

Energy and Momentum Correction Coefficients in Meandering Channels

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HIGHLIGHTS

- Lateral velocity variation alters energy and momentum correction factors.
- Smooth channels show higher α and β than rough channels.
- Results improve hydraulic modeling of meandering flows.

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ABSTRACT

Understanding flow behaviour in meandering channels is essential due to their complex velocity distribution influenced by centrifugal forces. Unlike straight channels, meandering flows exhibit lateral variations in velocity and associated energy losses, necessitating correction factors such as the kinetic energy correction coefficient (α) and the momentum correction coefficient (β). This study investigates these coefficients in a highly sinuous meandering channel (sinuosity 4.1) under varying discharge conditions and surface roughness (smooth and rough). Velocity measurements were obtained using Pitot tubes across multiple cross-sections along the meander path. The results reveal significant lateral variation in depth-averaged velocities and the correction coefficients, highlighting the influence of channel roughness and discharge on the distribution of α and β . Comparative analysis between smooth and rough channels shows higher energy and momentum correction coefficients in smooth conditions, attributed to reduced turbulence and frictional effects. These findings contribute to a better understanding of flow mechanics in natural and engineered meandering systems, aiding in more accurate hydraulic modelling and design.

1. INTRODUCTION

The study of open-channel flow has traditionally relied on simplified assumptions of uniform velocity distribution and prismatic channel geometry. However, in practical applications, particularly in meandering channels, these assumptions are inadequate due to the presence of centrifugal forces, secondary flows, and irregular boundary conditions, all of which significantly influence the velocity distribution and pressure gradients across the channel cross-section (Leopold 1960). These complexities

necessitate a more refined approach to flow analysis, especially in natural streams and engineered sinuous channels.

In such scenarios, the use of mean velocity to compute flow properties can lead to substantial errors in the estimation of energy and momentum. To compensate for these deviations, correction factors, namely, the kinetic energy correction coefficient (α) and the momentum correction coefficient (β) (Chow 1959). These coefficients are essential for accurately describing the flux of kinetic energy and momentum

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in cases of non-uniform flow. Several methods have been developed to determine these coefficients, including graphical, analytical, and numerical approaches (Jin et al. 2004; Zarrati et al. 2005). While graphical methods such as isovel mapping are time-consuming and prone to error, analytical techniques based on velocity power laws and depth-averaged assumptions offer greater efficiency (Esposito et al. 2024; Vatanchi and Maghrebi 2024a; b).

Studies by Keulegan 1938; Pradhan and Khatua 2018a, b) emphasized the theoretical derivation of α and β and linked their values to the frictional characteristics of the channel, as cited in Chow 1959). Values of these coefficients are sensitive to flow unsteadiness, particularly under convectively decelerating conditions. The relationships among energy, momentum, and resistance coefficients highlight their importance in backwater profile calculations and unsteady flow simulations. Al-khatib (1999) further observed that streamwise velocity distributions exhibit significant deviations from the average velocity, reinforcing the necessity of incorporating these coefficients in hydraulic modelling.

This study aims to experimentally evaluate the momentum and energy correction coefficients variation in a highly sinuous meandering channel with a sinuosity of 4.1. The research investigates how flow structure and boundary interactions affect α and β by conducting experiments under both smooth and rough bed conditions. Velocity measurements were obtained using Pitot tubes across multiple vertical and lateral sections. The outcomes contribute to a more accurate understanding of flow behaviour in meandering systems and provide insights relevant to both river engineering and hydraulic structure design

2. THEORETICAL CONSIDERATION

Velocity plays a fundamental role in the study of open channel hydraulics, as it governs the flow characteristics and regime in both natural and engineered systems. In open channel flows, the velocity distribution is typically assumed to follow a logarithmic profile due to the inherently turbulent nature of the flow. The total energy of fluid moving along a streamline per unit weight, commonly referred to as the total energy line or hydraulic grade line, comprises pressure head, velocity head, and elevation head. In real-world conditions, the velocity across a channel cross-section is not uniform. Consequently, each streamline possesses a distinct velocity head. The actual kinetic energy per unit weight is, therefore, greater than what is computed using mean velocity. The kinetic energy correction coefficient (α), also known as the Coriolis coefficient,

is introduced to account for this discrepancy. It adjusts the velocity head calculation to $\propto \frac{v^2}{2g}$, where v is the mean velocity and g is the acceleration due to gravity. Several key velocity-related parameters and coefficients are used to describe the average flow characteristics across a cross-section.

2.1 Mean Velocity

The mean velocity V over the entire cross-sectional area A is computed using the integral of the point velocities:

$$v = \frac{1}{A} \int_A v \cdot dA \quad (1)$$

2.2 Depth-Averaged Velocity

The depth-averaged velocity is often estimated using isovel contours or by applying velocity distribution models such as the logarithmic or power-law profiles. A simplified approach considers velocities at 0.2H and 0.8H depths (where H is the total flow depth), averaged as;

$$v_{avg} = \frac{v_{0.2H} + v_{0.8H}}{2} \quad (2)$$

2.3 Kinetic Energy and Momentum Correction Coefficients

Velocity varies across the section; therefore, correction coefficients are introduced to adjust the kinetic energy and momentum terms in hydraulic computations. The kinetic energy correction coefficient (α) accounts for the difference between the actual kinetic energy and that calculated using the mean velocity.

$$\alpha = \frac{\int_A v^3 \cdot dA}{V^3 A} = \frac{\sum v^3 \cdot \Delta A}{V^3 A} \quad (3)$$

The momentum correction coefficient (β) corrects the momentum flux across the cross-section and is given by;

$$\beta = \frac{\int_A v^2 \cdot dA}{V^2 A} = \frac{\sum v^2 \cdot \Delta A}{V^2 A} \quad (4)$$

Typically, the relationship $\beta < \alpha$ holds true, reflecting the greater sensitivity of kinetic energy to velocity variation compared to momentum.

3. EXPERIMENTAL SETUP

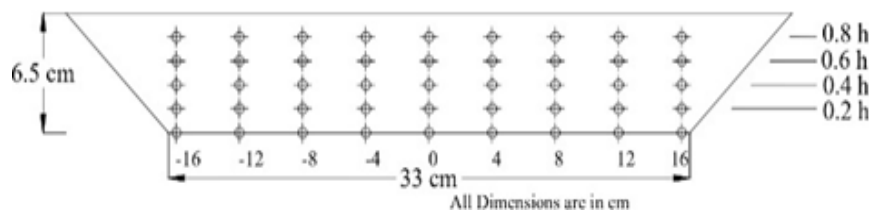
The experiments were carried out in a meandering channel constructed within a large tilting flume, measuring 4 m in width and 15 m in length, located at

the Fluid Mechanics and Hydraulics Laboratory, NIT Rourkela. The flume is equipped with hydraulic jacks, allowing adjustment of the bed slope to simulate varying flow conditions. The constructed channel

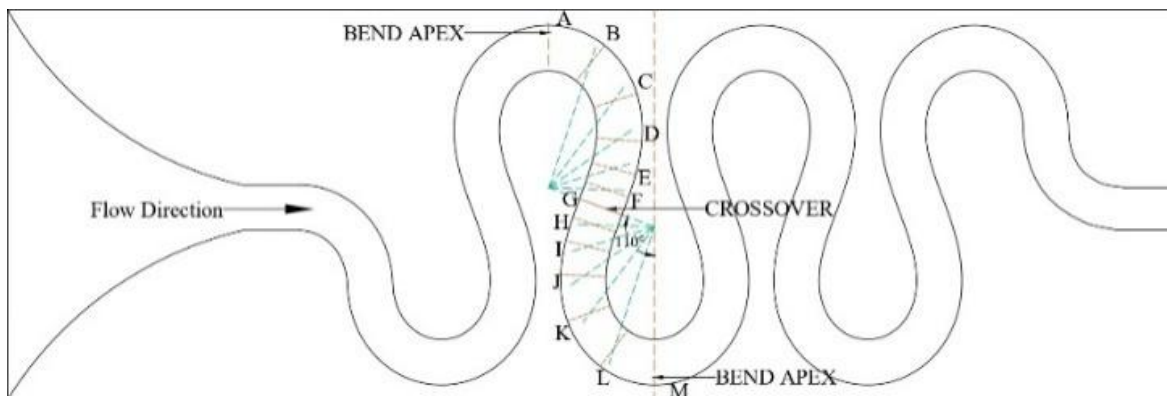
features a bankfull depth of 0.065 m, a bottom width of 0.33 m, and side slopes of 1:1. The region between the second and third bend apexes formed the core test section, as in Figure 1.



(a) Photograph of the Experimental Channel



(b) Cross-sectional data points for velocity measurement



(c) Plan view of the Experimental Channel with the study sections

Figure 1: Experimental Setup a) Photograph of the Experimental Channel b) Cross-sectional data points for velocity measurement c) Plan view of the Experimental Channel with the study sections

A highly sinuous channel was selected to investigate flow behaviour in meandering rivers, and velocity measurements were taken along the full meander path as shown in Figure 1(c). This setup enabled detailed analysis of the velocity distribution and flow structures typical of natural meandering streams. A

constant discharge was maintained throughout the experiments. Velocity measurements were obtained using five Pitot tubes with a 4.7 mm external diameter arranged across predefined grid points along the channel cross-section as in Figure 1 (b).

Velocity readings were taken at various vertical positions from the channel bed and at elevations corresponding to 0.4H, 0.6H, 0.8H, and 0.99H, where H is the local flow depth. For constructing vertical velocity profiles, the surface velocity was assumed to be zero in accordance with the no-slip condition.

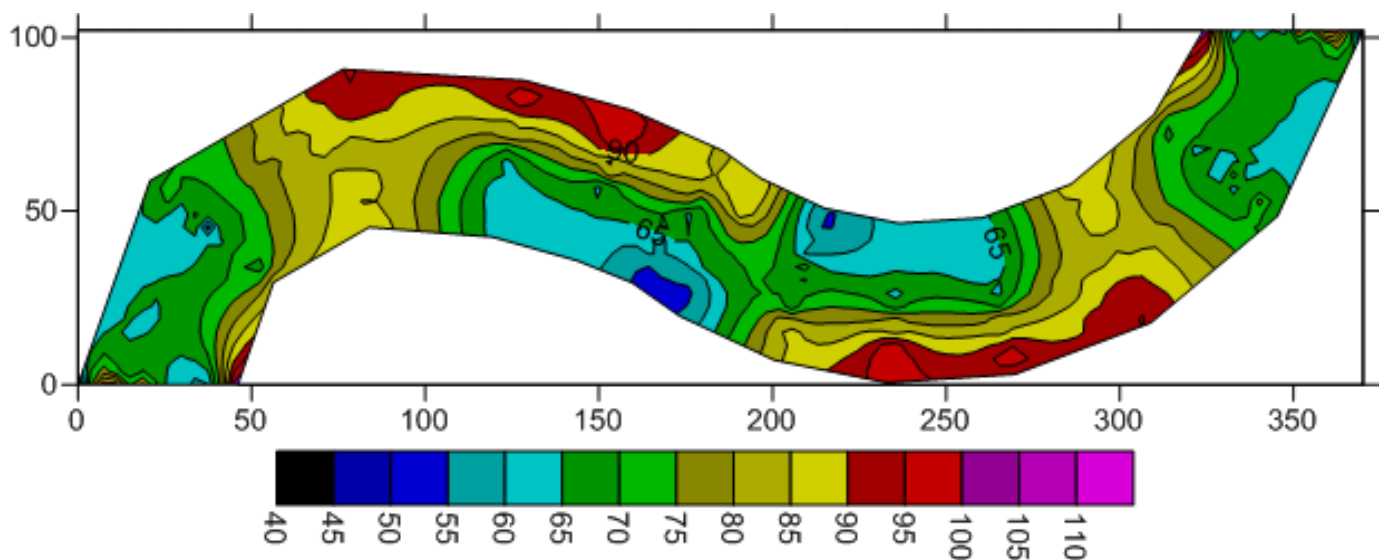
4. RESULTS AND DISCUSSIONS

4.1 Depth-Averaged Velocity

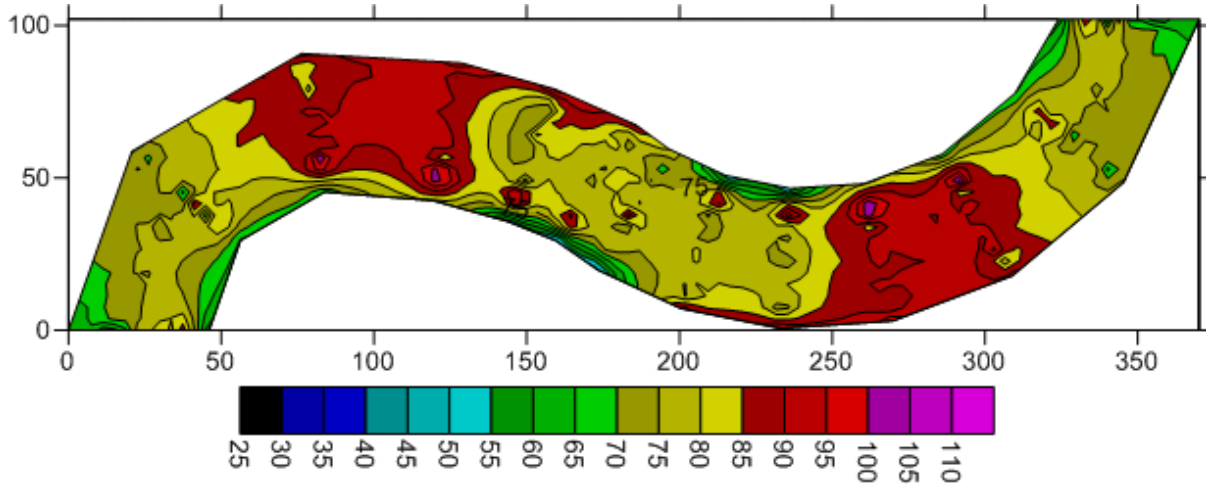
The depth-averaged velocity (DAV) contours provide detailed insights into the flow behaviour within the meandering channel under both rough and smooth surface conditions. As shown in Figure 2(a), which represents the DAV contour for the rough channel (R1), with constant discharge of $6.233 \times 10^{-3} \text{ m}^3/\text{s}$, the maximum velocities are predominantly located near the outer bank, especially between sections C and E. This pattern is characteristic of meandering flows, where centrifugal force shifts the high-velocity core toward the outer wall of the bend. Additionally, the crossover region, the transitional area between bends, exhibits nearly symmetrical velocity bulges on both sides of the central axis, reflecting lateral acceleration and convergence of flow due to secondary circulation. The contours predominantly show velocity values ranging between 80 and 90 cm/s, indicating moderate energy levels. In contrast, the inner bank, particularly from sections B to F, demonstrates substantially lower velocity values, often less than half the peak, attributed to boundary layer formation, energy loss due to wall friction, and flow stagnation near the inside curvature.

In the case of the smooth channel with a discharge of 42.36 l/s (referred to as S1), depicted in Figure 2 (b), the flow pattern changes noticeably. The high-velocity region (95-100 cm/s) is more localized and appears near the inner wall; an unusual deviation from the typical outer-wall acceleration seen in rough channels. This may be due to reduced boundary shear stress, which allows the flow to maintain higher energy near the centre or inner zones without significant lateral dispersion. The flow appears more laminar in nature, with narrower high-velocity zones and sharper transitions in the contour lines. This demonstrates how smoother boundaries limit turbulence generation, leading to a concentrated, less mixed velocity profile.

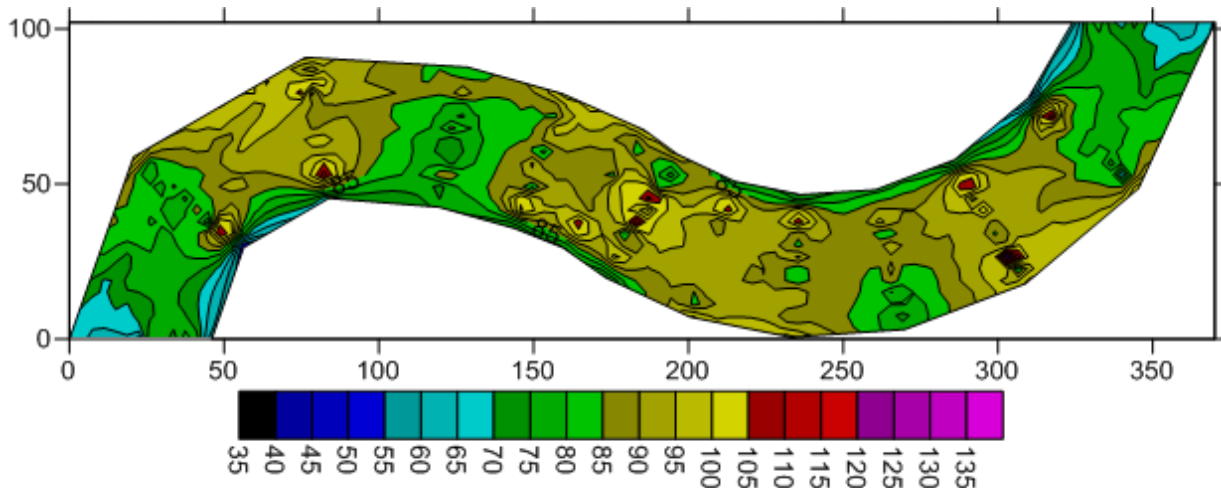
Further, in Figure 2 (c), which corresponds to the depth-averaged velocity distribution for S2 (smooth channel at a slightly higher discharge of 42.43 l/s), the velocity contours become more expansive and energetic. The maximum velocity recorded in this case is between 100-105 cm/s, with a broader spatial spread compared to S1. High-velocity zones now extend toward both the inner and outer banks, covering nearly half the cross-sectional area. This indicates a transition toward a more turbulent flow regime, where the increased discharge amplifies inertia forces, enhances flow mixing, and expands the zone of momentum dominance. The comparison of these three cases - Figures 2(a), (b), (c) and (d); clearly highlights how both surface roughness and discharge magnitude influence velocity structure and energy distribution across a meandering channel section.



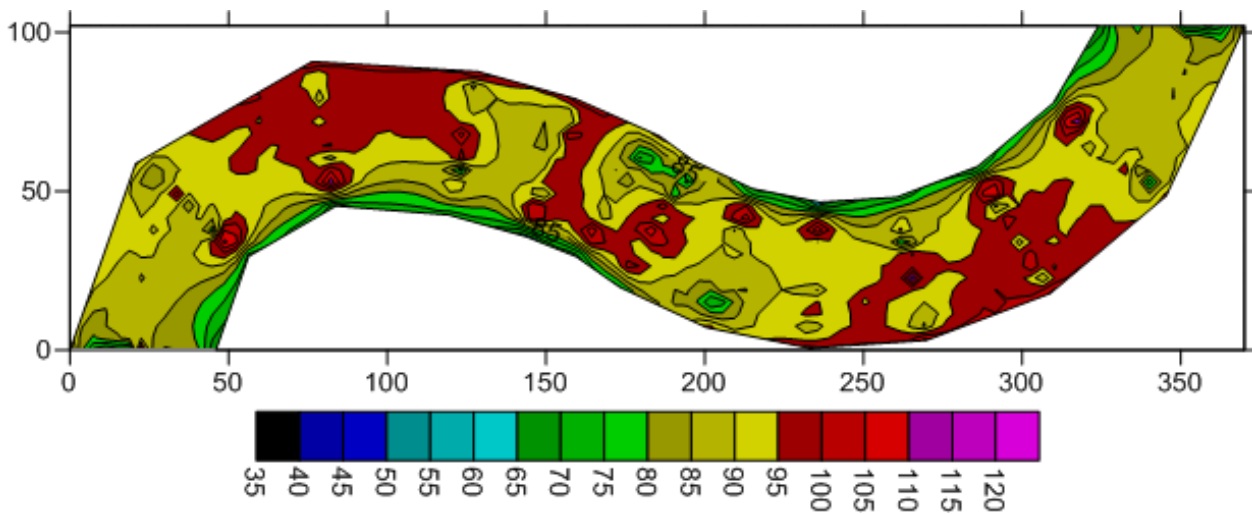
(a) Depth Average Velocity contour for R1



(b) Depth Average Velocity contour for S1



(c) Depth Average Velocity contour for S2



(d) Depth Average Velocity contour for S3

Figure 2: (a-d) Depth-averaged velocity contour

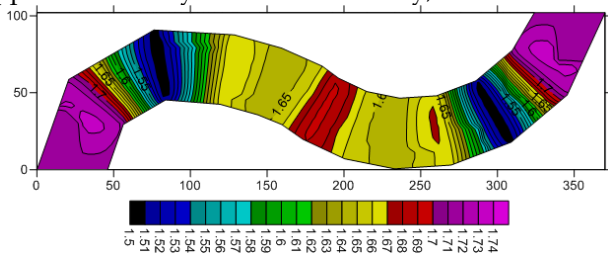
4.2 Energy and Momentum Correction Coefficients

The spatial variation of the kinetic energy correction coefficient (α) and the momentum correction coefficient (β) under different flow conditions is presented in Figures 3 (a) - (c) (for α) and Figures 4 (a) - (c) (for β). These coefficients quantify the effects of non-uniform velocity distribution and are critical for correcting theoretical energy and momentum flux calculations.

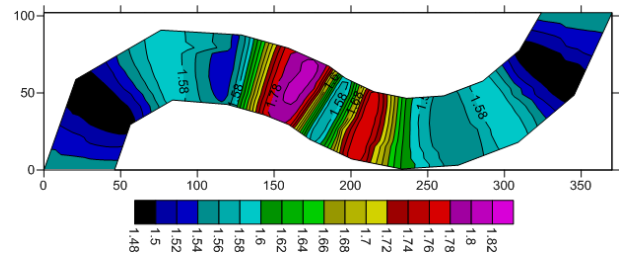
Starting with the rough channel case (R1), Figure 3 (a) displays the α -contour, which shows moderate values, peaking around 1.6. The lower values of α in this scenario are consistent with the energy-dissipative effect of the rough boundary, which distributes energy more uniformly across the cross-section and suppresses velocity extremes. Similarly, in the smooth

channel at lower discharge (S1), shown in Figure 3 (b), α increases slightly, reaching up to 1.8. This rise can be attributed to reduced wall friction and sharper velocity gradients near the channel walls, especially as flow remains more centrally focused.

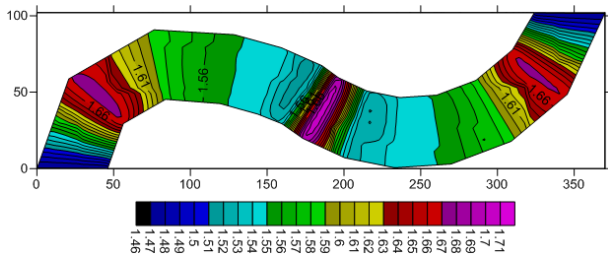
In contrast, Figure 3 (c) (for S2) and Figure 3 (d) (for S3) demonstrate a significant increase in α values under higher discharge conditions. In these cases, α reaches a maximum of approximately 2.2, especially in regions near the crossover and downstream of the bend apex. These high values are indicative of intense turbulence, increased lateral momentum exchange, and secondary current effects. The broad high- α zones in these figures reflect the expansion of high-velocity gradients caused by stronger inertial forces and curvature-induced flow asymmetry.



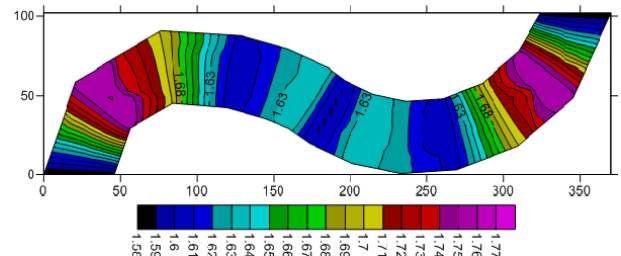
(a) Kinetic energy coefficient across R1



(b) Kinetic energy coefficient across S1

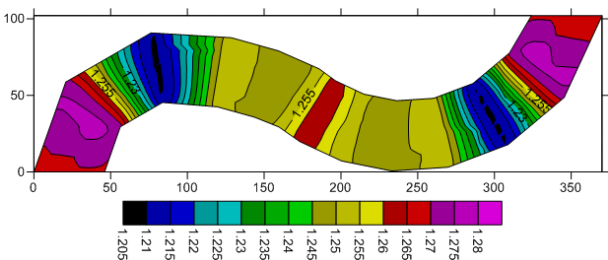


(c) Kinetic energy coefficient across S2

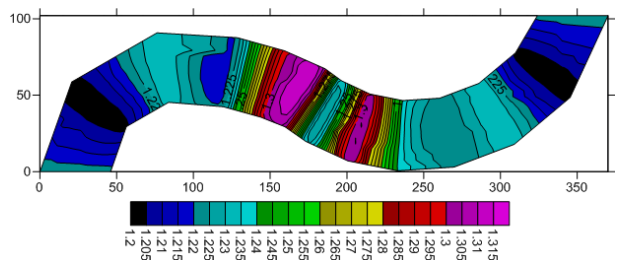


(d) Kinetic energy coefficient across S3

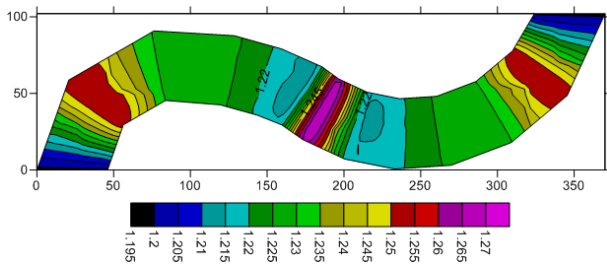
Figure 3: Kinetic energy coefficient across the meander path



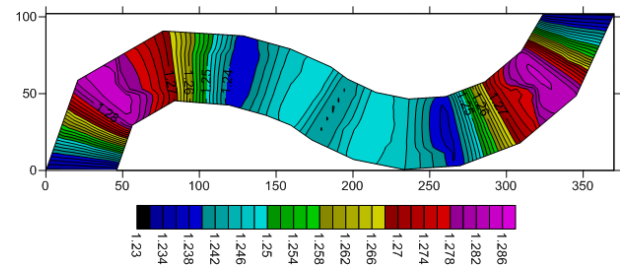
(a) Momentum correction coefficient for R1



(b) Momentum correction coefficient for S1



(c) Momentum correction coefficient for S2



(d) Momentum correction coefficient for S3

Figure 4: Momentum correction coefficient across the meander path

The contour maps for both α and β across all flow cases consistently show that the highest correction factors are located near the crossover zones and just downstream of the bend apexes locations, where secondary flows are most pronounced due to flow convergence, separation, and curvature-induced acceleration. Meanwhile, the lowest values are typically seen at the bend apexes themselves, where the flow undergoes stagnation or directional shift. This spatial trend reinforces the role of channel planform geometry and boundary characteristics in influencing the distribution of energy and momentum.

The study reveals that smooth channel surfaces coupled with higher discharges yield significantly greater values of α and β due to stronger flow gradients and increased turbulence. While still exhibiting variation, rough channels tend to moderate these extremes due to enhanced boundary layer development and energy dissipation. These findings underscore the necessity of incorporating correction coefficients in hydraulic modelling of meandering channels to improve the accuracy of energy and momentum-based flow predictions.

5 CONCLUSION

The experimental investigation of energy and momentum correction coefficients in a meandering channel reveals a clear relationship between flow behaviour, surface roughness, discharge, and channel geometry. The velocity distribution patterns observed from the depth-averaged velocity contours indicate that maximum velocities generally occur near the outer banks of bends due to centrifugal effects, with a pronounced lateral spread at crossover sections where flow realignment takes place. The influence of bed roughness is evident in the reduced velocity peaks and more uniform energy distribution in the rough channel, whereas the smooth channel, especially under higher discharges, exhibits higher velocity gradients and expanded high-energy zones. This, in turn, leads to increased values of both the kinetic

energy correction coefficient (α) and the momentum correction coefficient (β). Notably, the highest values of α and β are concentrated around crossover zones and the regions immediately downstream of bend apexes, highlighting the role of secondary circulation and turbulence in enhancing energy and momentum flux. Conversely, the lowest values are recorded at the bend apexes where flow stagnation and redirection occur. The results emphasize that the coefficients α and β increase with flow depth and discharge, and their magnitudes are significantly influenced by channel roughness and curvature. These findings underscore the necessity of applying appropriate correction factors in hydraulic computations for meandering channels, particularly in scenarios involving complex flow structures and varying boundary conditions, to ensure more accurate modelling of energy and momentum exchanges.

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