Turbulence characteristics in a rough open channel under unsteady flow conditions

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Abstract

The present study investigates the vertical and lateral fluctuating velocity profiles under unsteady flow condition in a rectangular open channel. Experiment investigations are led with vegetated open channel flow. One hydrogram is passed through the rectangular flume with a fixed bottom with rough bed. An experiment is accordingly conducted to investigate the turbulence characteristics under unsteady flow conditions in a rough open channel for two different flow depths. For two typical flow depths, the velocities in both the rising limb and falling limb are observed. Hysteresis effect between stage-discharge (h ~ Q) rating curve between rising and falling limbs is illustrated. Turbulence characteristics, i.e. variations of Reynolds stress along the vertical and lateral direction are analyzed.

***Key words*:** open channel flow; unsteady flow; hydrogram; turbulence characteristics; Reynolds stress

1. Introduction

Flows in the regular waterways, rivers and channels are frequently unsteady. At the point when discharge changes gradually, the issue of unsteady flow can be comprehended with the state of steady flow (Mahmood and Yevjevich, 1975). However, in some extraordinary cases, for example, reservoir activities, where discharge fluctuates quickly, the learning of steady flow may prompt unique or mistaken outcomes when managing issues of sediment transport, scour, deposition, and etc. (Song and Graf, 1996).

The main objective of the present study is to investigate the fluctuating velocities (i.e., u', v' and w') and Reynolds stresses (i.e., $\overline{u'v'}$ or $\rho u'v'$, $\overline{v'w'}$ or $\rho v'w'$ and $\overline{u'w'}$ or $\rho u'w'$) by laboratory experimentation under unsteady flow conditions over rough bed. Also, Reynolds stresses have been compared at a lower depth case as well as higher depth case in both rising and falling limb of a hydrogram.

2. Experimental Setup and Procedures

The experiments were carried out in a 12m long, 0.6m wide and 0.6m deep recirculating, rectangular, tilting flume in the Hydraulics Engineering Laboratory (H. E. Lab.) of Civil Engineering, National Institute of Technology Rourkela (Khuntia et al., 2018). The flume has glass walls in the testing section and the rest walls and bottom are of mild steel. The bottom of flume has been modified as a rough bed by fixing rigid grass along the channel bed. A schematic diagram of the experimental set-up is shown in Fig. 1. Photographs of experimental set-up, H. E. Lab., NITR is shown in Fig. 2.

The cross-section distribution of velocities was measured at three different positions (see Fig. 1), at x= 5.5m, 7m, and 8.5m.

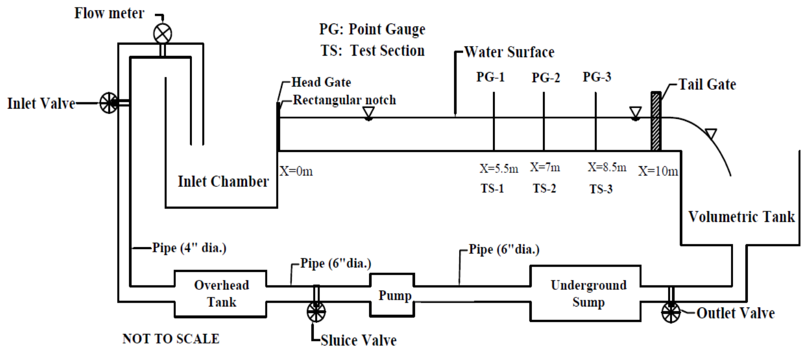


Fig. 1. A schematic diagram of the experimental set-up, NITR

Fig. 2. Photographs of experimental set-up, H. E. Lab., NITR

3. Results and Discussions

A total of 198 hydrograms was investigated during the experimental repetition. The flow and depth hydrogram in an unsteady flow run has shown in Fig. 3. The hysteresis effect of stage-discharge ($h \sim Q$) rating curve between rising and falling limbs is illustrated in Fig. 4.

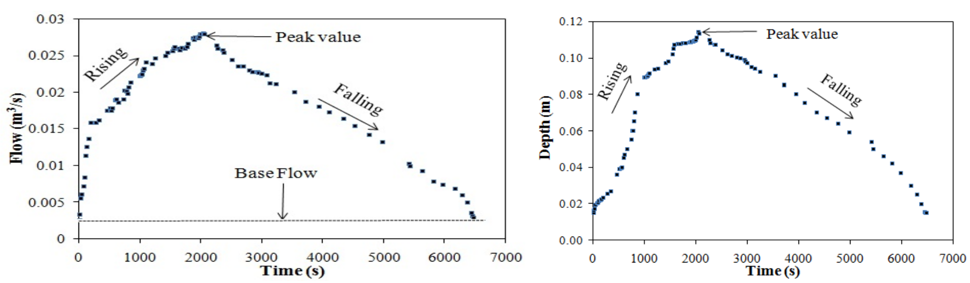


Fig. 3. Flow and depth hydrogram in an unsteady flow run

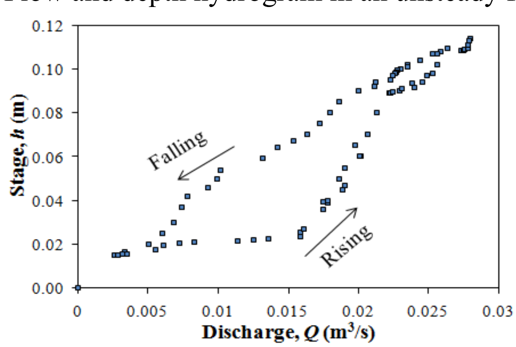


Fig. 4. Hysteresis effect in stage-discharge curve

3.1 Reynolds Shear Stress Distributions

For open channel flow the respective instantaneous velocity fluctuation components i.e., u', v' and w' in longitudinal, transverse and vertical directions were calculated to determine the Reynolds stress components i.e., $\overline{u'v'}$, $\overline{u'w'}$ and $\overline{v'w'}$. The Reynolds stress for all the three planes is seen to be substantially higher for the test with vegetation (Dorcheh, 2007). The three Reynolds stresses are calculated as per the following equations:

$$\overline{u'v'} = \frac{\sum u' \times v'}{N_T}, \quad \overline{u'w'} = \frac{\sum u' \times w'}{N_T}, \quad \overline{v'w'} = \frac{\sum v' \times w'}{N_T} \qquad (1)$$

where N_T is total number of data taken at a single point. In the present study, all the three Reynolds stresses (i.e., $\overline{u'v'}$ or $\rho u'v'$, $\overline{v'w'}$ or $\rho v'w'$ and $\overline{u'w'}$ or $\rho u'w'$) along the vertical direction of the channel has been observed and analyzed which are shown in Fig. 7.

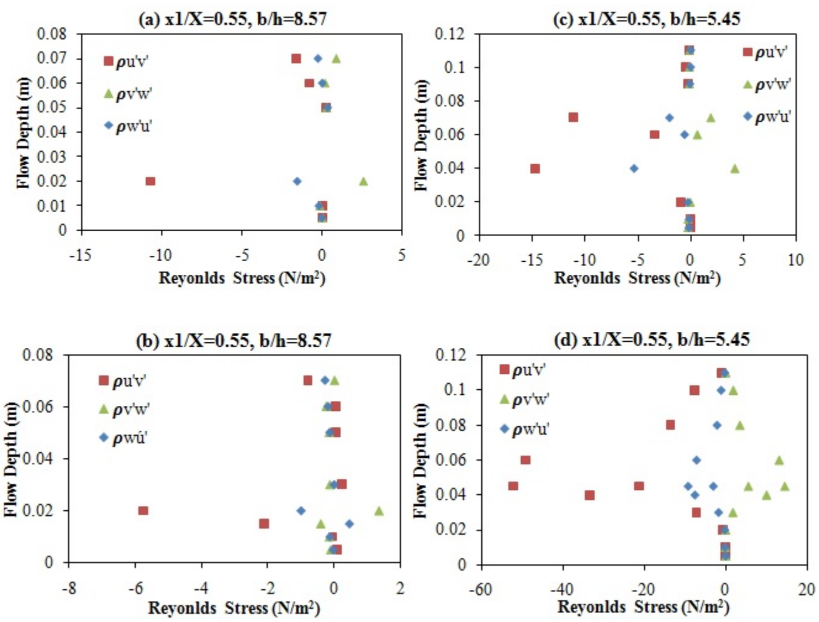
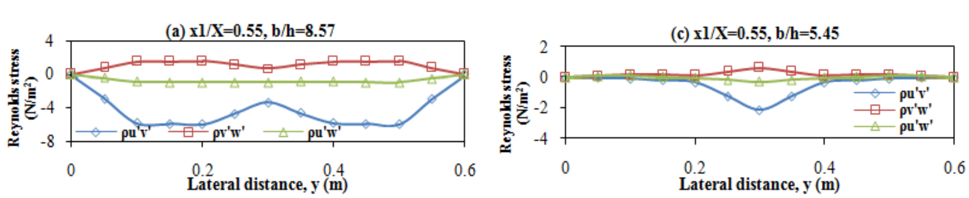


Fig. 7. Vertical variation of Reynolds shear stress at section 1 (x1/X=0.55), (a) and (c) rising limb, (b) and (d) falling limb respectively

Also, in the present research work all the three Reynolds stresses (i.e., $\overline{u'v'}$ or $\rho u'v'$, $\overline{v'w'}$ or $\rho v'w'$ and $\overline{u'w'}$ or $\rho u'w'$) along the lateral direction of the channel have been observed and analyzed which are shown in Fig. 8.



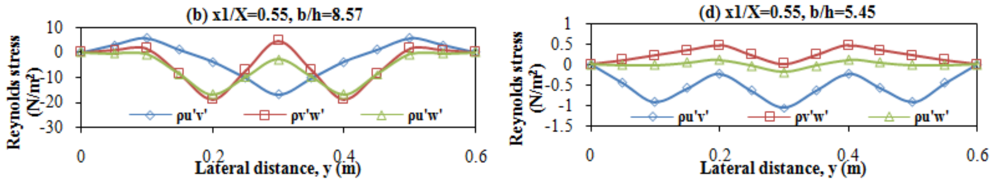


Fig. 8. Lateral variation of Reynolds shear stress at section 1 (x1/X=0.55), (a) and (c) rising limb, (b) and (d) falling limb respectively

4. Conclusions

The following concluding remarks have been drawn from this study:

1. An experiment has been conducted to investigate the turbulence characteristics in terms of Reynolds stress variation under unsteady flow conditions in a rough open channel for two different flow depths each in rising and falling limbs of hydrogram.
2. In lower flow depth case and in rising limb, the magnitude of Reynolds stress is less as compared to higher flow depth cases. Also, all the three turbulent components reduce their magnitude gradually towards the surface of water.
3. In rising limb, the more fluctuations in three Reynolds stresses have been observed in the lower flow depth case, but higher magnitude in case of $\rho u'v'$ only. But, in rising limb case of higher flow depth fluctuation in Reynolds stresses are less as compared to other three conditions.
4. The present study is a direct measurement of turbulence characteristics. So, this may be helpful for solving any turbulence models (i.e., Spalart-Allmaras (S-A) model, k-ε model, k-ω model and Menter's Shear Stress Transport (SST) model etc.)especially in unsteady flow conditions.

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