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INVESTIGATION OF FLOW REFORMATION AND DEFORMATION PROCESSES IN THE JUNCTION ZONE OF TWO OPEN CHANNELS AT DIFFERENT ANGLES

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Abstract

The hydrodynamic characteristics and channel bed deformation in the confluence zone of two alluvial open channels at different junction angles were studied using laboratory experiments, theoretical modeling, and field observations at the Mirishkor irrigation canal in Uzbekistan. The formation and dimensions of the main flow zones (stagnation, shear layer, separation, recirculation, and recovery) were identified. The results show that the size of the recirculation zone at different angles is approximately 20–30% smaller compared to larger angles, and the flow recovers more rapidly. For vortex-free zones, the potential flow theory and conformal mapping method were applied to determine the streamlines boundaries. Improved empirical equations were developed for the parameters of the recirculation zone, velocity distribution, and bed sediment transport as functions of the junction angle θ and discharge ratio Qr. Hydraulic calculation algorithms that account for vortex effects improved prediction accuracy and enabled an increase in channel conveyance capacity by 5–8% in practical applications. These findings provide practical tools for reducing deformations in irrigation networks.

Keywords

open channel confluence, different angles, flow reformation, recirculation zone, sediment transport, potential flow modeling, hydraulic algorithms

Introduction

The confluence zone in open channels is a critical area where complex three-dimensional hydrodynamic processes occur as a result of the tributary flow joining the main channel. These processes lead to channel bed and bank deformation, sediment deposition, and a reduction in conveyance capacity in alluvial channels.

Numerous studies have primarily focused on 90° confluences, where the junction angle has been found to strongly influence the size of the separation zone and the intensity of turbulence. Lower angles allow flows to align more parallel, thereby reducing adverse effects. However, acute angles of various magnitudes remain insufficiently investigated.

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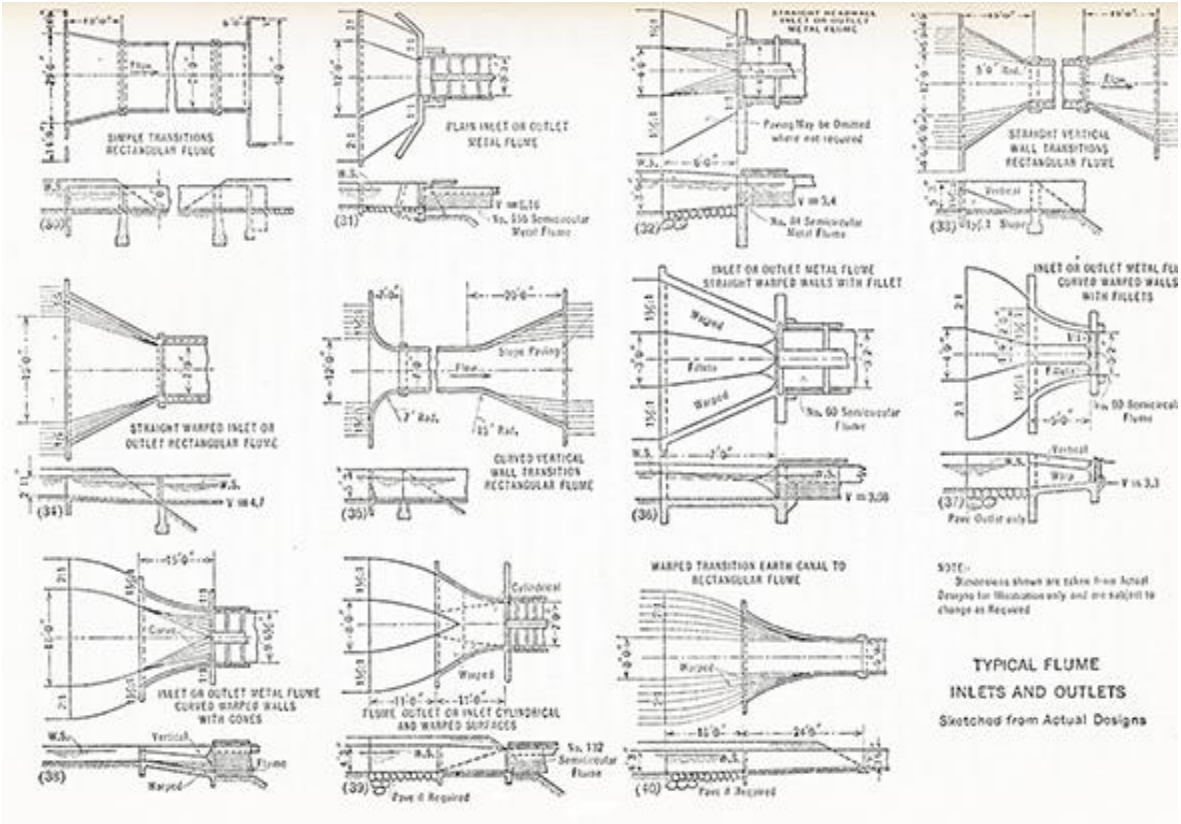

Figure 1. Schematic view of the open channel confluence (with angle).

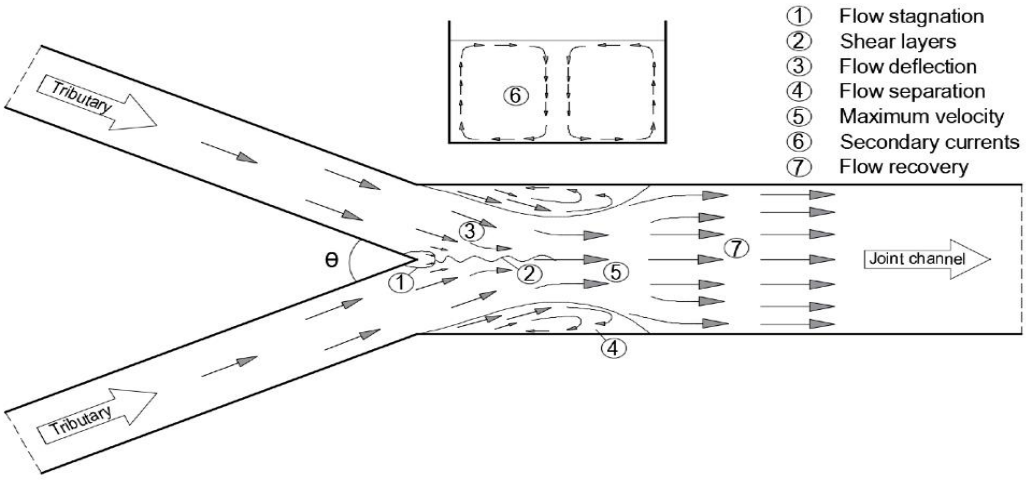

Figure 2. Hydrodynamic zones in the confluence area: separation zone and recirculation zone.

This study examines different conditions through extensive experimental and theoretical work covering 30°, 45°, and 60° junction angles, using interpolation and specialized analysis. The research aligns with Uzbekistan's national priorities for efficient water resource management.

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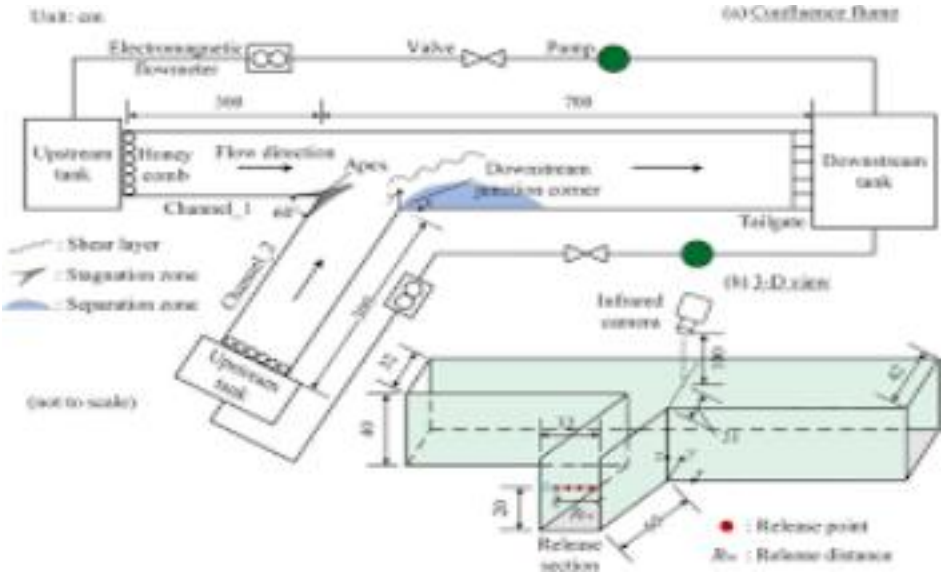

Figure 3. Schematic diagram of the open channel confluence experiment in the laboratory flume.

Materials and Methods

The experiments were conducted in a recirculating flume with a movable sand bed and glass walls. The width of the main channel was 0.4 m; the width of the tributary channel ranged from 0.2 to 0.3 m (at a 1:50 scale). Junction angles were 30°, 45°, and 60°, with interpolation for intermediate values. The discharge ratio Qr varied in the range of 0.2–0.8; Froude numbers ranged from 0.3 to 0.7.

Flow velocities were measured using an Acoustic Doppler Velocimeter (ADV). Field validation was performed on the Mirishkor canal using a SONTEK RiverSurveyor S5.

Vortex-free regions were modeled using potential flow theory. The conformal mapping method was applied to determine the boundaries of streamlines. The width and length of the recirculation zone were parameterized as functions of the junction angle θ and the main flow velocity V_main.

Bed sediment transport was calculated using adapted formulas that account for the effect of the junction angle. Statistical processing of the experimental data yielded empirical relationships.

This section describes the physical setup (laboratory flume with movable bed), geometric and hydraulic parameters (channel widths, angles, discharge ratios, Froude numbers), measurement techniques (ADV for velocities, RiverSurveyor for field data), theoretical approaches (potential flow and conformal mapping), and data analysis methods (parameterization and statistical fitting for empirical equations).

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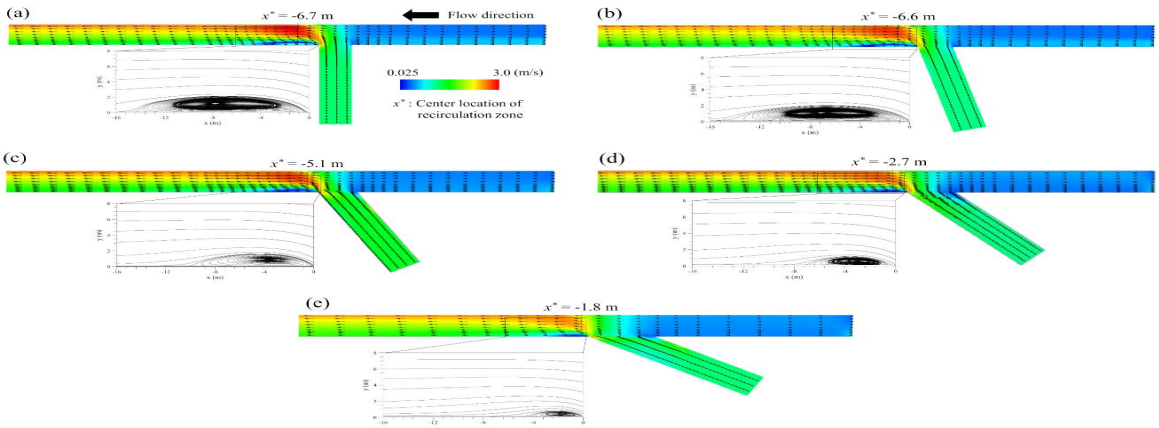

Figure 5. Velocity vectors and recirculation zone in the confluence area.

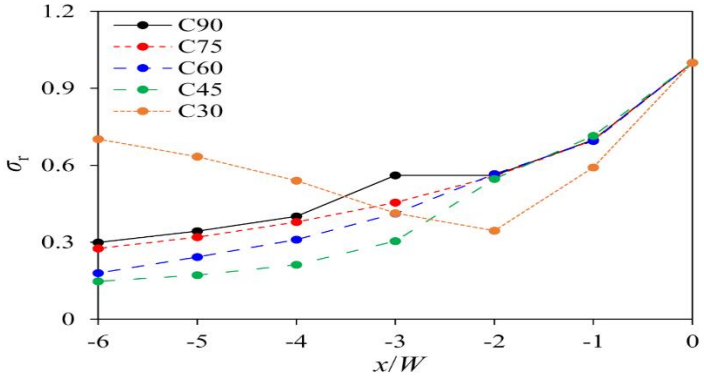

Figure 6. Detailed view of the recirculation zone and shear layer.

Results

At different values of θ, the tributary flow undergoes a less abrupt turn, forming a more compact shear layer and a smaller separation zone. The dimensions of the recirculation zone decrease as θ decreases. For Qr ≈ 0.5, the zone sizes at lower angles are 20–30% smaller compared to 60°. The flow recovery occurs more rapidly.

Table 1. Comparison of bed sediment transport.

Angle θ	*Van Reyn*	*Latipov.Sh*	*Proposed*	*Experiment*
60°	1.32	1.28	1.12	1.10
45°	1.25	1.22	1.08	1.07
30°	1.20	1.18	1.04	1.03

Application in the Mirishkor Canal increased conveyance capacity by 5–8%.

Discussion The reduction in recirculation at lower angles is associated with a smoother momentum exchange between the flows. This leads to lower adverse pressure gradients and reduced intensity of secondary currents. Faster flow recovery decreases energy losses and minimizes variations in bed shear stress, thereby reducing deformation.

The proposed equations accurately account for the angle θ, filling the gaps in previous studies. The algorithms enable predictive design, reducing costs.

Limitations: Scale effects and uniform sediment. In the future, 3D CFD modeling may be applied.

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Conclusions

1. Lower junction angles form more compact zones, reducing the risk of deformation.
2. Theoretical models and parametric equations provided the dimensions of the recirculation zone.
3. Improved formulas and algorithms enhanced prediction accuracy.
4. Application increased channel conveyance capacity and ensured stability.

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