

MORPHODYNAMICS IN RIVER CONFLUENCES

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ABSTRACT

Within the fluvial network, confluences are considered particular areas in what concerns ecological connectivity, flood safety and water quality. These characteristics were degraded in many cases, by previous channelization works, which resulted in rivers with quasi-homogeneous hydro and morphodynamic conditions. To rehabilitate such impoverished ecosystems, it is essential to deepen the knowledge about the confluence morphodynamic processes. These respond to complex and three-dimensional patterns, which are influenced by parameters such as discharge and momentum flux ratios, confluence angle, sediment grain size distribution, and bulk geometry. In addition, the existence of bed discordance between the main channel and the tributary affects the main hydro-morphodynamic features in the confluence. This study analyzes the effects caused on the confluence morphodynamics by discharge and momentum ratios, confluence angle, grain size distribution, ratio of tributary to main-channel width (B_t / B_m), and local widening of the tributary mouth. For that purpose 24 experimental tests, divided in 8 sets, were carried out in two laboratory confluences. Three discharge ratios ($Q_r = 0.11; 0.15; 0.23$) were tested in two different confluences in which the ratio of tributary to main-channel width was $B_t / B_m = 0.30$ for the sets 1 to 6, and it was reduced to 0.15 by doubling the width of the main channel for the sets 7 and 8. In the first two sets, the confluence angle was 90° whereas for the rest of the experiments the angle was 70° . All the experiments were run under mobile bed condition by supplying sediment into both channels at constant but different rates for each flume. For the sets 1 to 4, the supplied sediment were composed by two different poorly sorted mixtures of sand and gravel with high gradation coefficients ($\sigma = 3.50$ and 4.15), whereas for the sets 5 to 8 a more uniform sand ($\sigma = 1.40$) was supplied in both channels. Bed topography and water level were registered periodically during the tests duration and the bed grain size distribution was analyzed at equilibrium. Differences in bed morphology and hydrodynamics together with patterns of spatial distribution of bed sediment are summarized and discussed in this study.

Keywords: river confluences, local widening, sediment transport, geomorphology, sedimentology

1. INTRODUCTION

Confluences systems or rivers, constituted by a main channel into which a tributary flows, are complex in terms of hydro- and morphodynamics. In river confluences, the flow is highly three-dimensional, and a close interaction between the flow dynamics, bed morphology, bulk geometry and sediment transport occurs therein (Mosley, 1976; Best, 1988; Biron et al., 1993; Best & Rhoads, 2008; Rhoads et al., 2009; Leite Ribeiro et al., 2012; Leite Ribeiro et al., 2015; Guillen-Ludeña, 2015; Guillen-Ludeña et al., 2015). These singularities are considered environmental hot spots within the fluvial network, contributing to the river ecosystem by providing ecological connectivity and high heterogeneity to the flow (Benda et al., 2004). Confluences play also a major role in the viability of the fluvial transportation grids; it is through the confluence of tributary creeks into main rivers that the main affluences of liquid discharge and sediments are provided to the main rivers and where, occasionally, external chemical and biological elements are introduced. Several parameters influence the morphodynamics and hydrodynamics of river confluences, including discharge and momentum ratios, angle of confluence and sediment transport.

Herein the influence of discharge and momentum ratios (q_r and M_r), confluence angle (α), grain size distribution (σ), ratio of tributary to main-channel width (B_t/B_m), and local tributary widening on the hydro-morphodynamics of river confluences are assessed. The study focuses on confluences where the main stream provides the dominant discharge and the sediments are predominantly and abundantly supplied by the tributaries. The bed of the tributaries is higher than the bed of the main channel (bed discordance). Tributaries are narrower but steeper than the main stream, and they provide coarser sediments than the main stream. Sediment, in both cases, consists of poorly sorted gravel with high gradation coefficients. This type of confluences is characterized by low discharge and momentum ratios.

2. EXPERIMENTAL SET-UP

The experiments were performed in two different laboratory confluences. The first confluence consisted of a rectangular straight main channel 8.5 m long and 0.5 m wide. The tributary of the first facility was a 4.9 m long 0.15 m wide rectangular straight PVC flume which joined the main channel at two different angles: $\alpha = 90^\circ$ and 70° (see Figure 1a-b). The second experimental confluence consisted of a rectangular straight main channel 12 m long and 1 m wide, and a rectangular straight tributary 5.2 m long and 0.15 m wide; both channels joined at an angle of $\alpha = 70^\circ$ (see Figure 1c-d). In the second confluence, two width ratios (B_t/B_m) were tested by considering only half of the width of the main channel

($B_t/B_m = 0.30$), and the total width ($B_t/B_m = 0.15$) (see Figure 1c-d). In all geometries, the tributary was widened up to 0.45 m wide along 0.60 m from the junction (see Figure 1).

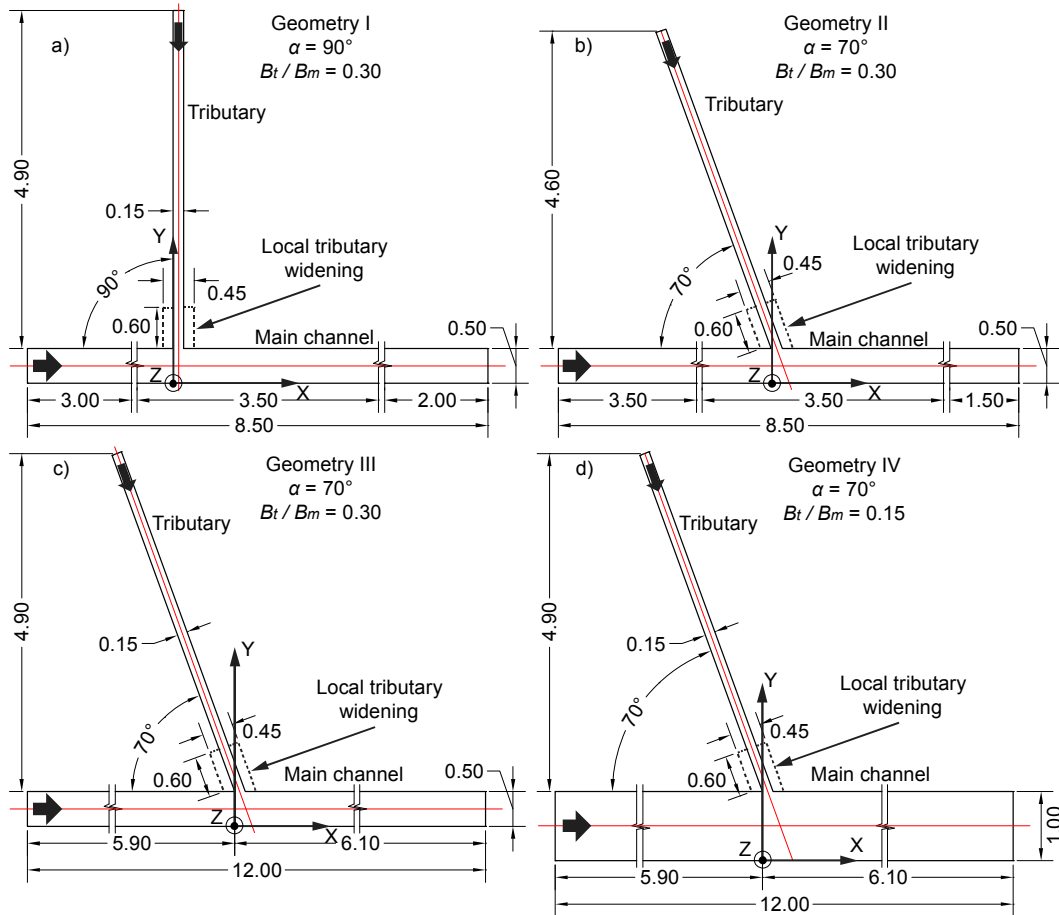


Figure 1. Plan view of the different geometries tested in this study. a) Experimental facility at LCH in Lausanne with a confluence angle of $\alpha = 90^\circ$ and a width ratio $B_t/B_m = 0.30$; b) Experimental facility at LCH in Lausanne with a confluence angle of $\alpha = 70^\circ$ and a width ratio $B_t/B_m = 0.30$; c) Experimental facility at IST in Lisbon with a confluence angle of $\alpha = 70^\circ$ and a width ratio $B_t/B_m = 0.30$; d) Experimental facility at IST in Lisbon with a confluence angle of $\alpha = 70^\circ$ and a width ratio $B_t/B_m = 0.15$. Each geometry was tested with and without local widening in the tributary.

Three discharge ratios were tested ($q_r = 0.41; 0.50; 0.77$) in each geometry with and without local widening in the tributary, which makes a total of 24 experiments divided in 8 sets of three (see Table 1). The discharge ratios are defined between the tributary unit discharge (q_t) and the main channel unit discharge ($q_r = q_t/q_m$), thus keeping the unit discharges the same for every geometry (cf. Table 1).

For the first 12 experiments, carried out in the first laboratory confluence (Figure 1a-b) at the Laboratory of Hydraulic Constructions in Lausanne, two different mixtures were supplied into the tributary and main channel. For the tributary, the sediments consisted of a 0.1 – 8 mm sand-gravel mixture with a gradation coefficient of $\sigma = 4.15$ and a characteristic diameter of $d_{50} = 0.8$ mm. For the main channel, the sediment mixture was a 0.1 – 4 mm sand-gravel mixture with a gradation coefficient of $\sigma = 3.50$ and a characteristic diameter of $d_{50} = 0.8$ mm.

For the last 12 experiments, performed in the second laboratory confluence (Figure 1c-d) at the CEHIDRO of Instituto Superior Técnico in Lisbon, a more uniform 0.1 – 2 mm sand was supplied both into the tributary and main channels. This sand had a gradation coefficient of $\sigma = 1.40$ and a characteristic grain diameter of $d_{50} = 0.9$ mm.

All the experiments were run until bed morphology reached a steady state, so called equilibrium. During the experiments systematic surveys of bed topography and water surface were recorded in both flumes.

Table 1. Experimental parameters for each set of experiments

Set	α [°]	σ [-]	B_t/B_m [-]	Tributary Widening	q_t/q_m [-]
1	90	3.50-4.15	0.30	No	0.41;0.50;0.77
2	90			Yes	
3	70		0.30	No	
4	70	1.4	0.30	Yes	
5	70			No	
6	70		0.30	Yes	
7	70		0.15	No	
8	70			Yes	

3. RESULTS

The ensemble of the 24 laboratory experiences herein presented allows assessing the influence of the discharge and momentum ratios, grain size distributions, and geometric configuration on the hydrodynamics and morphodynamics of river confluences. The main results can be summarized in the following:

- Increasing discharge ratios (q_r) enhance the erosion and reduce the height of deposition in the main channel.
- Different confluence angles (α) result in different flow regimes in the tributary. For $\alpha = 90^\circ$, the tributary was supercritical for all the discharge scenarios, whereas for $\alpha = 70^\circ$ the flow regime in the tributary was subcritical. In addition, for $\alpha = 70^\circ$ the tributary bed penetrates further into the main channel.
- Lower values of σ enhance the formation of bedforms such as dunes in the main channel and in the bed of the tributary. Moreover, the bed armoring was suppressed by decreasing the gradation coefficient of the sediments.
- Local tributary widening enhances the morphologic gradient in the main channel by means of deeper erosions and larger depositions. In addition, the morphological diversity is also enhanced within the widened area.
- The increase in the width ratio (B_t/B_m) induces a higher concentration of flow between the deposition bar and the outer bank of the main channel, responsible for a deeper scour hole here observed.

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