# Structure of Turbulent Flow in a Meander Gravel Bed Channel

**Abhimanyu Kumar, Pritam Kumar, and Anurag Sharma**

**Abstract** Various types of bed materials are present in rivers or canals, and they have important effects on hydrodynamic characteristics such as velocity distribution and turbulence characteristics. Study of the flow behavior in gravel bed channels is limited until the flow structures are described and their origin explained. In the meandering river consisting of gravel as bed material, eddies can be seen at the surface due to which flow turbulence is not random. The experimentations were performed in a prismatic rectangular concrete meander channel having a slope of 0.001 and sinuosity of 1.06 and this channel bed is arranged with non-uniform gravel with $D_{50}$ as 12 mm to study the turbulent flow characteristics such as time-averaged velocity and turbulent intensity along longitudinal and vertical directions at two different discharges. The experimental data were collected by a 3D Acoustic Doppler Velocimeter. In this investigation, longitudinal velocity decreases in the downstream direction near the bed surface but increases along the free surface and vertical velocity reduces in the direction of the stream. Analysis and comparison of turbulent flow properties in a gravel bed meander channel at two different discharges and different sections are studied in this chapter. It will give a better impact on the field of hydraulics and provide a comprehensive idea for studying some important flow characteristics in a more advanced manner for different conditions.

**Keywords** Meander · Gravel · Flow velocity · Turbulent

## 1 Introduction

To determine the intensity and character of river processes, one of the main factors is turbulence. These consist of sediment transport, erosion, deposition, flow resistance, transfer of heat, diffusion of matter, and origin of bed and channel systems. Turbulence in free surface flows is currently the subject of extensive research. Turbulent fluctuations are thought to be chaotic and unpredictable, so it is expected that

A. Kumar · P. Kumar · A. Sharma (✉)
Department of Civil Engineering, National Institute of Technology, Rourkela, India
e-mail: sharmaan@nitrkl.ac.in



S. Dutta and V. Chembolu (eds.), *Recent Development in River Corridor Management*, Lecture Notes in Civil Engineering 376, https://doi.org/10.1007/978-981-99-4423-1_8

all turbulent structures would be elucidated experimentally and conceptually using standard statistical techniques. At the origin of analysis of extensive turbulent variations, a series of “rolling” vortices of depth-wise were included in the mathematical model of free surface flow [13]. The kinematic structure of the flow in lab channels through rough and smooth beds was carefully considered by Fidman [2]. He discovered that the small-frequency turbulent variations brought on by the biggest turbulent instabilities contain the most turbulence energy. In the flume studies with moveable gravel beds, Klaven and Kopaliani [7] used the visualization method.

A significant and recognized element of flow through the curvature of a meandering bend induced secondary motion that develops in the bend’s center as a result of a discrepancy between the transverse pressure gradient and the centrifugal force close to the bed [4]. A streamwise coherent vortical structure is created as a result of this imbalance, and its sense of rotation causes it to steer near-bed flow along the inner bank and surface flow along the outer bank. Johannesson and Parker [5] created a mathematical model for the analysis of secondary flow in slightly sinuous channels, and Kalkwijk and De Vriend [6] devised a mathematical model characterizing primary and secondary flow velocities in large and slightly curved bends in open channel. Frothingham and Rhoads [3] used field experiment in irregular compound meander bend to look at the 3D flow structure and streambed modifications. They observed inside a lobe that no mean streamlines complete a full cycle of helical rotation and that helical mean flow motion connected to the center area cell gradually degrades as the flow approaches inflections in curvature. In the investigation of flow in a meandering gravel bed watercourse, Thompson [11] noted a region of upwelling along the stream’s concave bend and inward flow along water’s surface into a region of convergence over pool’s deepest portion. Van Balen et al. [12], in order to replicate the flow in a sinuous flume with a rectangular cross-section, used Large-Eddy Simulation (LES) which they used to confirm that centrifugal force and cross-stream turbulent loads are key factors in the creation of outer bank cell. Sukhodolov et al. (2012) effort was motivated by mounting evidence that the riffle-pool geometry in bends can have major effects on flow structure. This study uses field data to examine the flow in a lowland river bend with a shallow riffle and a deep pool. According to the investigation, the reach flow in the riffle is nearly uniform. Two layers make up the vertical structure of the stream in the pool, which has a nearly uniform flow along the riverbed. Ferguson et al. [1] performed 3D Reynolds Averaged Navier–Stokes (RANS) simulations. He noted the recirculation region along the convex bend of the meander and solved flow in natural bends. They claimed that by forming clumps of fine sediment, the slow flow in the convex bend recirculation region can alter the dynamics of sediment. The creation of bars at the convex bend of the bank is associated with flow separation, which has a significant impact on meander morpho-mechanics, according to all previous field and laboratory research.

The aforementioned literature study demonstrates the difficulty of meander bend flows and displays that even through substantial advancements, there are numerous features of such flows that are not fully understood. Therefore, there is a need for more study on turbulent flow properties in a gravel bed meander channel. In this paper, we experimentally investigate turbulent flow properties in a gravel bed meander channel at different sections and compare them with two different discharges.

## 2 Experimental Setup

The experiment was performed in a 10 m long, 1.7 m wide, and 0.9 m depth compound meandering channel with a bed slope of 0.001. The cross-section of the main meandering channel was rectangular with a breadth of 0.28 m and depth of 0.10 m. Sinuosity of the main channel was 1.06 with a bend angle of 30 degrees. An overhead reinforced cement concrete tank was erected upstream of the channel to carry water to the testing flume. Steady head conditions are beneficial for testing purposes. To maintain a constant water supply, the overflow water is routed through line links directly to the sump tank, and the volumetric tank collects all the channel water before directing it to the sump tank as well. The distribution of water along the channel is provided by three 10HP diffusive syphons together with suction and conveyance pipes. In order to straighten and minimize the flow turbulence, a stilling chamber with a baffle arrangement is placed at the beginning of the channel. An almost uniform flow was achieved by adjusting the tailgate. The 2.2-m test section was selected at a distance of $3.85 < \times < 6.05$ (x is the distance of examination section from the inlet in the direction of flow) because it was in a location where the flow was fully developed and unimpeded by backwater. The bed of the main channel was covered by river gravel whose particle size ($D_{50}$) is 12 mm. Over the breadth of the canal where the experimentation setup was located, the moveable bridge arrangement is positioned. Two different discharges of 0.011971 $m^3/s$ and 0.0106 $m^3/s$ were taken for this investigation. Three-dimensional velocity was measured using a SonTek 16 MHz Micro-Acoustic Doppler Velocimetry system (ADV). The bend apex and cross-over parts of the examination section were measured for their respective velocities. Section S1 and S3 are bend apex, and S2 and S4 are cross-over of the channel cross-section shown in Fig. 1, and experimental setup in laboratory is shown in Fig. 2. All the data are taken at the middle of channel cross-section. To provide correct datasets, each point velocity was filtered via WIN ADV software with a signal to noise ratio (SNR) of 15 and a correlation value of 70 [8].

## 3 Results and Discussion

In this segment, different turbulent flow characteristics have been discussed for flow in the gravel bed meandering channel in the direction of the stream and compared between two different discharges Q1 and Q2 of 0.01197 $m^3/s$ and 0.0106 $m^3/s$, respectively. Due to ADV's limitations, it was not able to measure the flow field in the area that was 5 cm below the free surface. Therefore, the flow region close to the free surface is outside the possibility of this investigation.

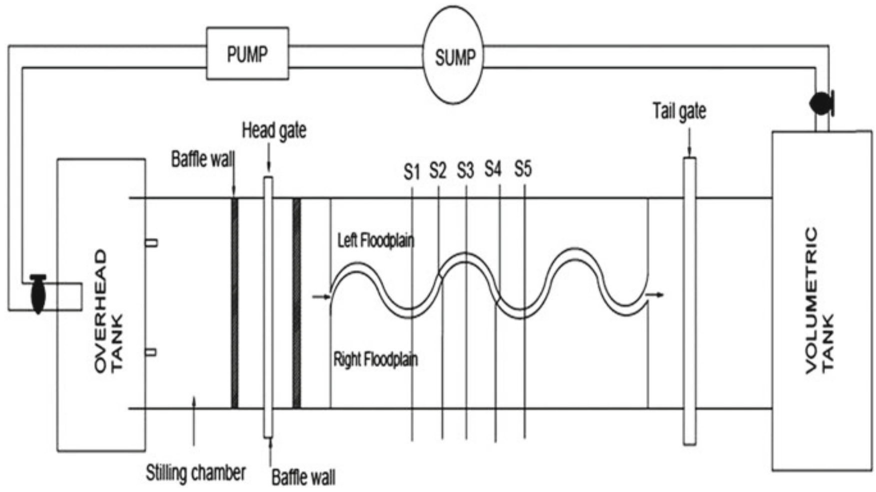


**Fig. 1** Plan view of experimental setup and test section

**Fig. 2** Experimental setup in laboratory

## *3.1 Longitudinal Velocity*

Vertical distribution of longitudinal velocity at different sections with respect to normalized depth of flow ($y/H$, where $y$ = height from bed surface and $H$ = total depth of flow) are shown in Fig. 3. A comparison of the differences in discharge illustrates the variation in longitudinal velocity at the 4 sections. Bend apex sections are shown by Section S1 and S3, whereas S2 and S4 are the cross-over sections. On observing the profiles across streamwise and comparing with two different discharges Q1 and Q2, where Q1 > Q2; it is seen that the velocity remains higher towards upper surface. Near the bed, velocity is minimum for both discharges under the case of gravel bed. Near the bed surface, velocity is smaller for cross-over sections than bend apex sections. In the comparison of discharge, velocity is higher for Q2 than Q1 for all sections. The roughness of bed increases in a channel would suggest a greater value of Manning's 'n' and hence velocity will decrease. A meandering waterway should have also allowed for such an observation. However, as seen in bend apex sections (S1 and S3), the longitudinal velocity for lesser discharge (Q2) is lower than the longitudinal velocity for larger discharge (Q1) towards the free surface but in inner layer higher longitudinal velocity for smaller discharge in the gravel bed meandering channel. However, longitudinal velocity is higher for smaller discharge than higher discharge throughout the flow depth at cross-over sections. The gravel bed meandering channel's velocity distribution is seen to be higher for increased discharge for the bend apex section as depth increases. The curvature is the sole additional impact, and it is same for both discharges. As a conclusion, the resistance brought on by the meandering effect is more pronounced at the curve apex than at the cross-over. Thus, it may be concluded that channel curvature, rather than only bed roughness, affects velocity variation significantly.

### *3.2 Vertical Velocity*

Distribution of vertical velocity at bend apex and cross-over are shown in Fig. 4 of S1, S3 and S2, S4; respectively. On observing the profile of vertical velocity, found that close to the bed surface water particles move in upward direction after that it tends towards downward direction at a normalized depth of 0.05 to 0.1. In case of vertical velocity in outer layer, water particles moved towards upward direction. Intensity of vertical velocity is higher for bend apex than cross-over near the bed surface and smaller for bend apex towards the outer layer. In this experimentation, we also observed that smaller discharge has smaller vertical velocity intensity than higher discharge at bend apex section. At cross-over section, smaller discharge has higher intensity than higher discharge. In general, when water particles moved along streamwise direction from bend apex with higher discharge then transverse velocity is also higher than the smaller discharge of water flowing through meandering gravel bed channel but at the cross-over, it is opposite from bend apex, that is, when water particles moved along streamwise direction from cross-over then smaller discharge have higher vertical velocity intensity than higher discharge.

### *3.3 Longitudinal Turbulence Intensity*

The turbulent intensity is analyzed by the value of the root-mean-square (rms) of longitudinal velocity variations. Distribution of longitudinal turbulent intensity at different sections with respect to normalized depth of flow ($y/H$, where $y$ = height from bed surface and $H$ = total depth of flow) is shown in Fig. 5. The results

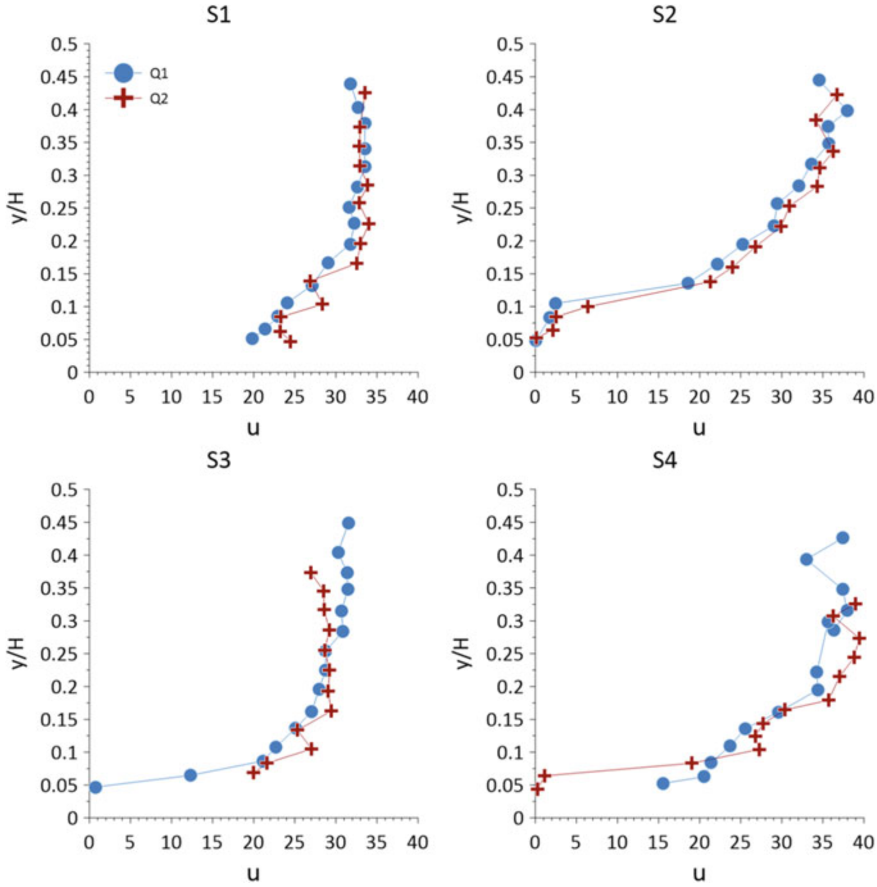


**Fig. 3** Longitudinal velocity profile at different section

display a respectable agreement with the experimental results [9]. We observed that longitudinal turbulence intensity is slightly higher for smaller discharge than higher discharge at bend apex sections, but at cross-over section, it is slightly higher for higher discharge than smaller discharge. Hence, turbulent intensity in gravel bed meander channel decreases when flow discharge increases at bend apex section and increases when flow discharge increases at cross-over of the channel cross-section. Magnitude of longitudinal turbulence intensity is higher for cross-over sections as compared to bend apex sections. It means when water particles move in the direction of stream through bend apex section then longitudinal turbulence intensity decreases, while at cross-over section increases.

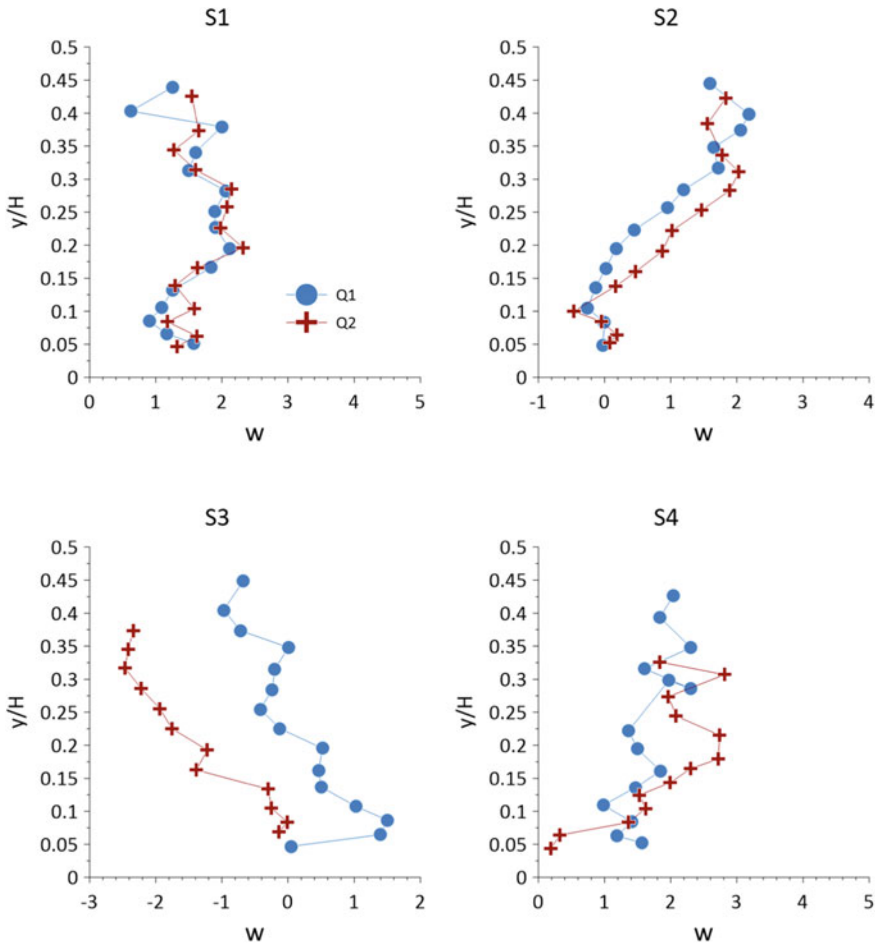


**Fig. 4** Vertical velocity profile at different section

## 3.4 *Vertical Turbulent Intensity*

Distribution of vertical turbulent intensity at different sections with normalized depth of flow is shown in Fig. 6, where S1 and S3 are bend apex sections and S2 and S4 are cross-over sections for two different discharges (Q1 > Q2) in a gravel bed meander channel. The result shows that vertical turbulent intensity is smaller near the bed surface. Near the bed surface, it is higher for bend apex than cross-over. Vertical turbulent intensity is higher for smaller discharge (Q2) than higher discharge (Q1) at bend apex section, but smaller for smaller discharge at cross-over section in gravel bed meander channel. In the comparison of bend apex and cross-over section, vertical turbulent intensity is higher for bend apex section than cross-over section near the bed surface.

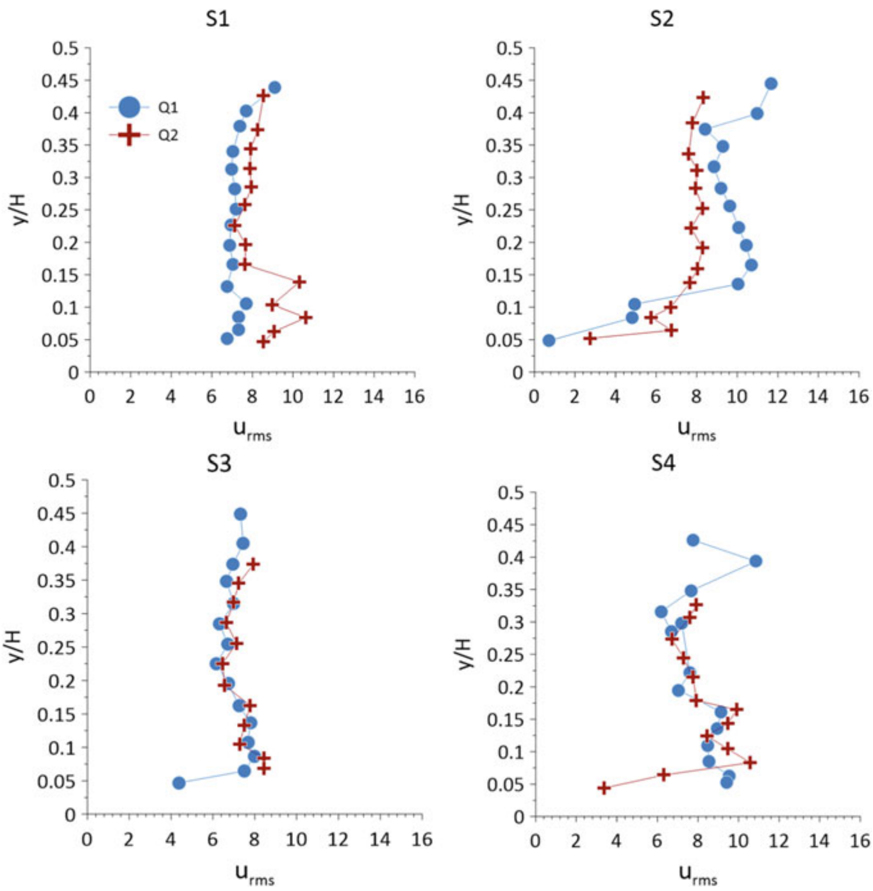


**Fig. 5** Longitudinal turbulent intensity profile for different section

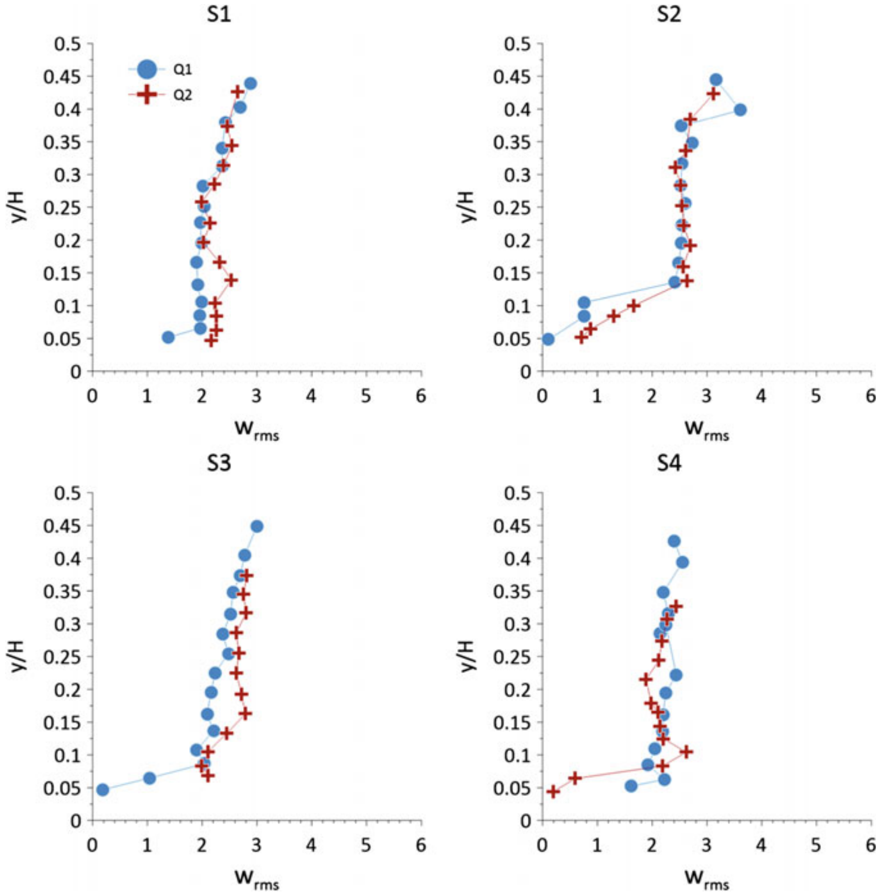


**Fig. 6** Vertical turbulent intensity at different sections

# 4 Conclusion

This chapter presents an experimental investigation of two-dimensional flow property in a meandering compound channel whose bed is covered by gravel. This investigation is done under two different flow discharges 0.011971 $m^3/s$ and 0.0106 $m^3/s$. The flow properties such as the two-dimensional time-averaged velocity and turbulent intensity are examined in this chapter. Further, the results of the vegetation zone at two different bend apex and two different cross-over are analyzed and compared between two different discharges.

The results conclude that the longitudinal velocity decreases near-bed surface for both discharge and higher for bend apex than cross-over. For smaller discharge, longitudinal velocity is smaller for higher discharge at cross-over section but at bend apex section, it is smaller in outer layer for bend apex sections. Thus, the velocity variation may be affected by discharge variation significantly in the gravel bed meander channel. When discharge increases in gravel bed meander channel, then vertical velocity increases in upward direction at bend apex section. However, it decreases when flow passes from cross-over section for higher discharge. Longitudinal turbulent intensity decreases at bend apex section when discharge of flow increases, while it increases at cross-over section. Vertical turbulent intensity is higher for smaller discharge in gravel bed meander channel. The investigations show the two-dimensional flow property in a gravel bed meandering channel, which has implications on the understanding of the behavior of a gravel bed meandering channel.

## References

1. Ferguson RI, Parsons DR, Lane SN, Hardy RJ (2003) Flow in meander bends with recirculation at the inner bank. Water Resour Res 39(11)
2. Fidman BA (1953) Principal results of experimental study of the structure of turbulent flows. Prob Channel Process 138–150
3. Frothingham KM, Rhoads BL (2003) Three-dimensional flow structure and channel change in an asymmetrical compound meander loop, Embarras River, Illinois Earth Surface Processes and Landforms. J Br Geomorphol Res Group 28(6):625–644
4. Humphrey JAC, Whitelaw JH, Yee G (1981) Turbulent flow in a square duct with strong curvature. J Fluid Mech 103:443–463
5. Johannesson H, Parker G (1989) Secondary flow in mildly sinuous channel. J Hydraul Eng 115(3):289–308
6. Kalkwijk JT, De Vriend HJ (1980) Computation of the flow in shallow river bends. J Hydraul Res 18(4):327–342
7. Klaven AB, Kopaliani ZD (1973) Laboratory investigations of the kinematic structure of turbulent flow over a rough bed. Trans State Hydrol Inst 209:67–90
8. Kumar P, Sharma A (2022) Experimental investigation of 3D flow properties around emergent rigid vegetation. Ecohydrology 15(8):e2474
9. Muto Y (1997) Turbulent flow in two-stage meandering channels. PhD thesis, University of Bradford, UK
10. Sukhodolov AN, Nikora VI, Katolikov VM (2011) Flow dynamics in alluvial channels: the legacy of Kirill V Grishanin. J Hydr Res 49(3):285–292
11. Thompson A (1986) Secondary flows and the pool-riffle unit: A case study of the processes of meander development. Earth Surf Proc Land 11(6):631–641
12. Van Balen W, Uijttewaal WS, Blanckaert K (2009) Large-eddy simulation of a mildly curved open-channel flow. J Fluid Mech 630:413–442
13. Velikanov MA (1949) Dynamics of Alluvial Flows. *Gidrom-eteoizdat, Leningrad, Russia*