomena occur very near the wall ( $y^+ = yu_*/\nu \leq 50$ ) and produce the streaky structures. The streaky structures can be easily visualized by putting sand on the channel bed. The sand particles are accumulated along the low-speed streaks. Two kinds of secondary currents are included in the large scale vortical motions. The secondary currents of the first kind occur at river bends. The secondary currents of the second kind occur at the straight channel and are driven by turbulence. The secondary currents produce cells in the cross section and accumulate the sand on the bed in the region where upward currents exist.

Interaction of flow and sediment transported by the flow has been controversial topic. Although many attempts (Vanoni, 1953; Bennett and Bridge, 1995; Umeyama and Gerritsen, 1992; Kulick *et al.*, 1994; Muste and Patel, 1992) were made to quantify the effects of sediment on the flow characteristics, no acceptable theory has been developed yet. Sometimes similar researches showed contradictory results. This may be attributable to the difficulty of distinguishing the flow characteristics from sediment movement and defining appropriate friction velocity which is used for nondimensionization.

In this study, therefore, friction velocity and turbulent characteristics were investigated for an open channel flow with bed load only. Flow characteristics were measured using PTV, which is capable of distinguishing the flow characteristics from those of sediment.

## 2. EXPERIMENTS

### Principle of PTV

This study employed PTV to measure the flow characteristics. Compared to PIV, PTV has a merit of directly measuring particle velocities. Fig.1 shows the conceptual diagram of the PTV system used in this study. PTV measures the

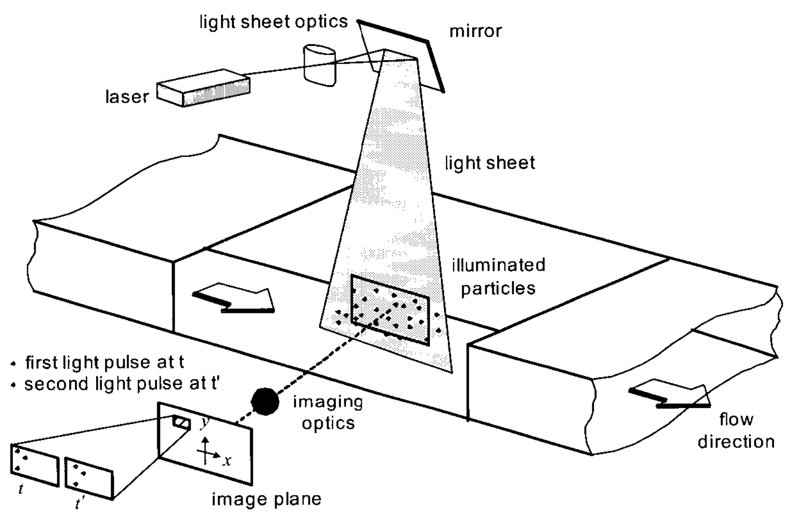



**Fig. 1. Conceptual diagram of the PTV system**

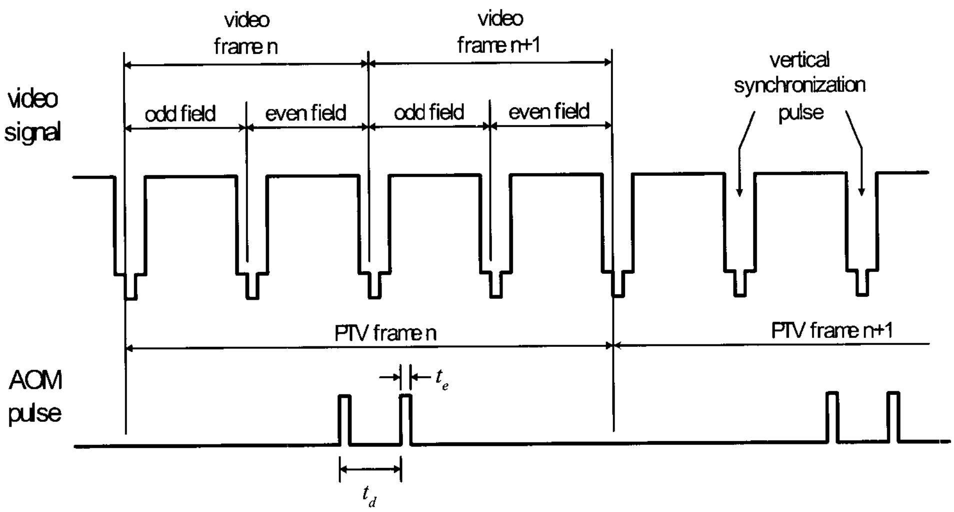



**Fig. 2. Synchronization process of video**

flow velocity by analyzing the images recorded using video camera. PTV system consists of laser source, video camera and recorder, and synchronization system. The laser used in this study is 2W argon-ion laser. An AOM (acoustic optical modulator) is used to synchronize the exposure interval of laser light with the video recorder. The AOM deflects the laser light using the ultra sonic wave. The video camera used in this study is standard NTSC type which takes 30 frames per second. Each frame consists of odd field and even field. The laser illuminates the flow field at the even field of frame $n$ and the odd field of frame $n + 1$, as seen in Fig.2, using an AOM. Since the two images produce one flow velocity field, this system can measure the flow field with the frequency of 15 Hz.

The images obtained are analyzed by following the procedure shown in Fig. 3. Detail procedures are described in Muste *et al.*(1998).

**Experimental procedure**

The experiments were carried out using the circulating open-channel which is located at Iowa Institute of Hydraulic Research (IIHR). The channel is 30 m long and 0.91 m wide. Preliminary experiments showed that the channel bed is divided into 2 categories; high and low sediment concentration regions. Therefore, the measurement was taken to represent both regions. Attempts were made to measure the flow field over high-speed and low-speed streaks. Since, however, the streak spacings are too narrow and the streak patterns changed quickly from time to time, it was impossible to measure flow field over the streaks with this experimental set up. Instead, it was determined to measure flow characteristics over the high and low bed load concentration region.

Fig. 4 shows the experimental set up. The mirror is installed on the traverse so that the laser light can illuminate the desired section. For each case of experiment, two kinds of images were taken: plan-view images without laser light and side-view images. The side-view images were taken with laser light in order to get vertical velocity field. The plan-view images were used to analyze the low-speed streak spacing.

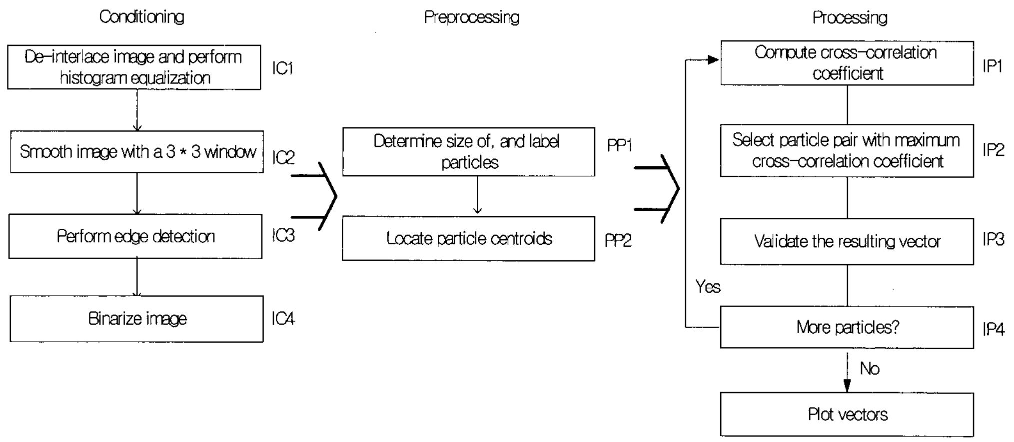



**Fig. 3. Procedure for image analysis**

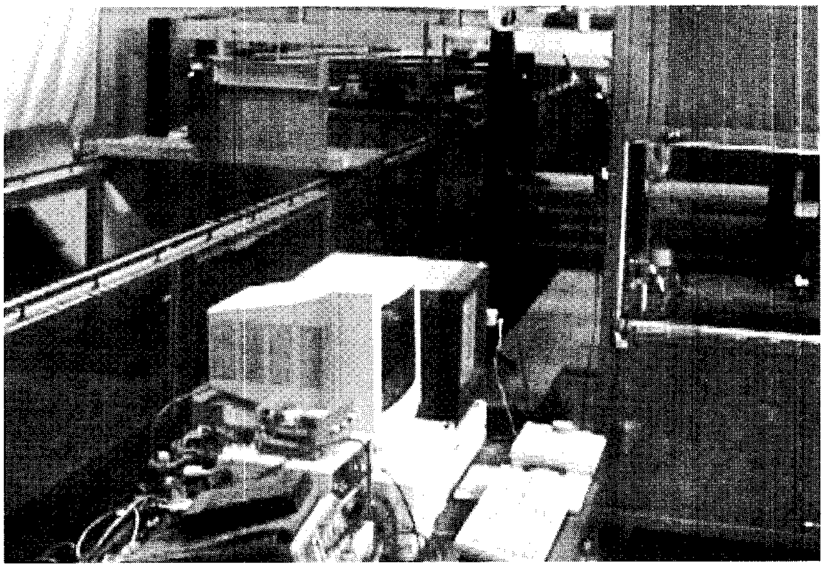


**Fig. 4. Experimental setup for PTV**

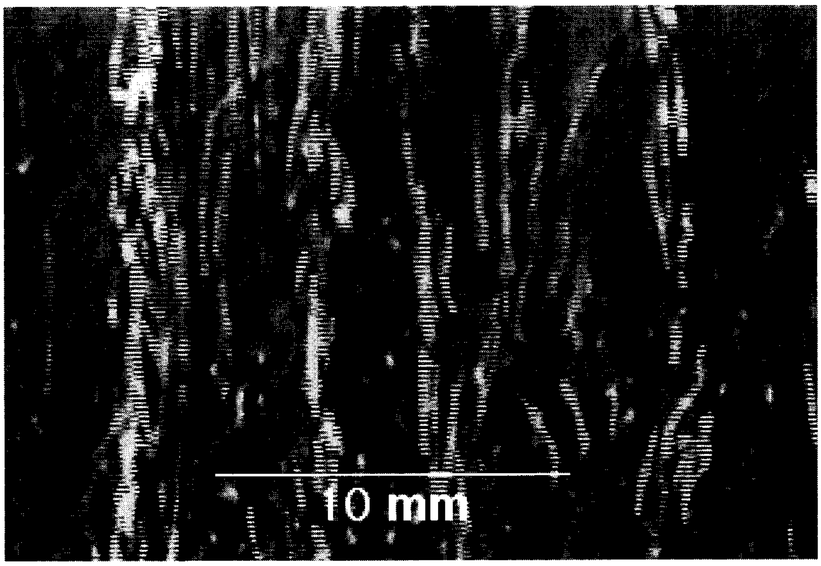



**Fig. 5. Streaky structures marked by the sand**

The experiment began with making uniform flow without sediment. The flow uniformity was checked using 8 manometers installed along the channel with 305 cm spacing. After taking images for clear water, sediments were added into the flow, and images were taken. Special attention was made, through the experiment, to maintain the flow uniformity

## 3. RESULTS

Fig. 5 shows the streaky structures formed on the bed. The high-speed and low-speed streaky structures are clearly shown clearly. The streaks marked by the accumulated sand represent the low-speed region, and the high-speed streaks are located between the low-speed streaks. Although low-speed streaks appear at random in space and interact with the neighboring streaks, the statistical average of the instantaneous span wise spacing $\lambda$ is known to have constant value of $\lambda^+ = \lambda u_*/\nu = 100$ irrespective of Reynolds and Froude numbers (Nezu and Nakagawa, 1993). This is also proved in this study where the average $\lambda^+$ is about 92.

The velocity profiles were measured at locations chosen to represent the high- and low- bed-load concentration regions. Fig. 6 shows, velocity profiles above high- and low- concentration regions. This graph was obtained from 2-minute image (3600 frames, 1800 instantaneous velocity fields).

The friction velocity for each location was determined using velocity defect law.

$$\frac{u - u_{\max}}{u_*} = \frac{1}{\kappa}\ln\left(\frac{y}{h}\right) \tag{1}$$

where $u_{\max}$ is the maximum velocity of the point, $u_*$ is the friction velocity, and $\kappa$ is the Karman constant.

Fig. 7 shows the velocity distribution based on the velocity defect law. In this figure the velocities were normalized by the friction velocity at the corresponding locations. The velocity distribution of the measured data show good agreement with the velocity defect law, Eq. (1).

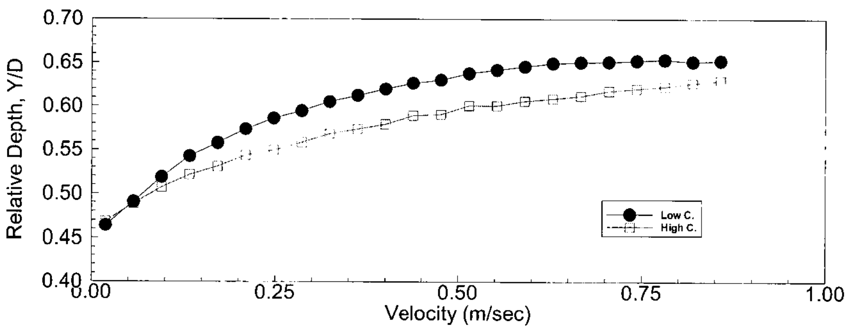



**Fig. 6. Velocity distribution**

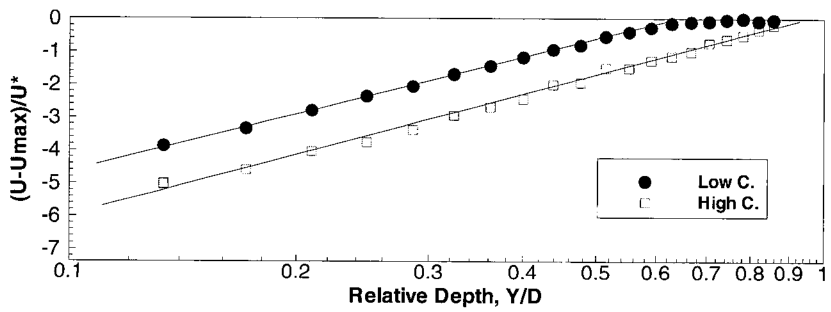



**Fig. 7. Velocity distribution with velocity defect law**

**Table 1. Characteristics of velocity distribution.**

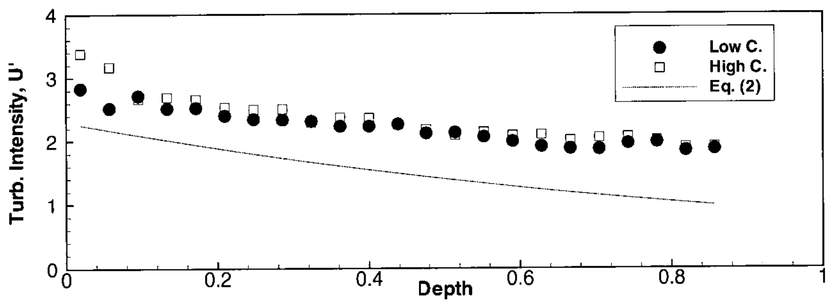
| Sediment Concentration | Avg. Vel. $\overline{U}$ (m/s) | Max. Vel. $U_{max}$ (m/s) | Shear Vel. $U_*$ (m/s) |
|---|---|---|---|
| Low C. | 0.598 | 0.662 | 0.0287 |
| High C. | 0.575 | 0.633 | 0.0225 |

The friction velocities measured at low- and high-concentration regions are 0.598 m/s and 0.575 m/s, respectively. The average of these two measurements is 0.587 m/s, which is close to the friction velocity calculated using the channel slope, $u_* = \sqrt{gRS} = 0.0251 \text{m/s}$.

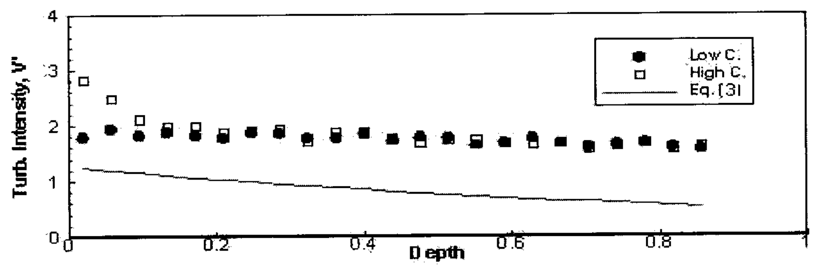
The characteristics of velocity distribution are summarized in Table 1.

As shown in Table 1, all the characteristics, including average velocity, maximum velocity and shear velocity of the low-concentration region are higher than those of the high concentration region.

In addition to the mean flow characteristics such as mean velocity profile and friction velocity, some turbulence characteristics are also investigated in this study. Fig. 8 and Fig. 9 show the longitudinal- and vertical-turbulence intensity and Reynolds stress, respectively. In each figure, the distributions of the turbulence intensity for smooth wall measured by Nakagawa et al. (1975) are also presented for comparison




(a) Longitudinal turbulence intensity $\sqrt{\overline{u'^2}}/u_*$




(b) Vertical turbulence intensity $\sqrt{\overline{v'^2}}/u_*$

**Fig. 8. Turbulence intensity distribution**

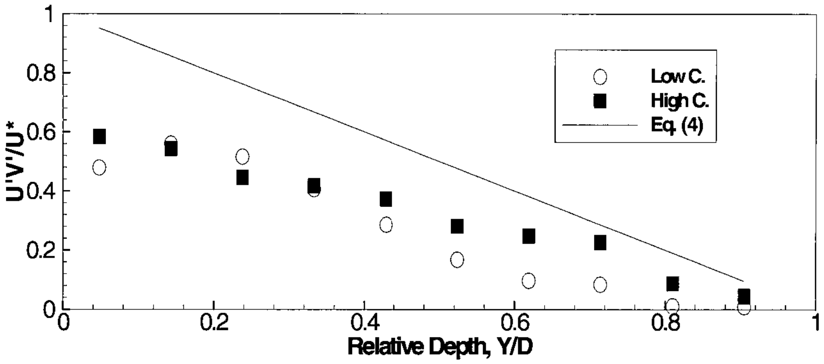



**Fig. 9. Reynolds stress distribution**

with solid lines. The equations for these solid lines are as follows;

$$\frac{\sqrt{\overline{u'^2}}}{u_*} = 2.30\exp\left(-\frac{y}{h}\right) \tag{2}$$

$$\frac{\sqrt{\overline{v'^2}}}{u_*} = 1.27\exp\left(-\frac{y}{h}\right) \tag{3}$$

$$-\frac{\overline{u'v'}}{u_*^2} = 1 - \frac{y}{h} \tag{4}$$

In Fig. 8 and Fig. 9, the measured turbulent characteristics show a bit large scattering. The measured data show a bit large scattering and systematic disagreement with the above equations. The scattering in Reynolds stress seems to be caused by the insufficient number of data or inadequate measuring frequency. According to Nezu and Nakagawa (1993), the sampling frequency for turbulent characteristics should be chosen so as to satisfy the condition $f \geq f_{\max}$ in order to eliminate data aliasing, where the maximum response frequency, $f_{\max} \approx 50\overline{u}/\pi h$. Since $f_{\max} \approx 80$ in this study, the adequate sampling frequency would be 160 Hz. It means that this problem can be fixed either by taking images for longer period or by putting more seeding into the flow with high speed camera.

## 4. CONCLUSIONS

This study investigated the effect of sediment, transported as bed load, on the flow characteristics. The sediment was transported as bed load only without suspended load. The amount of sediment added to the flow was limited not to make sediment deposition on the channel bed. Flow characteristics were measured in the high and low bed-load concentration regions.

The conclusions obtained from the study are as follows;

(1) The flow over the high-speed streak has higher value of mean velocity, maximum velocity and friction velocity, compared to those of low-speed streak, along which sediment particles are accumulated.

(2) Turbulence intensities of flow over the moving sediment obtained in this study show higher values than the universal relations for smooth walls. Turbulence intensities for high concentration region have higher values than those for low concentration region, particularly near the bed.

(3) To improve the accuracy of turbulence characteristics, it is useful to take images for longer period or to put more seeding into the flow with high-speed camera.

## REFERENCES

Bennett, S.J. and Bridge, J.S. (1995). "The geometry and dynamics of low-relief bed forms in heterogeneous sediment in a laboratory channel, and their relationship to water flow and sediment transport." *J. Sediment. Res., A65*, 29-39.

Kulick, J.D., Fessler, J.R., and Eaton, J.K. (1994). "Particle response and turbulence modification in fully developed channel flow." *J. Fluid Mech., 277*, 109-134.

Muste, M., Fujita, I., and Kruger, A. (1998). "Experimental comparison of two laser-base d velocimeters for flows with alluvialsan d." *Experiments in Fluids*, Vol. 24, pp. 273-284.

Muste, M. and Patel, V.C. (1992). "Velocity profiles for particles and liquid in open-channel flow with suspended sediment." *J. Hydraul. Eng., 118*, 971-988.

Nakagawa, H., Nezu, I., and Ueda, H. (1975). "Turbulence of open channel flow over smooth and rough beds." *Proc. of Japan Soc. of Civil Engrs.*, 241, pp.155-168.

Nezu, I. and Nakagawa, H. (1993). *Turbulence in open-channel flows*, Int. Ass. Hydraul. Res. Monograph Series, A.A. Balkema, Rotterdam, 281 pp.

Umeyama, M. and Gerritsen, F. (1992). "Velocity distribution in uniform sediment-laden flow." *J. Hydraul. Eng., 118*, 229-245.

Vanoni, V.A. (1953). "Some effects of suspended sediment on flow characteristics." *Proc. of 5th Hydraul. Conf., Bulletin 34*, State Univ. of Iowa, Studies in Eng.

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