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FLOW MEASUREMENT AROUND DIFFERENT TYPES OF BRIDGE PIERS USING ACOUSTIC DOPPLER VELOCIMETER (ADV)

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Highlights

- Placement of bridge piers as single axis and double axis
- Effect of bridge piers of different geometries on the flow field
- Investigation of the effect of size change in bridge piers on the flow field in equal net flow length
- Consistency of Yarnell's equation

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ABSTRACT: The effective management of water resources is a critical global objective, necessitating the construction of hydraulic structures to mitigate the adverse effects of water and ensure its efficient use. Among these, bridges are prominent engineering solutions. The presence of bridge piers, however, inherently alters the natural flow structure, creating complex hydrodynamic interactions. Consequently, a central challenge in hydraulic engineering is to determine the most suitable pier type and configuration that minimizes these disturbances for a given stream regime. To address this challenge, the present study conducts a systematic investigation through controlled laboratory experiments, comparing bridge piers of varying geometries and sizes under consistent hydraulic conditions. The results demonstrate that both the geometry and configuration of the piers significantly influence the flow structure, even when the net flow passage width is held constant.

Keywords: *ADV, Bridge Piers, Physical Model, Velocity Distribution*

1. INTRODUCTION

Water resources are influenced by factors such as population growth, pollution, and global warming. As a result of this interaction, studies are being conducted on managing existing water resources, protecting against water damage, and using water more effectively. Various engineering structures are built to serve this purpose. One of these structures is bridges built over rivers and open channels. Bridge crossings generally interfere with the natural flow of the current. A bridge constructed over an open channel narrows the channel's cross-section and obstructs the flow. At this point, energy loss occurs, and the flow width narrows as it passes through the bridge, then returns to its original width. To balance the energy loss, the upstream water level rises to a higher level compared to the normal condition. This additional rise is referred to as backwater height (Δh) [1], [2], [3].

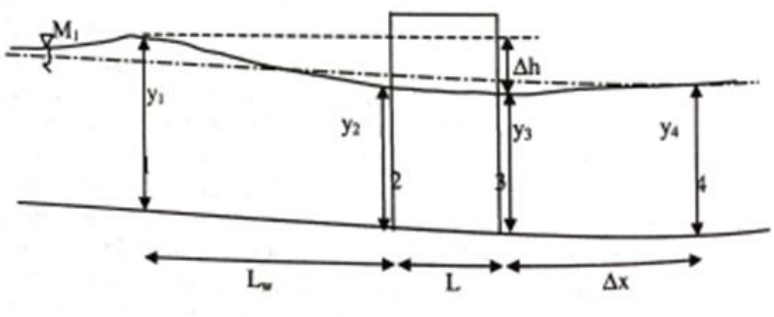

Figure 1. Schematic of the backwater effect (Δh) caused by a bridge pier

In Figure 1, where the backwater phenomenon occurs, the water level difference between cross-sections 1 and 3 is denoted as Δh. The water level difference in these two sections depends on the constriction coefficient and the geometrical characteristics of the piers. For a rectangular river cross-

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section, the contraction coefficient (┌) is defined as ┌ = b_2/b_1, where b_1 and b_2 represent the clear widths at cross-sections 1 and 2, respectively. Yarnell [4] expressed Δh as follows:

$$\frac{\Delta h}{y_3} = kF_{r_3}^2\left(k + 5F_{r_3}^2 - 0.6\right)\left(m + 15m^4\right) \quad (2.1)$$

The parameters are defined as follows:

y_3: water depth at cross-section 3 (downstream flow depth)

k : Yarnell's pier shape coefficient

F_{r_3} : Froude number at section 3

m : 1- ┌

In hydraulic analyses involving bridge structures, it is typically necessary to estimate bridge-induced water level variations, examine the flow modifications around bridge piers, and assess their potential impacts. Some of the studies conducted in this context are as follows. Yarnell [4] studied the effect of pier geometry and maximum scour depth. He developed one of the methods used to determine the amount of surge and velocity. It is the first study on pier shape. Barbhuiya and Dey [5] experimentally investigated the three-dimensional turbulent flow field around a rectangular-shaped pier positioned on the channel wall in a rectangular channel. In this study, they determined values of time-dependent velocity, turbulence intensity, turbulent kinetic energy, and stress. Seçkin and Atabay [6] aim to analyze the effect of backwater created by bridges on the flow field and compare the performances of different calculation methods (energy method, momentum method, WSPRO method, Yarnell's method, USBPR method, and arch bridge method) with experimental data. Seçilir [7] investigated the effects of bridge structures on the water surface profile through experiments. Experiments were conducted on four different bridge spans in rectangular, circular, elliptical sections with two different roughnesses (16 different flow conditions for each roughness). As a result, it was determined that the maximum swell height could be calculated with a polynomial approach in polished and rough flow conditions in rectangular section bridges and in this case, the correlation coefficient was relatively high. It was observed that Biery and Delleur methods gave more accurate results in both flow conditions in elliptical section bridges, and approximately the same accuracy in circular section bridges. Fayyadh et al. [8] modeled a skewed bridge using the finite element method for different flow velocities. The primary purpose of their study was to examine the effect of flow velocities on scour depths at bridge piers. From the experimental and numerical comparison of maximum scour depths, they noted that the results around bridge piers showed inconsistencies due to the hydrodynamic flow structure and movable scour occurring in the experiments. Demirci et al. [9] conducted three-dimensional numerical modeling using the FLOW-3D computer program to examine the velocity distribution in the x-direction around bridge abutments with rectangular, cylindrical, and trapezoidal geometries. They found that the

flow velocities were well represented in the numerical solutions obtained from the modeling and that the FLOW-3D results were larger than previously obtained experimental results. Ismael et al. [10] examined the effect of changing the position of bridge piers relative to the flow direction on scour reduction. In this study, three different bridge piers (circular pier, upstream-facing round-nosed pier, and downstream-facing round-nosed pier) were tested under live bed conditions at a flow rate of 58 l/s for 3 hours. Velocity measurements were made using an Acoustic Doppler Velocimeter (ADV). As a result, it was determined that the round-nosed pier facing opposite to the flow reduced local scour. Jalal and Hassan [11] aim to investigate the effects of bridge pier shape on local scour depth to identify an optimal hydraulic design for minimum scour. They utilize a computational fluid dynamics (CFD) model, Flow-3D, to simulate scour processes around various pier shapes (circular, rectangular, square, octagonal, elliptic, and lenticular) under clear-water conditions and validate the model against experimental data. The study reveals that the rectangular pier shape produces the maximum scour depth, whereas the lenticular shape results in the minimum depth, reducing it by approximately 40% compared to other shapes. Gargari [12] examined the flow structure of bridge piers with different cross-sectional shapes under variable flow conditions. Using an ADV, the flow velocity and turbulence characteristics around the bridge piers were extensively measured in both vertical and horizontal planes. As a result of the study, it was determined that extended cross-section bridge piers could offer a safer design compared to circular sections under variable flow conditions. Rastello et al. [13] compare two fundamental velocity measurement devices, the ADV and the Laser Doppler Anemometer (LDA), in a narrow open channel flow. This study has three main objectives: to investigate the 'intrusion effect' of the ADV probe on the flow, to demonstrate whether this effect is dependent on the Froude (Fr) number, and to compare the measurements from the two devices. Yıldız et al. [14], investigated the flow patterns and velocity field on the upstream side of two spurs which are placed opposite each other on both sides of the open channel, using experimental and numerical approaches. While experimental measurements were carried out using ADV, ANSYS Fluent software was used for numerical modeling. The study emphasizes that, unlike single-sided spur configurations in the literature, the hydraulic behavior of opposing spurs is significantly different. Furthermore, it has been confirmed that the velocity data obtained from the numerical model are in high agreement with experimental measurements.

Previous studies have extensively investigated the effects of single or single-row bridge piers on flow characteristics (e.g., Yarnell, 1934; Barbhuiya and Dey, 2004; Gargari, 2021). However, despite these advancements, a significant gap remains in the literature concerning the comparative hydrodynamic performance of single-axis versus double-axis pier configurations, particularly when the net flow blockage is held constant. Specifically, a systematic experimental investigation comparing how different geometric configurations (square and circular) behave under identical hydraulic conditions while maintaining a constant net flow width is lacking.

This study aims to fill this lacuna by experimentally investigating the combined effects of pier geometry, number, and alignment (single-axis and double-axis) on flow velocity distributions and backwater heights. The primary novelty of this research lies in its systematic evaluation of eight different pier configurations while maintaining an equal net flow width, thereby isolating the influence of the geometric arrangement on the flow field. Therefore, the main objective is to determine which configuration offers the most favorable hydraulic performance, providing valuable insights for the optimal design of bridge pier systems.

2. MATERIAL AND METHODS

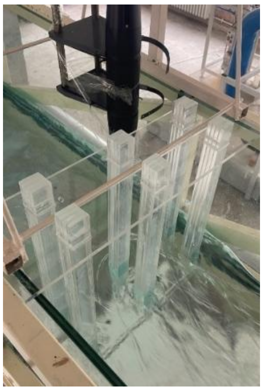
2.1. Experimental Setup

Physical models are considered simulations of structures to be built in reality and thus form an important part of the studies.

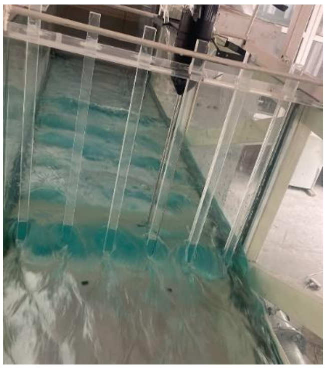
The physical model experiments were conducted in a 6.5 m long, 0.6 m wide, and 0.5 m deep flume at the Hydraulics Laboratory of Konya Technical University, with scale effects being neglected. Initially, the flow conditions were investigated without the piers to establish a baseline. Then, square and circular piers with dimensions of b = 2 cm and b = 4 cm were placed in single-axis and double-axis configurations in the channel, and experimental setups were created.

Figure 2 presents the general views of the experimental setups with smooth-surface square and circular bridge piers positioned in single-axis and double-axis configurations.

Three bridge piers of square geometry placed along a single axis (Model 1)

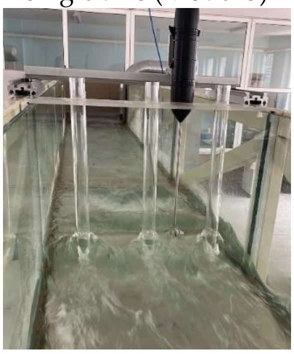


Three bridge piers of square geometry placed along a double axis (Model 2)

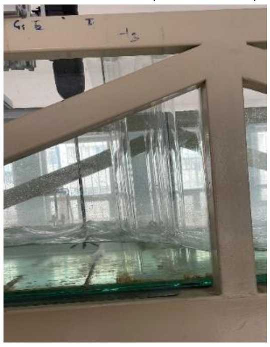


Six bridge piers of square geometry placed along a single axis (Model 3)

Six bridge piers of square geometry placed along a double axis (Model 4)



Three bridge piers of circular geometry placed along a single axis (Model 5)



Three bridge piers of circular geometry placed along a double axis (Model 6)

Six bridge piers of circular geometry placed along a single axis (Model 7)

Six bridge piers of circular geometry placed along a double axis (Model 8)

Figure 2. General view of the experimental setup

2.2. Experimental Procedure

The experimental procedure was conducted in a laboratory flume where flow was initiated from a reservoir and regulated by a frequency converter control panel to achieve four distinct discharge values. For these four discharges, which were monitored with a flowmeter, velocity distributions were measured using an ADV, with the general setup illustrated in Figure 3. The accuracy of the ADV is specified as ±0.5% by the manufacturer. ADV devices measure the velocity of water based on a physical principle called the Doppler Effect. The Doppler Effect is the change in the frequency of a sound wave when a wave source moves relative to the observer or vice versa. The ADV measures velocity by transmitting a pair of short sound pulses at a specific frequency into the water column. A portion of the sound wave is reflected back to the device; the detected return signal is then processed by the device to determine the water's speed. The measurement volume is defined by the intersection of the three curved receivers and the central transmitter. The measured velocity values are recorded from this point, specifically from within the measurement volume [14].

To characterize the flow field on the upstream side, velocity profiles were measured along the z-axis at distances of 7.5 cm, 15 cm, and 22.5 cm from the piers. These measurements were taken at a height of 6.5 cm above the channel bed. To avoid sidewall effects, measurement points were positioned away from the sidewalls, encompassing 15 points for three-pier systems and 27 points for six-pier systems (Figure 4). Each measurement was recorded for a duration of 180 seconds to adequately capture the turbulent fluctuations.

Although the ADV can capture three-dimensional velocity components, this study presents a detailed analysis of the streamwise (x-direction) velocity component. This focus is justified as the streamwise velocity is the primary determinant of backwater rise and overall flow conveyance, the central objectives of this investigation. A comprehensive analysis of secondary flow structures and turbulence characteristics, utilizing the transverse and vertical components, is reserved for a future study.

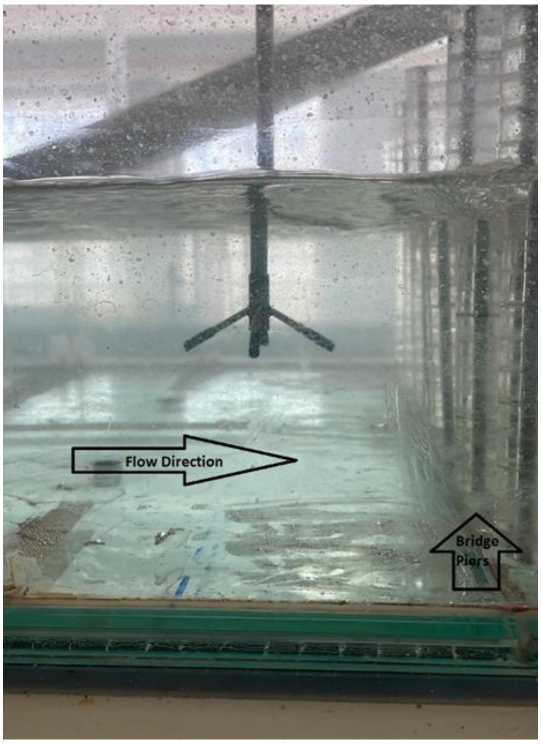


Figure 3. Typical ADV Setup

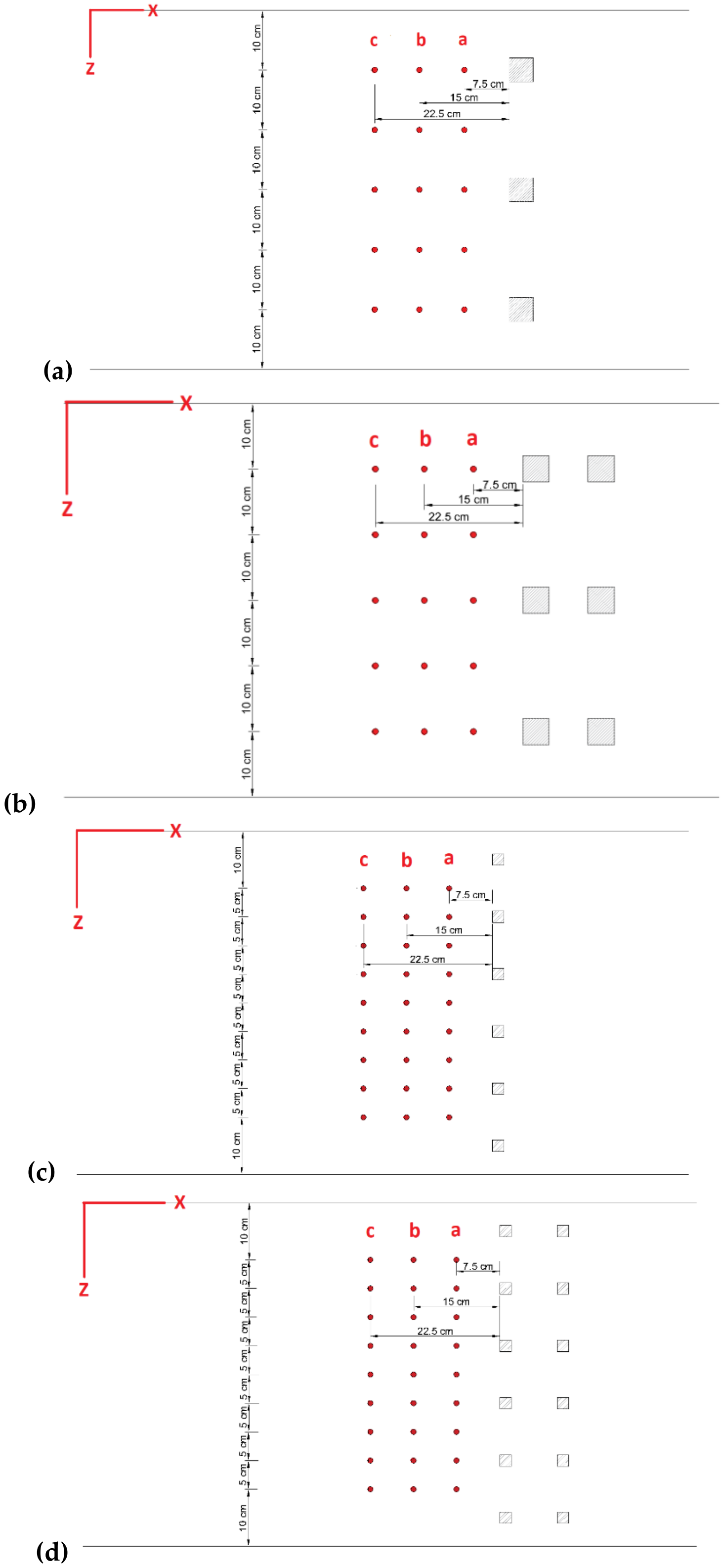


Figure 4. Coordinate system which shows measurement points. **a.** Three Single-Axis Bridge Pier Configurations. **b.** Three Double-Axis Bridge Pier Configurations. **c.** Six Single-Axis Bridge Pier Configurations. **d.** Six Double-Axis Bridge Pier Configurations

3. RESULTS AND DISCUSSION

In this study, firstly, the effect of the presence of the piers on the backwater height was investigated by measuring the water height values approximately 10 cm before the piers, first in the empty channel and then in the systems where the piers were placed, with the help of a limnimeter. Then, in order to investigate the effect of bridge piers with different geometries on flow, velocity measurements were recorded with ADV at five different points in systems with three piers along the z-axis (channel width) and at nine different points in systems with six piers. Measurements were repeated at distances of 7.5 cm (a-axis), 15 cm (b-axis), and 22.5 cm (c-axis) upstream of the piers. Measurements were conducted along three defined axes (a, b, c) for each of the four different flow rates obtained via the frequency converter control panel, and the behavioral changes of the same systems in different geometries were analyzed.

While measuring the water height value in the current state where the bridge piers are present, due to the fluctuation phenomenon caused by the presence of the piers, two different measurement values (the values of the high and low points of the wave) were obtained at the point determined for measurement and the average of these two values was taken.

The experimental results of the effect of the presence of bridge piers (Model 1-Model 8) on backwater formation compared to the empty channel (Model 0) are shown in Figure 5.

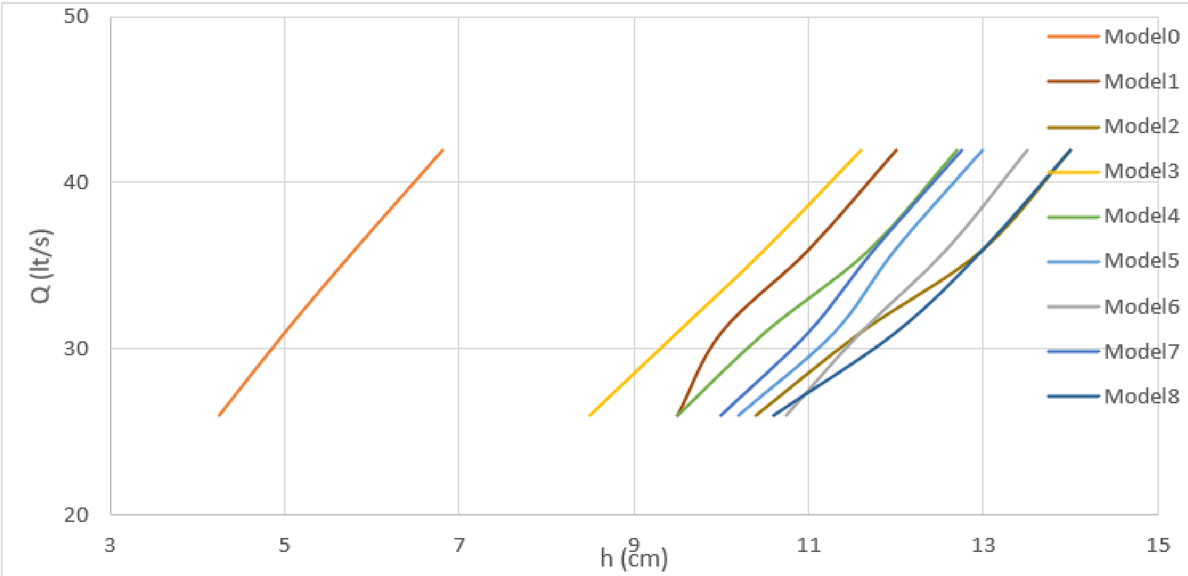


Figure 5. The effect of different pier sizes on backwater

As observed in Figure 4, when the net flow area inside the channel decreases due to the presence of piers, it was determined that, for the same discharge values, the measured water height values in the flow section with piers were higher compared to the empty channel. The validity of this change was tested using the Yarnell equation, and sample solutions were presented for one discharge value in each of the two different geometries to serve as an illustrative example. It was found that the water height values before and after the piers expressed in Yarnell's equation (Figure 1) (Δh=y1-y3) were in agreement with the results obtained from the experiment.

The value of Yarnell's pier coefficient was used as 1.25 for square piers and 0.90 for circular piers in this experimental study [4], [3].

For the purpose of validating the experimental backwater measurements, a comparison was made against values derived from the empirical Yarnell equation. Representative cases from each pier geometry—Model 1 (there square piers) and Model 6 (six circular piers)—were selected for this validation. As detailed in Table 1, the calculations demonstrate a satisfactory agreement between the experimental values and the predictions from the Yarnell equation. This strong correlation for the representative cases provides confidence in the overall validity and accuracy of the experimental measurements across all tested configurations.

Table 1. Comparison of Yarnell equation and experimental results

	k	Fr	m	y_1	Yarnell y_3	Lim. y_3
Model 1	1.25	0.61	0.2	9.50	7.53	7.60
Model 6	0.90	0.73	0.2	11.60	8.80	8.20

The graphs presented below show single-axis systems with square and circular geometries on the left and double-axis systems on the right (Figures 6-9.). It was generally observed that in single-axis systems containing both three and six piers, the velocity values in square piers were higher than those in circular piers. This situation can be explained by the square geometry posing a greater obstruction to the flow and creating a larger blockage effect at its front part. The flow separation at the sharp corners of the square pier, leading to high-pressure zones in front of the pier and acceleration along its sides. In double-axis systems, except for the Q1 discharge value, the velocity values in the flow condition with circular piers were higher for other discharge values. In measurements made upstream of the piers (a, b, c axes), it was observed that fluctuations in velocities decreased as the distance from the piers increased. In flow conditions with square piers, fluctuations in measurements along the z-axis were greater compared to systems with circular piers. This situation was evaluated as a specific effect of the geometry on the flow.

When the measurements taken at the midpoint of the channel were compared across all systems, it was observed that in systems with square-shaped piers, the velocity values in double-axis systems were generally lower than those in single-axis systems. However, in systems with circular piers, the opposite was observed (Figure 10). This can be attributed to the fact that the double-axis arrangement of square piers constricts the flow more complexly than single-axis arrangements, leading to additional turbulence generation. This situation, by increasing the total energy loss, can cause a loss of momentum and consequently a reduction in the observed velocity values. While, the phenomenon for circular piers can be attributed to the double-axis configuration guiding the flow with less turbulence and causing local accelerations in the passages between the piers.

Upon examining the axis-based measurements conducted at the midpoint of the channel, it was determined that velocity values exhibited a negligible increase as the distance from the piers increased (The corresponding graph for the Q3 discharge value is presented in Figure 11). This indicates that the local turbulence caused by bridge piers gradually dissipates as it propagates downstream, and the flow returns to a more organized and stable state. The smoother velocity profiles observed at greater distances suggest that the flow approaches the general characteristics of the channel.

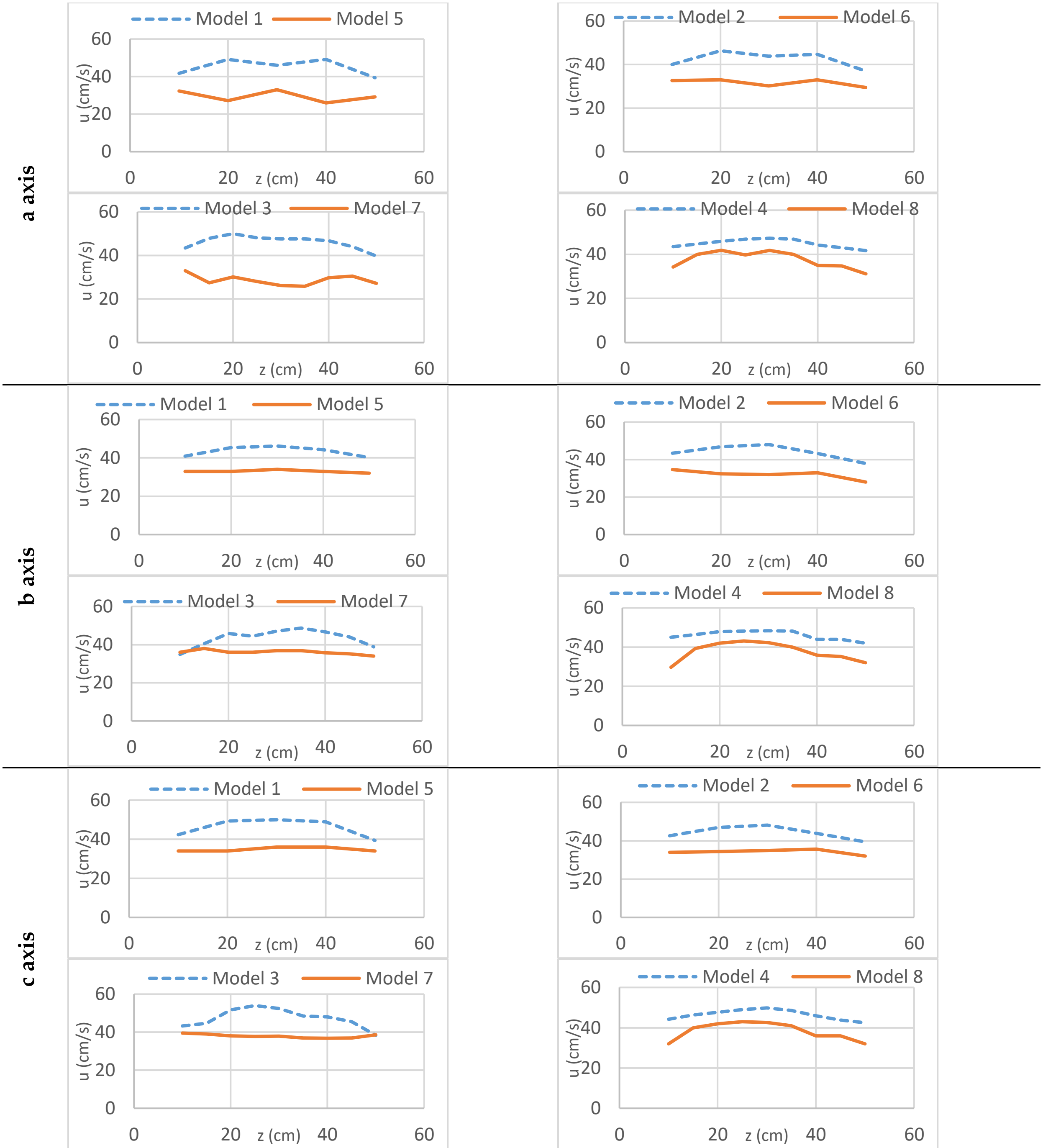


Figure 6. Current velocity values along the channel width (Q1)

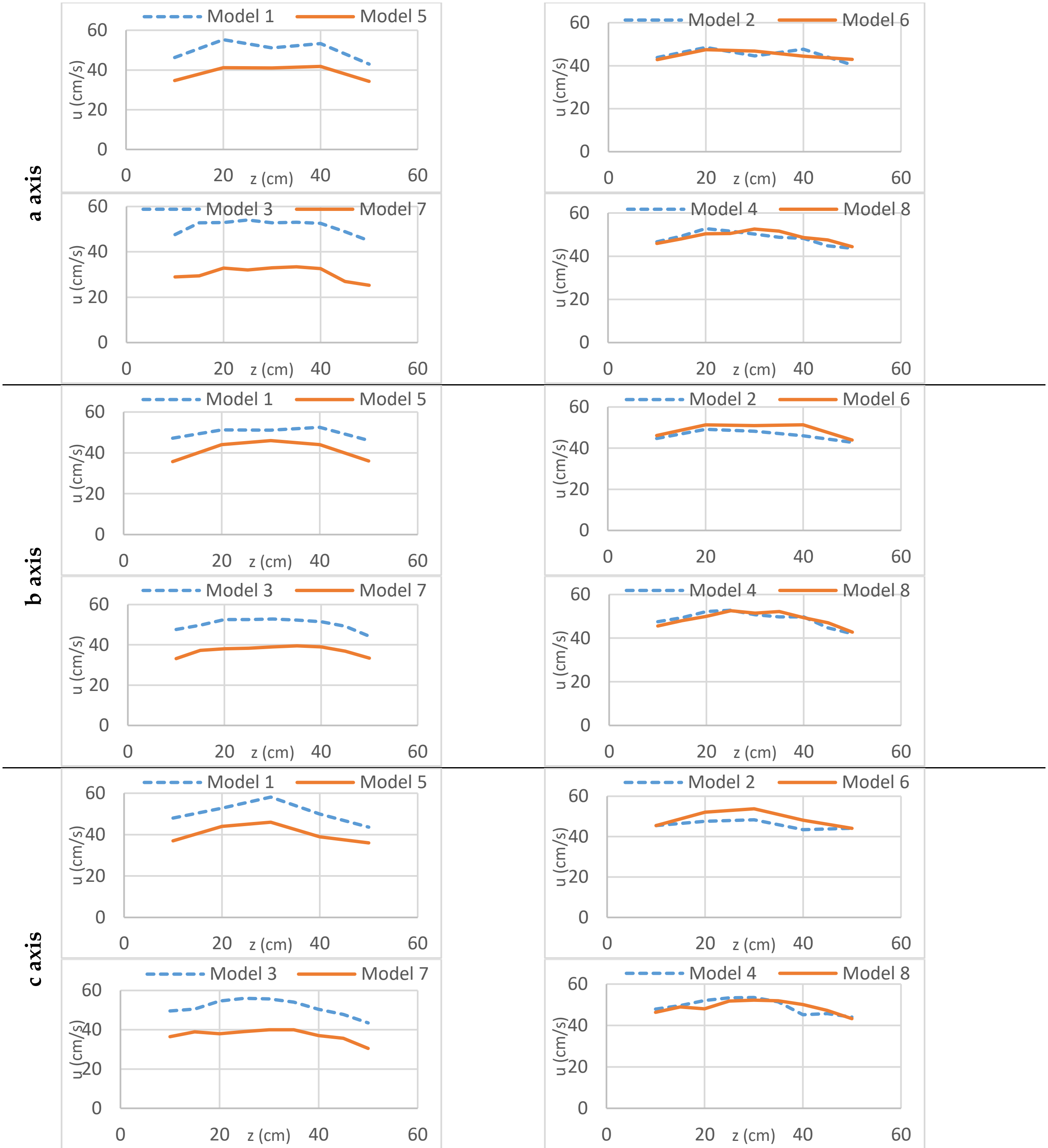


Figure 7. Current velocity values along the channel width (Q2)

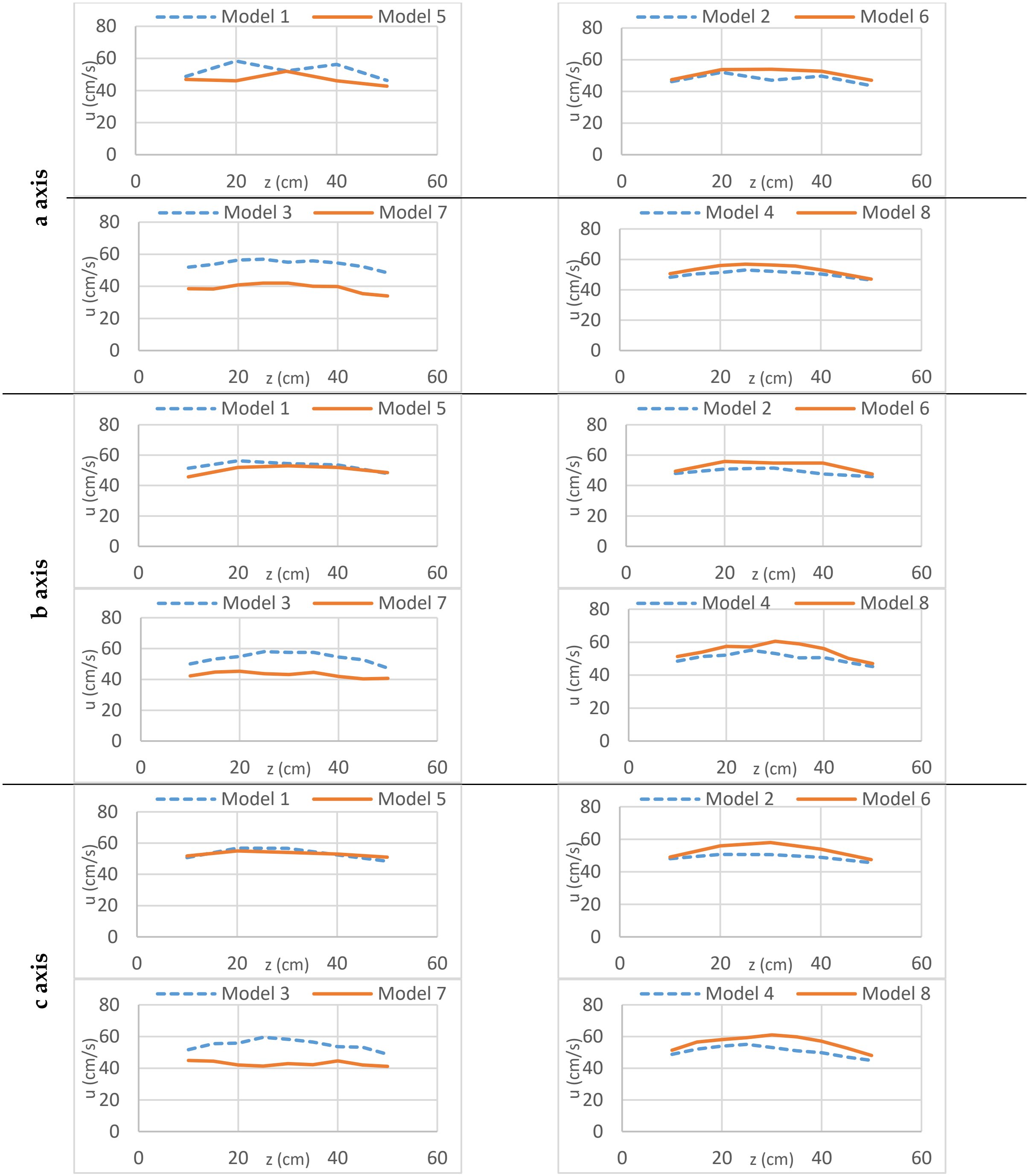


Figure 8. Current velocity values along the channel width (Q3)

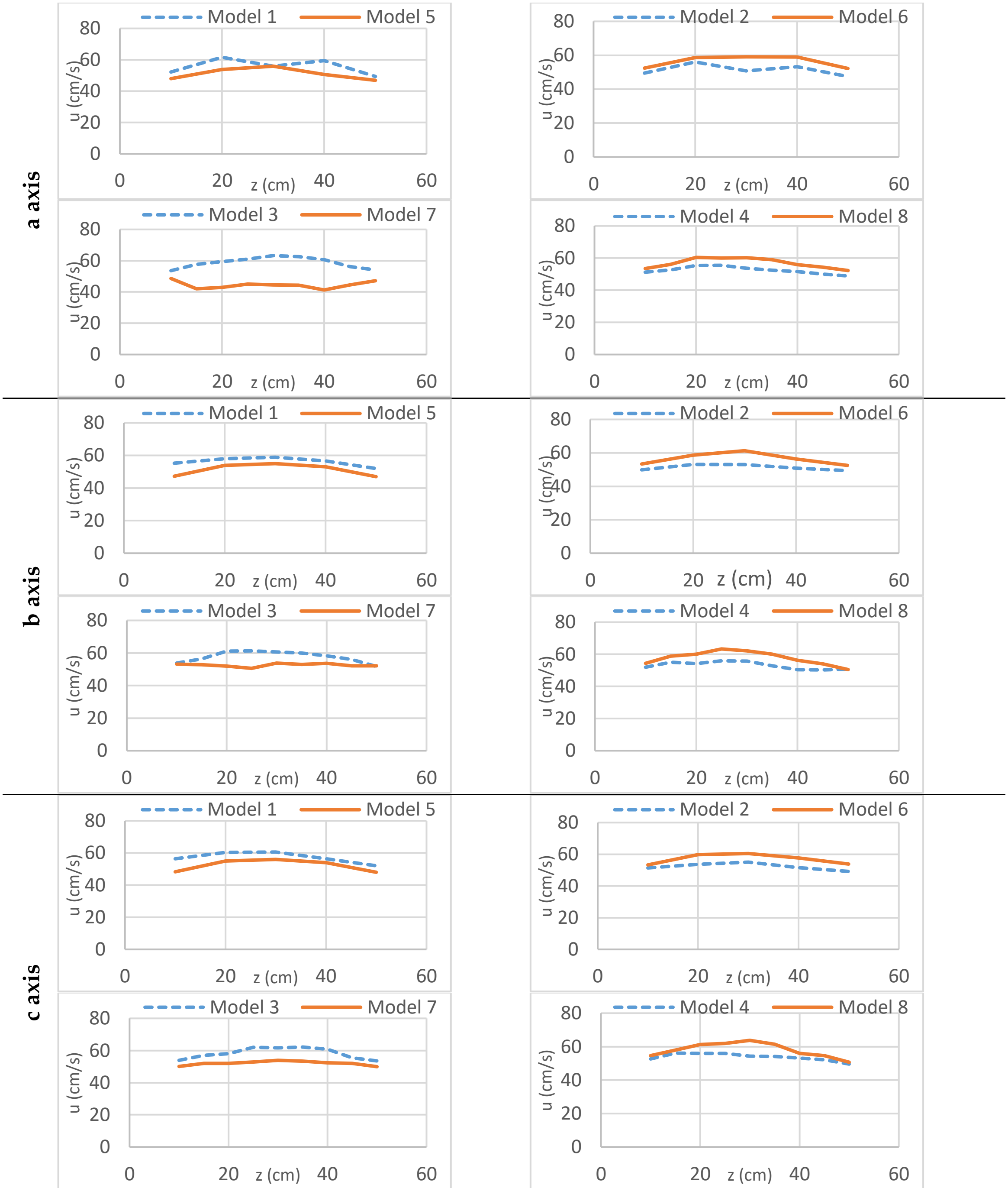


Figure 9. Current velocity values along the channel width (Q4)

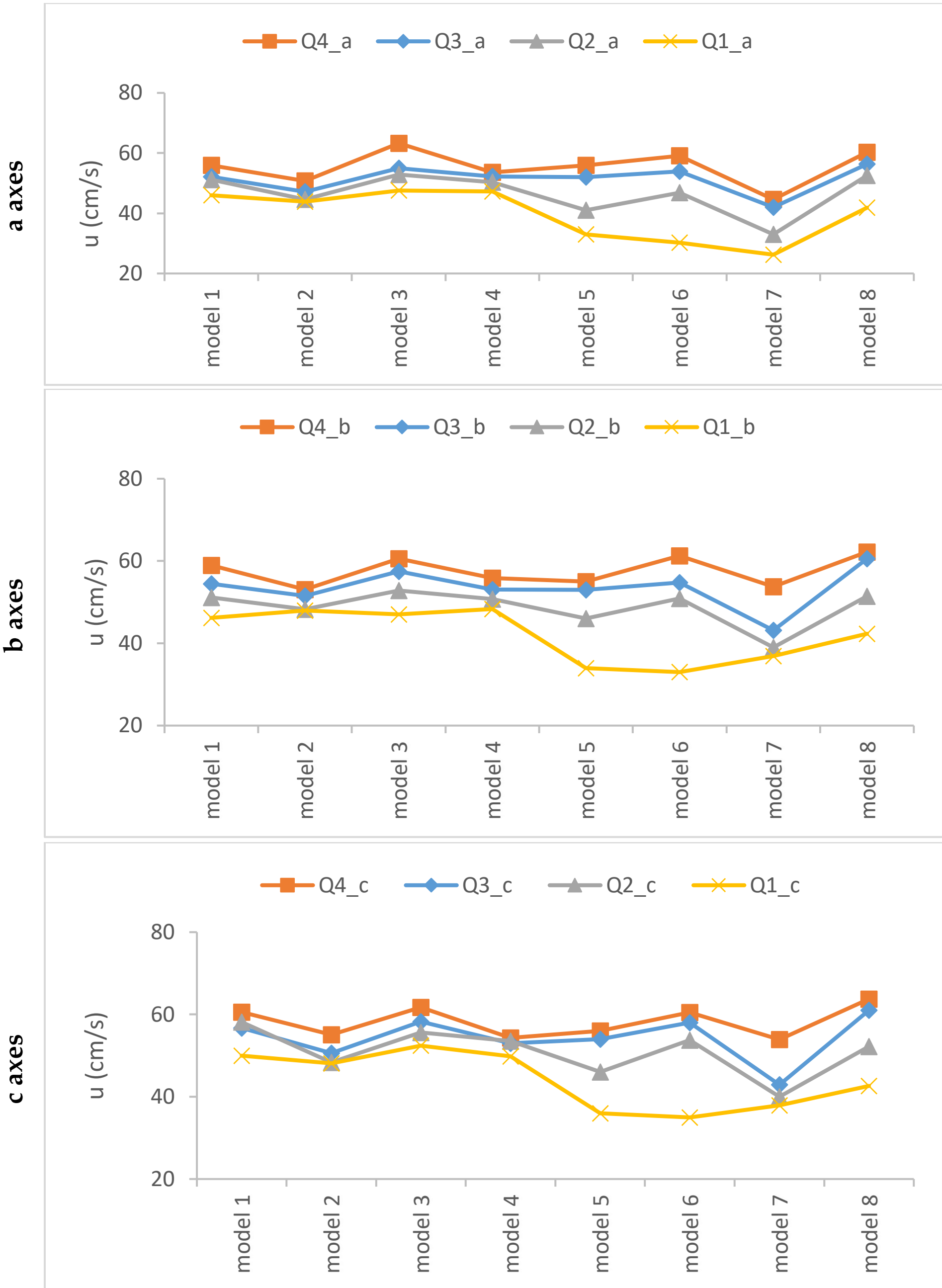


Figure 10. Increased flow rate

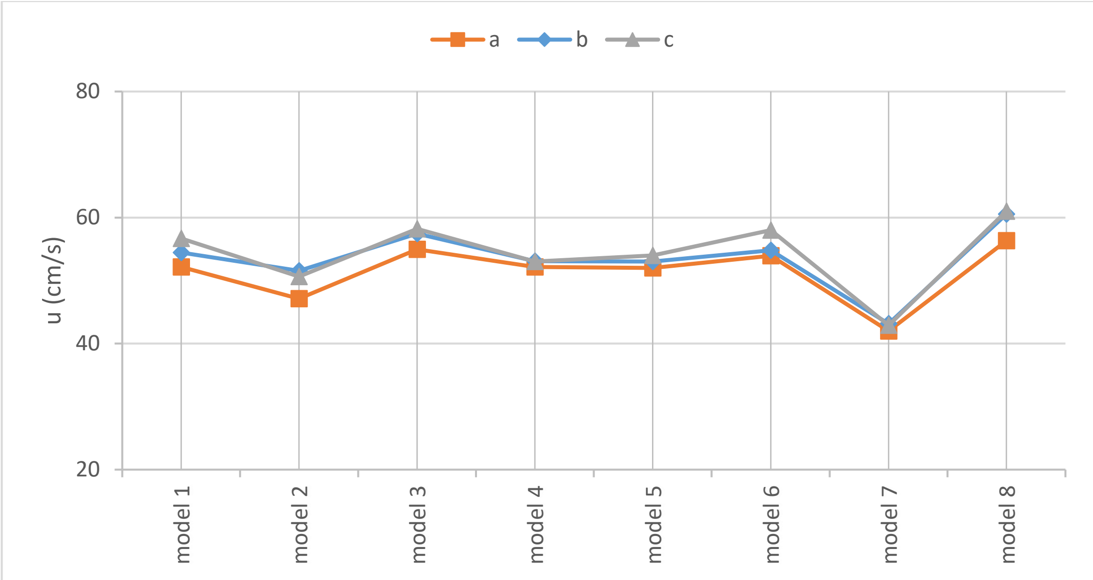


Figure 11. Changing axis status

4. CONCLUSIONS

Unlike previous research focusing on single-pier systems, this study demonstrated that the interaction effects in multi-pier, double-axis systems lead to significantly different flow patterns. By maintaining a constant net flow passage, this investigation isolated the effects of pier geometry and spatial arrangement. Specifically, two configurations were identified as having lower flow velocities compared to the other systems tested: the double-axis system with three square piers and the single-axis system with six circular piers. Furthermore, velocity fluctuations along the z-axis were more pronounced for square piers than for circular piers, highlighting the significant influence of pier geometry on flow turbulence.

The practical implications of these findings are significant for hydraulic engineering. The finding that single-axis arrangements of six circular piers induced lower flow velocities suggests this configuration may be preferable in river environments sensitive to erosion. Conversely, the higher conveyance efficiency of other arrangements could be beneficial in flood management scenarios where maximizing flow through the bridge crossing is critical.

For future work, it is recommended that these physical models be supported by numerical solutions that account for the measurement uncertainty of the ADV. The findings of this study are expected to provide a valuable dataset for the validation of such numerical models and contribute to the development of more refined hydraulic design guidelines.

Declaration of Ethical Standards

The authors declare that they followed all ethical guidelines including authorship, citation, data reporting, and publishing original research.

Credit Authorship Contribution Statement

G. E. YARBAŞI KAYHANLAR: Conceptualization, methodology, validation, formal analysis and investigation, writing-original draft preparation, writing-review and editing.

A. YARAR: Conceptualization, writing-review and editing, funding acquisition, resources, supervision.

Declaration of Competing Interest

The authors declare that they have no financial conflicts of interest or personal relationships that could have influenced the work presented in this manuscript.

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Data Availability

Data available on request from the authors.

REFERENCES

[1] A.M. Yanmaz, "Bridge Hydraulics, " in Metu Press, vol 1, Ankara, Türkiye, pp. 99-106, 2002.
[2] A. M. Celik, "Experimental and Numerical Investigation of the Effect of Bridge Piers on Water Surface Profile, " Graduate School of Natural and Applied Sciences M.S. Thesis, Erciyes University, Kayseri, Türkiye, 2020.
[3] K. El-Alfy, "Backwater rise due to flow constriction by bridge piers," Thirteenth International Water Technology Conference, 13, pp. 1295-1313, 2009.
[4] D.L. Yarnell, "Bridge piers as channel obstructions, " U.S. Department of Agriculture, Tech. Bull. No. 442, Washington, 1934.
[5] A. K. Barbhuiya, S., Dey, "Turbulent Flow Measurement by the ADV in the Vicinity of a Rectangular Cross-section Cylinder Placed at a Channel Sidewall, " Flow Measurement and Instrumentation, vol. 15, pp. 221 – 237, 2004.
[6] G. Seçkin, S. Atabay, "Experimental backwater analysis around bridge waterways, "Canadian Journal of Civil Engineering, vol. 32, no. 6, pp. 1015-1029, 2005.
[7] S. Seçilir, "Effect of the bridges with various cross-section on the backwater profile on rivers, " Institute of Science and Technology M.S. Thesis, Erciyes University, Kayseri, Türkiye, 2005.
[8] M. Fayyadh, S. Akib, I. Othman, and H. A. Razak, "Experimental investigation and finite element modelling of the effects of flow velocities on a skewed integral bridge, " Simulation Modelling Practice and Theory, 19(9) pp. 1795-1810, 2011.
[9] M. Demirci, S. Kocaman, and B. Varli, "Numerical investigation of velocity distribution around bridge abutment with different geometries, " Erciyes University Journal of Science and Technology, Kayseri, Türkiye, 2012.
[10] A. Ismael, M. Gunal, and H. Hussein, "Effect of bridge pier position on scour reduction according to flow direction, " Arabian Journal for Science and Engineering, 40, pp. 1579-1590, 2015.
[11] H. K. Jalal and W. H. Hassan, "Effect of Bridge Pier Shape on Depth of Scour," IOP Conf. Ser.: Mater. Sci. Eng., vol. 671, Art. no. 012001, 2020.
[12] M. K. Gargari, "Experimental study on interaction of unsteady flow with bridge piers with different cross sections, " Ph.D. Thesıs, Istanbul Technıcal Unıversıty, Istanbul, Türkiye, 2021.
[13] M. Rastello et al., "Velocity measurements in developing narrow open-channel flows with high free-stream turbulence: Acoustic Doppler Velocimetry (ADV) vs Laser Doppler Anemometry (LDA)," Flow Meas. Instrum., vol. 86, Art. no. 102737, Aug. 2022.
[14] A. Yıldız, A. Yarar, M. A. Hınıs, and G. E. Y. Kayhanlar, "Experimental and numerical investigation of flow patterns in symmetrical spurs," J. Comput. Appl. Mech., vol. 54, no. 3, pp. 425-436, 2023.