ICUD-0569 Direct determination of shear stress using in-sewer ultrasonic velocity profiling sensor

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Summary

The knowledge of sewer flows characteristics is relevant for transport processes. In combined sewers, the surface runoff produces hydrographs with significant degree of flow dynamics and unsteadiness directly influencing transport characteristics. However, in-situ observations of velocity and turbulence are rare because of inadequate measuring techniques and/or other constraints related to sewer environment. We present our results from in-sewer flow velocity and Reynolds stress measurements using a multi-frequency ultrasonic velocity profiler with sampling frequencies from 50 to 100 Hz. We show the capabilities of the sensor to describe sewer flow hydrodynamics under different conditions.

Introduction

Key parameter for transport processes in unsteady turbulent flow is friction velocity (i.e. bottom shear stress). The variability of this parameter and other turbulence characteristics including their quantification in unsteady open-channel flow have been studied in several laboratory experiments (Bareš, 2008). Estimation of bottom shear stress under field condition is usually based on simplified methods, which can leads to gross errors when the flow is unsteady. Thanks to recent development of measuring devices, field experiments focused on unsteady turbulent flow are recently possible. Most valid approach for instantaneous bottom shear stress quantification is method based on direct estimation of Reynolds stress distribution mean (–u'v') (y) and fitting the data by linear model (Song, 1997).

The aim of this study is a hydrodynamic analysis of in-sewer flow velocities and turbulence patterns during different weather conditions. In particular, we focus on the employment of novel in-sewer two-component velocity profiler with asymmetric transducer geometry with high sampling rate for the evaluation of velocity profile and Reynolds stress distribution in varying sewer flow conditions.

Material and Methods

The experiment was conducted in trunk sewer of combined system in Duebendorf, Switzerland. The sewer pipe has a diameter of 1 m. The approximate flow depth during dry weather conditions is about h/D = 0.25, velocity range varies from 0.6 to 1.3 m/s. The experiments were proceeded during both dry and wet weather flows during February 23rd 2016.

Downstream the manhole we have installed UB-Flow (UBERTONE, France) probe working on pulse-to-pulse coherent Doppler method with two incorporated ultrasonic transducers. Each of the ultrasonic transducer has different band of working frequencies and both of them are multi-frequency with the possibility to change the emitting frequency during the experiment. UB-Flow profiler exploits transducer T1 and T3 to measure instantaneous axial velocities V1 and V3 (Fig. 1).

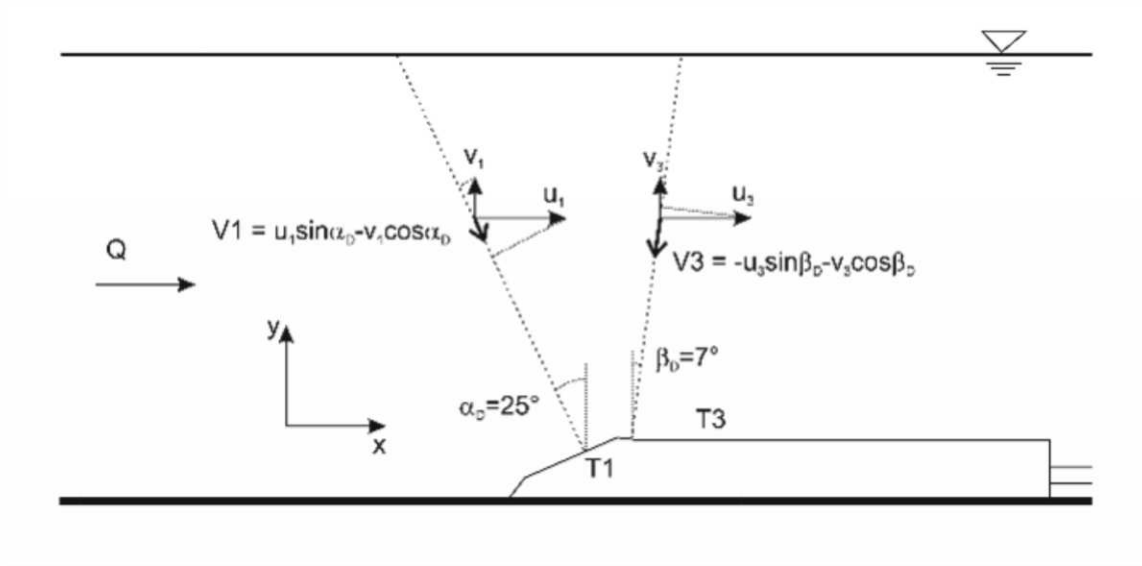

Fig. 1. *Probe installation at sewer invert and velocity decomposition.*

Further, in case of small distance between T1 and T3 compare to length of the reach and length of the hydrograph, the time-averaged hydraulic parameters (the time-averaged, velocities in horizontal and vertical direction, the turbulence intensities and the Reynolds shear stress) at the same vertical position can be assume to be same. This assumption is valid for both steady and unsteady flows (Song, 1996).

Estimated Reynolds shear stress profiles were fitted by linear model to estimate the bottom shear stress (Song, 1996) at the sewer bottom neglecting data the near-bed region.

$$u_*^2 = \frac{\tau_0}{\rho} = -(\overline{u'v'})\ (y \rightarrow 0)$$

where u_* is friction velocity and τ_0 is bottom shear stress, *mean (–u'v')* is time-averaged measured Reynolds stress.

Results and Discussion

First, we have analysed at Reynolds shear stress and velocity distribution during dry weather conditions. Two components of horizontal velocity distribution and the Reynolds shear stress distribution were evaluated. Measured values of mean (–u'v') decreased with increasing water depth. The trend of Reynolds shear stress values is almost linear with maximum values near the sewer invert and minimum values at the region near the water level (Fig. 2). Dimensionless values of mean (–u'v') /u*2 at the sewer invert were in the in the magnitude of 1.0, which corresponds to the theoretical consideration. Friction velocity u* is derived from channel slope u* = (gRS0)0.5

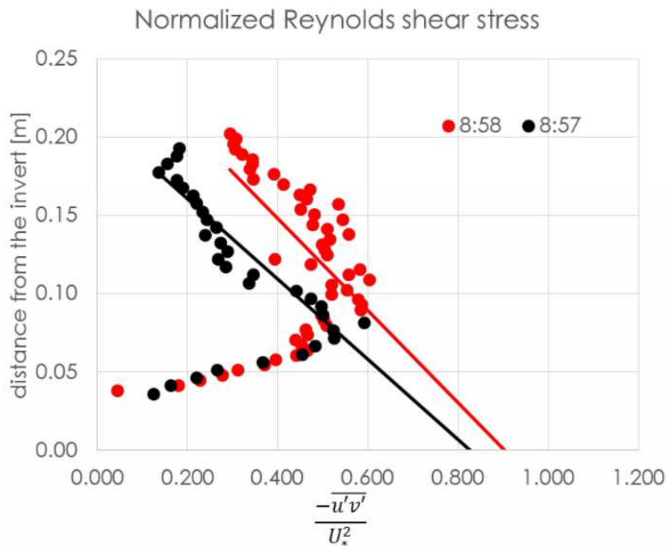

Fig. 2. *Normalized Reynolds stress distribution including fitting by linear model during dry weather period from two different time instance.*

During wet weather conditions, a unsteadiness of flow is expected. The individual velocity profiles from the different time instants of flow hydrograph (recorded from 16:17 to 17:13) with maxima at the beginning of the hydrograph and minima later. We can see the development of velocity distribution along the hydrograph including acceleration (Fig. 3 top) and deceleration (Fig.3 bottom).

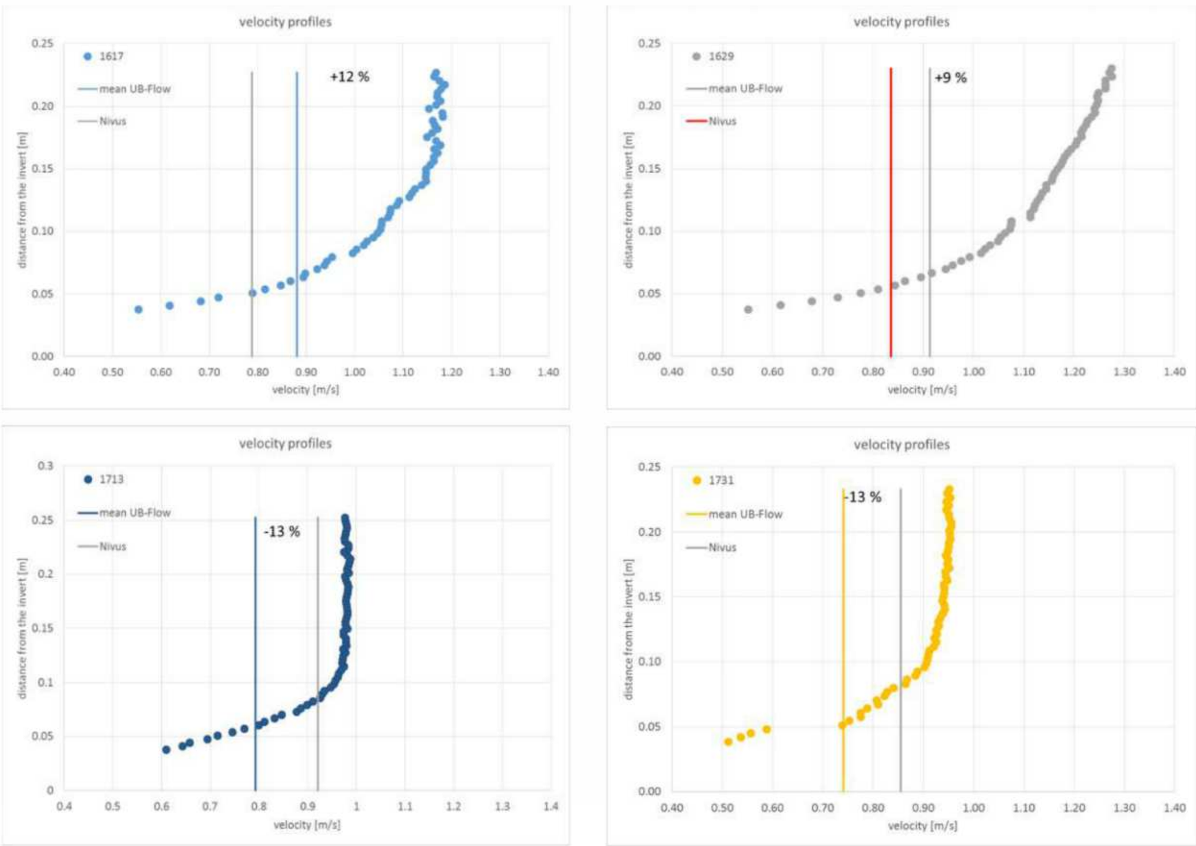

Fig. 3. *Evolution of velocity profiles along the wet weather hydrograph. The depth-averaged velocity is compared to reference cross-sectional velocity measured by NIVUS flowmeter.*

This corresponds to normalized Reynolds stress distribution. The values of Reynolds stress are again normalized by friction velocity u_* derived from channel slope $u_* = (gRS_0)^{0.5}$ which remains constant neglecting the hydrodynamic effect. The values varies from 0.5 – 1.4 with maxima during rising branch of hydrograph. This gives us the evidence about varying Reynolds stress (and bottom shear stress) along the hydrograph.

Conclusions

In this contribution, we investigated hydrodynamic characteristics of in-sewer flow as 2D-velocities and turbulence patterns by using ultrasonic Doppler technology. To achieve this goal a newly developed two-transducer ultrasonic profiler was used. The device is capable of measuring a two-component velocity profile with high frequency and thus turbulence patterns can be estimated. We show that device provide reliable results in both dry and wet weather flows. We can therefore conclude that applied methods can provide required data for description of transport processes in sewer flow.

References

Bareš, V., Jirák, J. , Pollert, J. 2008 Spatial and Temporal Variation of Turbulence Characteristics in Combined Sewer Flow. *Flow Measurement and Instrumentation*, **19** (3-4), 145-154.

Song, T. and Graf, W.H. 1996 Velocity and turbulence distribution in unsteady open-channel flow, *Journal of Hydraulic Engineering*. **122**(3), 141 – 154.