# TURBULENCE STATISTICS OF FLOW ON DEGRADED CHANNEL BED OF SAND

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## ABSTRACT

Turbulence characteristics of flow over the degraded bedforms of different type of sediment is not yet completely explored and understood. In this paper an attempt was made to determine the turbulence characteristics of flow over the degraded bed of sand, which is formed by the detachment of sand form its bed performed in a laboratory channel. Turbulence characteristics such as mean velocity, Turbulence intensity, Turbulent kinetic energy was measured at three section along the degraded profile of sand by using ADV. It was found that the maximum value of Turbulent intensity and Turbulent kinetic energy exist at initial bed level before the start of detachment. The value of Turbulent intensity and Turbulent kinetic energy was found to decrease towards downstream of degraded bed profile of sand.
*Keywords: Turbulence, Degraded bed, ADV, Detachment, Turbulence intensity*

## 1.INTRODUCTION

Turbulence is the most important factor which deals with character and intensity of river process. These include erosion and sediment transport, resistance flow, diffusion of matter, heat transfer and genesis of bed and channel forms. The knowledge of detachment and transport process of sediment is necessary for solving various problems like soil erosion in catchments, reservoir sedimentation, stable channel design, river morphological computations, etc.
Sediment transport in most of the alluvial river is followed by the formation of bedforms and flow resistance and turbulence characteristics of such type of flows are totally different from the flow through the streams which are having plane bed .In open channel flow ,Turbulent structure of flow is one of the controlling factor in river hydraulics because it is related with the sediment transport, waste material transport, and river bed degradation. Knowledge of Turbulent flow structure and their relation with the process of sediment transport mechanism is much required for the forecasting of river bed degradation.

In natural open channel flow, when the stresses developed on the bed exceeds a critical threshold value, the movement of the bed particle started from the bed. The instability of the bed itself lead to the formation of numerous bedforms. These bedforms developed at certain stage can be fully developed or it can continue to be in transient stage. Turbulent flow characteristics is the controlling factor which deals with the shape and size of bedforms. In a natural open channel flow, when the motion of bed particle initiated, they interact with the turbulent flow in a very complicated manner affecting the over channel resistance. The interaction between the bed morphology, flow and associated sediment transport continues to be an area of active research.

Turbulence studies have been inquired in an open channel flow over past few decades on numerous aspects such as turbulence characteristics of flow for uniform flow, steady flow, unsteady flow, action of changing discharge, roughness of bed, sediment flow, weakly mobile bed, fixed bed, rigid and flexible vegetation, effect of bed forms, effect of sediment flow over spur dykes, piers provide in channel bed by various researchers.

Therefore, in this present work the turbulent statistics of flow over the degraded channel bed of sand is examined by using Acoustic Doppler Velocimeter (ADV). Nikora and Goring (2000) found out turbulence characteristics on fixed bed and weakly bed in an irrigation canal and concluded that mean velocity, turbulence intensity and shear stress differ in several aspect and these differences are due to spanwise spacing between eddies. Shevchenko and Pender (2001) studied turbulent structure of flow over various size of gravel bed and concluded that depth-scale eddies are an important turbulence mechanism contributing to sediment transport. Cellino and Lemmin (2004) studied the influence of suspended sediments on coherent flow structure using APFP. They investigated the predominance of ejection and sweep events of burst cycle and showed the importance of ejection and sweep phases in sediment in sediment resuspension and transport. Corolla et al. (2005) described the turbulence intensity on gravel bed channels by using ADV and concluded that turbulence intensity decreases for increasing value of roughness height. Rodriguez and Garcia (2008) performed a laboratory experiment to study about secondary circulation in straight open channel flow on rough bed and found that bed shear stress and turbulence pattern were consistent with secondary flow. Jain and Kothyari (2009) shown the result of the process of erosion of cohesive sediment mixture and concluded that the process of detachment of cohesive sediment mixture containing gravel is different from that of cohesionless sediments. Duan et al. (2011) shown the 3-D turbulent flow field around an experimental spur dyke by using ADV and found that Ejection and Sweep event are dominant before local scour hole started and the outward interaction are prevalent after formation of scour hole. Debnath et al. (2012) described the effect of clay content on Turbulent characteristics within and above the equilibrium scour hole around circular cylinder embedded in cohesive sediment bed and found that sweeping event play an important role within the scour hole. Jain et al. (2014) measured the turbulent characteristics over sand-gravel bed that was degraded by the detachment of its bed material and found that turbulent intensity and Reynold shear stress occur maximum at the level of bed surface before detachment. Singh et al. (2017) shown the result of turbulence characteristics over the degraded bed of clay-silt-sand mixture and found that degradation of channel bed reduces due to higher resistance of cohesive bond.

## 2.EXPERIMENTAL PROGRAMME

### 2.1Experimental flume and material

The experiments were conducted in a rectangular open channel tilting flume of 10m long, 0.6m wide, 0.6m height located in Hydraulic Engineering Laboratory of Civil Engineering Department, National Institute of Technology, Rourkela, India. The channel had a test section of 3m long and 0.6 m wide, which is starting at a distance of 5m from channel entrance and sand was filled in the test section up to the depth of equal to 0.14 m. The depth of the channel test section for sand filling was 0.14 m which is considered as the channel bed level. The discharge in the channel was provided by the overhead tank. The supply of water in the channel is regulated by the valve provided in the inlet pipe. The discharge measurement is made volumetrically with the help of a volumetric tank provided just after the downstream end of the channel and also with the help of flow meter. Flow straighteners and baffle wall are used at the inlet section of channel to reduce the pump turbulence.

A circular trap used for the collection of bed load was provided at the end of the flume just after the tail gate. The trap was covered with a net bolting cloth having fine pores so that bed load was retained on the trap cover. The bed load collected on the cloth was first dried and then weighted.

Sand used as a bed material had a median size $d_{50}$ of 0.57mm.

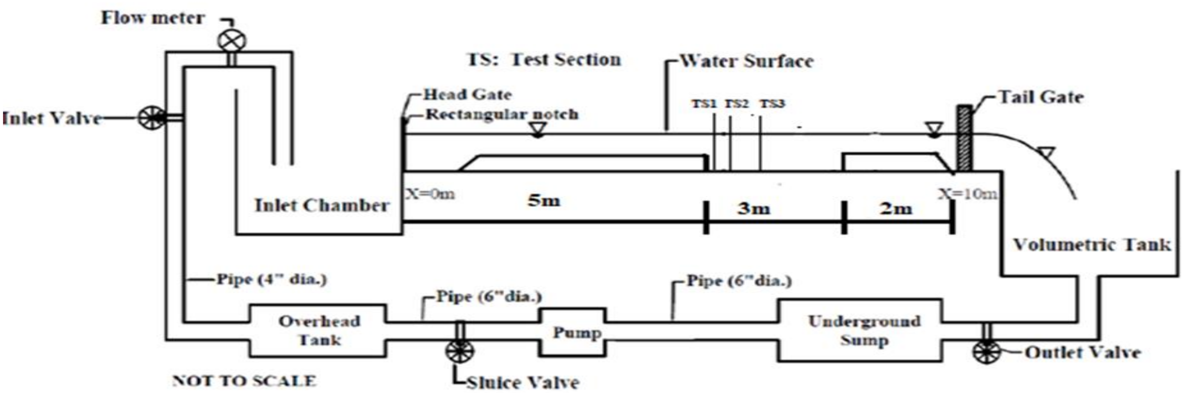


**Figure 1**. A schematic diagram of experimental set-up, NITR

**Figure 2.** Experimental flume at NITR Laboratory

## 2.2 Experimental Procedure

Sand was filled in the test section. The bed surface was made plain with the help of wooden plank after spreading the sand in the test section starting from upstream to downstream in order to achieve a height of 14cm in the test section. The degraded bed profile was measured with the help of flat gauge of least count 0.10mm. The water profile above the test section was measured with the help of pointer gage of least count 0.1mm. The channel bed slope was measured by closing the tail gate and by measuring the water level difference between upstream and downstream section. The uniform flow was maintained at the start of each experiment. The resulting degraded bed profile of sand was achieved when the transport of sand was almost ceased. After the development of final degraded bed. profile, measurement of bed profile and water level was measured at the interval of 0.2m. The experiment was performed to measure the three-dimensional instantaneous velocity at discharge of $0.013m^3/s$ and bed slope 0.0005012.

The ADV was placed over the test section in the flume at the measuring point to measure the 3-dimensional instantaneous velocity and turbulence characteristics within the profile of degraded channel bed after the stabilization of degradation bed surface or after the ceasing of removal of sand. ADV used in this experiment is having three probes to measure lateral, longitudinal, and vertical velocity with fluctuations. ADV is working on the principal of Doppler effect to measure the 3-D instantaneous velocity of very small suspended particle at sampling volume, which are generally available in the water due to the detachment of sand from bed surface. The velocity components in the cartesian coordinate system x, y, and z are represented by u, v, and w respectively. ADV was used to collect the data on various point at the frequency of 50hz in a sampling volume of 0.09 $cm^3$ which was 5cm away from the sensing element. ADV can measure the velocity up to 0.5cm above the bed. the ADV measurement was done along the center line of flume at three section. The sections are 0.25m (section-I), 0.6m (section-II), 1.20m (section-III) from the start of test section.

## 3.EXPERIMENTAL RESULTS AND DISCUSSION

This paper describes the of experimental result of turbulence statistics of flow over the degraded bed profile of sand. The raw data collected from the ADV need to be filtered first (Kose 2011: Dey et al. 2011) to examine the turbulence statistics of flow. Raw data of instantaneous three-dimensional velocity collected through ADV were filtered using WinADV software at the minimum signal -to -noise ratio of 17 and the minimum correlation of 70%. Data of ADV after filtering was reduced but still the data was sufficient to for evaluation. The measurement of velocities, turbulent intensities and turbulent kinetic energy was found at a fixed point for 1min time to ensure that results become stationary. Data after filtering from WinADV software was used to compute the turbulence parameter and these parameters were normalized with shear velocity of approach flow. Shear velocity ($u_*$) of approach was calculated by $\sqrt{gRSo}$; where $g$ is acceleration due to gravity, $R$ is hydraulic radius and $S_o$ is bed slope.

### 3.1 Profile of degraded bed at test section

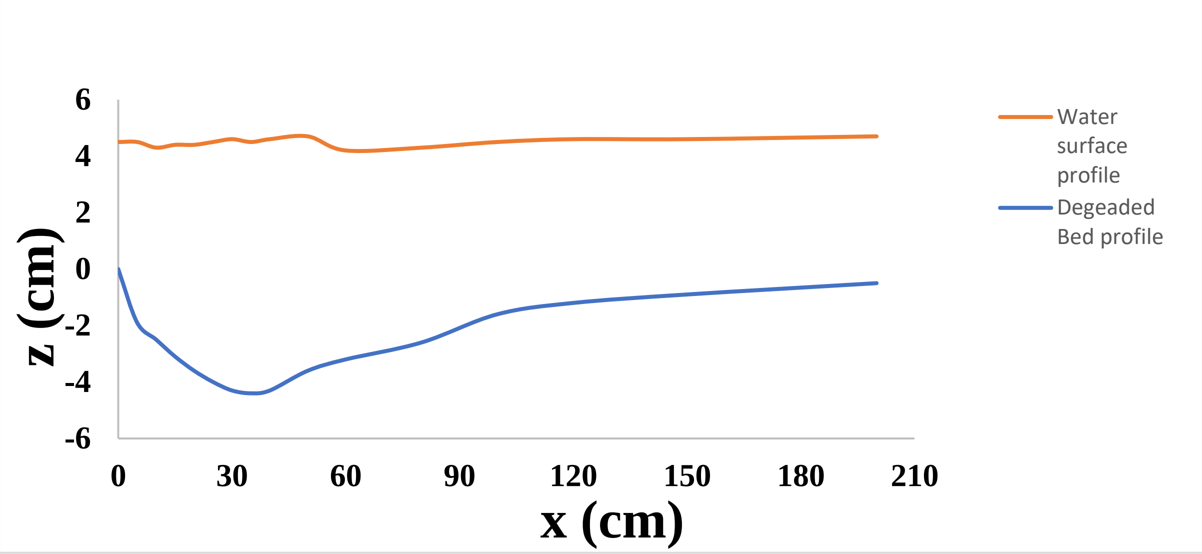


**Figure 3.** Degraded bed profile of sand

### 3.2 Velocity distribution

Measurement of average velocity in x, y, z direction at a point over the bed can be calculated by using equation

$$\bar{u} = \frac{1}{N}\sum_{i=1}^{N} u_i\ , \quad \bar{v} = \frac{1}{N}\sum_{i=1}^{N} v_i\ , \quad \bar{w} = \frac{1}{N}\sum_{i=1}^{N} w_i$$

Where $\bar{u}, \bar{v}$ and $\bar{w}$ are the average velocity at any point in x, y, and z directions respectively;

$u_i, v_i$ and $w_i$ represents the instantaneous velocity in respective directions;

$N$ is the number of data samples collected at particular point.

The vertical profile of mean velocity components ($\bar{u}$, $\bar{v}$ and $\bar{w}$) describes the characteristics features of flow over the bed surface. Fig.2 represent the stream-wise velocity distribution $\bar{u}/U$ versus z/h at three different section together. Here z is the distance above or below the initial bed surface and z=0 is considered as the initial bed surface before the start of motion of sand.

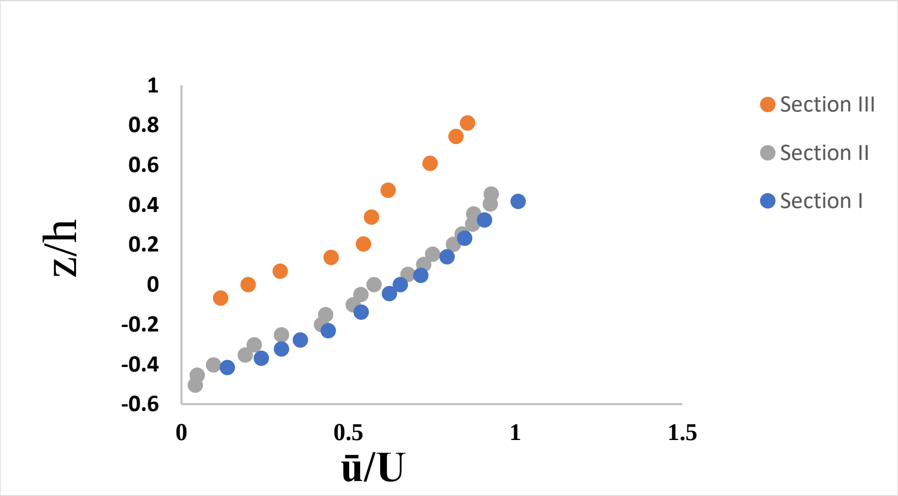


**Figure 4.** Normalized mean velocity

### 3.3 Turbulent intensity

The turbulent intensity is represented by the root mean squared value of fluctuating velocity component $(u', w')$ of instantaneous velocity.

$$TI_u = \sqrt{\overline{u'^2}} = \left[\frac{1}{N}\sum_{i=1}^{N}(u_i - \bar{u})^2\right]^{0.5}$$

$$TI_v = \sqrt{\overline{v'^2}} = \left[\frac{1}{N}\sum_{i=1}^{N}(v_i - \bar{v})^2\right]^{0.5}$$

$$TI_w = \sqrt{\overline{w'^2}} = \left[\frac{1}{N}\sum_{i=1}^{N}(w_i - \bar{w})^2\right]^{0.5}$$

where $TI_u$, $TI_v$, and $TI_w$ are the turbulence intensity in x, y and z directions, respectively.

After the collection and filtering the raw data of ADV, turbulence intensity (TI) is normalized with the parameter of shear velocity of approach flow. Shear velocity of approach flow was calculated by $\sqrt{gRSo}$; where $g$ is acceleration due to gravity, $R$ is hydraulic radius and $S_o$ is bed slope

The normalized Turbulent intensity in the x, y, z direction are computed as $TI_u^+$ $(= \frac{TI_u}{u_*})$, $TI_v^+$ $(= \frac{TI_v}{u_*})$, and $TI_w^+$ $(= \frac{TI_w}{u_*})$ , respectively.

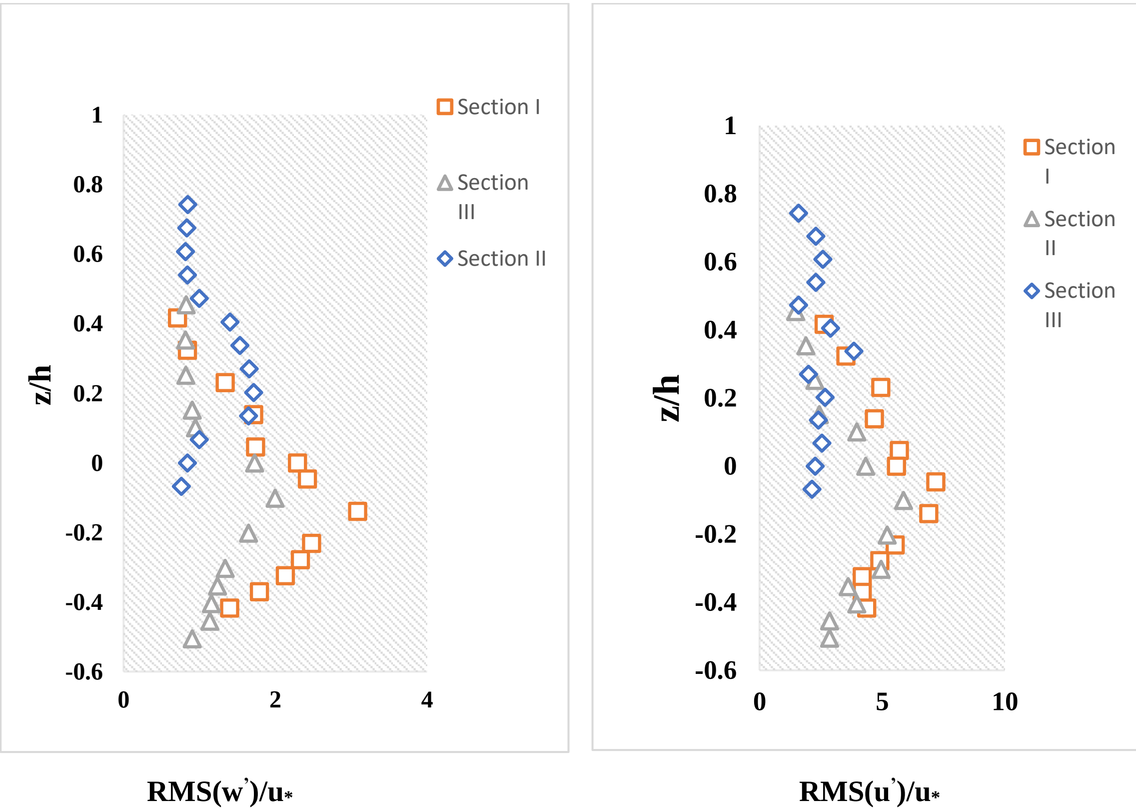


**Figure 5.** Turbulent intensity

### 3.4 Turbulent kinetic energy

TKE is one of the important factors of turbulence flow and is calculated as per equation

$$TKE = \frac{(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})}{2}$$

TKE is normalized with square of shear velocity corresponding to approach flow as per equation

$$TKE^{+} = \frac{TKE}{u_*^2}$$

Where $TKE^{+}$ is normalized velocity

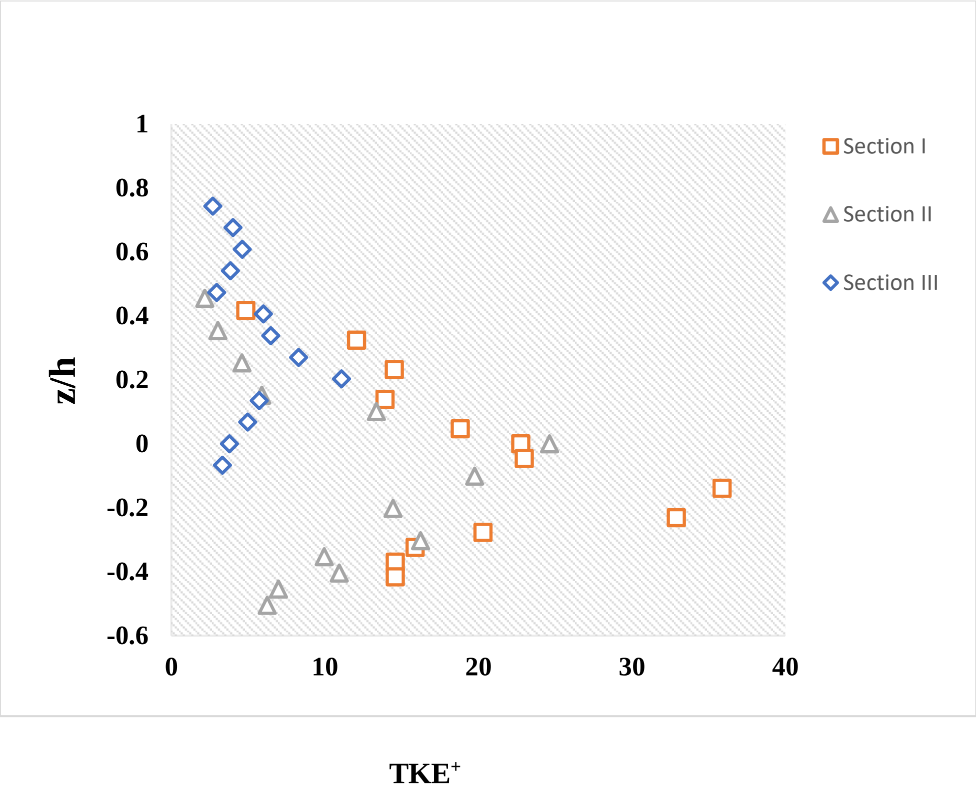


**Figure 6.** Turbulent kinetic energy

## 4. CONCLUSION

In this experiment Acoustic Doppler Velocimeter (ADV) was used to collect data of three-dimensional velocity in x, y and z direction. The data was collected at three different section of 0.25m, 0.6m and 1.2m from the start of test section. Experiment was conducted in the laboratory channel to collect the data regarding Turbulence characteristics such as Turbulence intensity, Turbulent kinetic energy and instantaneous velocity over the degraded profile of sand formed due to the detachment of sand. After analyzing the data, it was found that the value of Turbulent intensity and Turbulent kinetic energy is maximum at the initial level of bed before the start of detachment and the value of Turbulent intensity and Turbulent kinetic energy decreases towards the downstream along the degraded bed profile of sand

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