Equilibrium and stability of asymmetrical river bifurcations

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1. Introduction

Riverine bifurcations play a crucial role in controlling the flow and sediment distribution in the downstream branches and may lead to channel avulsion.

Previous studies on the morphodynamic equilibrium and stability of bifurcations have relied on a quasi-2D model approach originally developed for gravel bed rivers by Bolla Pittaluga et al. (2003) and later extended to the case of suspended dominated rivers by Bolla Pittaluga et al. (2015), hereafter BCK, finding that bifurcation stability is crucially dependent on the Shields stress (ϑ) and on the half-width to depth ratio (β) of the upstream channel. The Authors were able to include a nodal point condition for the transverse flow at the bifurcation and further assumed that the water levels between the upstream channel and downstream branches at the node are all equal. Such assumption has been recently relaxed by proposing a new nodal condition based on the energy balance at the bifurcation node (Durante et al., 2023). The stability of the equilibrium configurations obtained with the energy balance approach at the node has clearly shown the role played by the length of the downstream branches even in the case of symmetrical bifurcations. Indeed, the linear solution obtained performing a Taylor expansion around the basic state allowed for an algebraic relation for the critical aspect ratio β_{cr}, reading:

$$\beta_{cr} = \frac{4}{3}\frac{\alpha r}{\sqrt{\theta}}\frac{(6L+3Fr^2+4LFr^2)}{(^7/_3 L - {^3/_2} Fr^2)} \qquad (1)$$

where two new parameters appear: the dimensionless branch length L (scaled with the backwater length) and the Froude number in the upstream channel Fr. Results suggest that the stability of the bifurcation increases as the length of the branches decreases. Note that the stabilizing effect of relatively short downstream channels in loop systems has been already pointed out by Ragno et al. (2021).

Here we relax the hypothesis of symmetrical bifurcations and we focus our attention on the equilibrium and stability of configurations arising in uneven downstream branches. Considering the case of branches with different lengths ($\gamma_L = L_C/L_B$ =1.01), we find the emergence of multiple solutions as in the symmetrical case that might lead to a counterintuitive existence of configurations where the longest branch dominates (Figure 1). The linear stability analysis allows to identify the stability of the equilibrium configurations.

Furthermore, the theory is here validated by performing systematic numerical simulations with Delft3D considering asymmetric configurations. In particular, the upstream flow discharge per unit width, the slope, and the sediment diameter were kept constant, while the width was varied to consider different values of β. For every configuration three different simulations were performed in order to show the dependence of the morphodynamic evolution on the initial conditions.

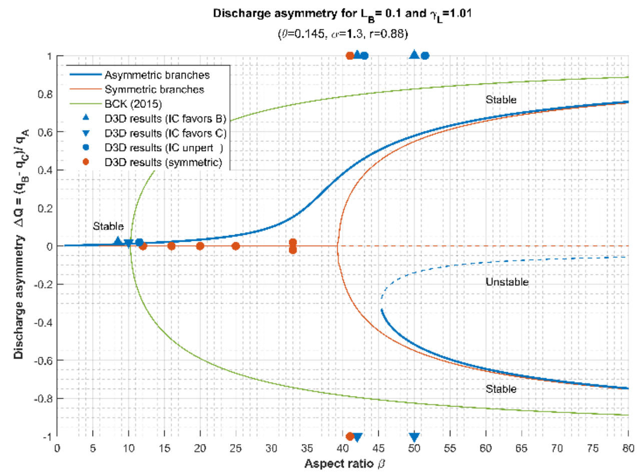

Figure 1: *The discharge asymmetry equilibrium diagram is shown as function of the aspect ratio β for fixed dimensionless branch length L and for fixed length asymmetry γ_L. The blue lines indicate the solution of the uneven length case, the orange ones are related to the symmetric configuration of the present theory, while the theory of BCK (2015) is shown with the green lines. The theory has been verified through numerical simulations represented as dots.*

2. Conclusions

Numerical investigations and a theoretical model for river bifurcations characterized by uneven branches show that if the aspect ratio of the upstream branch exceeds a critical value, the system might evolve towards unbalanced equilibrium configurations that also include the counterintuitive condition where the longest branch is favoured.

References

Bolla Pittaluga, M., Repetto, R., & Tubino, M. (2003). Channel bifurcation in braided rivers: Equilibrium configurations and stability. WRR , 39(3).

Bolla Pittaluga, M., Coco, G., & Kleinhans, M. G. (2015). A unified framework for stability of channel bifurcations in gravel and sand fluvial systems. GRL, 42(18), 7521-7536.

Durante, L., Tambroni, N., & Bolla Pittaluga, M. (2023). How is the length of symmetrical branches affecting the stability of riverine bifurcations? 15° International Symposium on River Sedimentation.

Ragno, N., Redolfi, M., & Tubino, M. (2021). Coupled morphodynamics of river bifurcations and confluences. WRR, 57(1), e2020WR028515.