Doctoral School in Environmental engineering

Stefano Miori

Bifurcation dynamics in gravel-bed braided rivers

Abstract

Bifurcations are key elements of braided river networks, and their dynamical behaviour widely affects the evolution of the whole network: bifurcations indeed rule discharge and sediment distribution in the downstream areas of the braided. In spite of their important role, little is known about bifurcations dynamical behaviour and their interaction with the other morphological elements and processes taking place in the network. The aim of this work is to give a systematic insight to bifurcation dynamics adopting both laboratory and theoretical modelling.

Such investigations start from the field observations of Zolezzi et Al. (in Braided Rivers 2003) and the study of the equilibrium configurations found in the experiments of Bertoldi et Al. (WRR 2007, in press) and in the theoretical modelling of Bolla Pittaluga et Al. (WRR 39-3, 2003 – hereinafter addressed as BRT). They show that, at fairly high values of the Shields stress of the incoming flow, bifurcations tend to assume a symmetrical configuration. As the Shields number decreases the symmetrical configuration becomes unstable and bifurcations evolve towards an unbalanced state, with one of the two branches being deeper and (if allowed) wider than the other, and carrying most of water and sediment discharge. Bertoldi et Al. (2007) suggest that the asymmetrical morphology and the consequent unbalanced configuration are induced by the upstream influence of the bifurcation on channel bed morphology, when the upstream channel width depth ratio exceeds a threshold (the so called resonant condition – Zolezzi and Seminara, JFM 483 – 2001).

The work is firstly oriented to a better understanding of the local characteristics of the bifurcation, with particular focus to flow field structures. To perform this analysis, a three dimensional numerical model is applied to the final topography produced in the laboratory experiments on the bifurcation (see above). In order to reproduce the complex features of these topographies, a porosity correction algorithm is adopted. The main feature resulting from the reproduced flow field is a flux diversion towards the banks in the upstream channel, which anticipate flow separation at the bifurcation. Results show that the higher is the difference in local bed elevation at the bifurcation,

the stronger is the intensity of this flux diversion (resulting in an asymmetry of the planimetric areas feeding the distributaries and an unbalance of water distribution), and the shorter is the length of the upstream channel interested by this flow structure, at least confined into the bifurcation area.

In the context of the braided system, a series of bifurcations have been analyzed, observing their formation, character and evolution in an experimentally reproduced braided network. The characterization regarded their density, the distinction between bifurcations with different shape and orientation and the presence of sediment transport and morphological activity in the different branches. Finally the analysis of frequency and the speed of reworking processes in the network, which modify the boundary conditions affecting the dynamic of the bifurcation, show that, in a network, hardly a bifurcation can reach its equilibrium respect to given boundary conditions. This is caused by the time scale of its free evolution being much bigger than the time scale of significant alterations in the surrounding network character.

In the second part of this work the dynamic behaviour of the bifurcation has been explored, when interacting with other dynamic processes like width adaptation to channel flow, discharge variability and migration of bed-forms in the upstream channel. This involved both experimental analysis and the extension of the one-dimensional BRT model.

Firstly the analysis of bifurcations behaviour when taking banks erosion is allowed has been considered. The BRT model has been extended assuming regime width as the asymptotical equilibrium condition to which channels tend to adapt. The three equilibrium configurations that the bifurcation can reach, according to the model, are qualitatively the same of the original BRT model, corresponding to [1] the balanced water distribution and morphological symmetry (this solution exists for any set of parameters) and [2] the left-dominated and [3] the reciprocal right-dominated unbalanced distribution which is related to a morphological asymmetry (configurations [2] and [3] appear when solution [1] becomes unstable). But while in BRT the morphological asymmetry simply results in a difference of depths, allowing width adaptation the asymmetry propagate to the width of distributaries, enhancing the unbalance of water distribution and confining the occurrence of the stable balanced solution to extremely infrequent sets of the flow parameters. Moreover initial conditions appear to be important when bifurcations evolve, if the different character of channel widening and narrowing phenomena is considered, as suggested by several experimental and field observations.

Unsteadiness in braided is recognised to be extremely common, being partially due to external factors but highly enhanced by the internal transformations of the network. This internal unsteady character results in frequent variations of the discharge feeding the different areas of the network and consequently the bifurcations. A series of laboratory experiments, coupled with model simulations, have been developed to explore the behaviour of bifurcations when subject to discharge fluctuations, in particular applying a sinusoidal feeding law, with different amplitudes and frequencies. Results reveal a strict relationship between bifurcation behaviour and the time scale of forcing conditions. In fact, for slow fluctuations of discharge, the bifurcation at each time tends to approach the steady equilibrium configurations correspondent to the present stage. When feeding variation speeds much more than the morphological adaptation process, a more complex behaviour appears. This effect is qualitatively reproduced with the one-dimensional model, allowing the inference of a more general picture of the bifurcation under unsteady flow conditions.

Migrating bars have been widely recognized as one of the most characterizing features in braided rivers. Their interaction with bifurcation dynamics, when migrating in the upstream channel, has been analyzed. In fact, extending BRT model with the application of appropriate upstream fluctuating boundary conditions it is possible to reproduce bars effect. Amplitude and speed of bars have been initially arbitrarily defined and later inferred from the non-linear theory of Colombini, Seminara and Tubino (JFM 181 – 1987). Results have been compared with a series of experiments realized on a fixed bank bifurcation, and three different behaviour have been invariably detected, both in model and in experimental outputs: (1) in presence of little amplitude and fast bars the bifurcation tends to behave as in the steady case, with the superimposition of a perturbation in time of amplitude proportional to bars amplitude and speed; (2) when bars amplitude increases and speed decreases enough (mainly corresponding to a threshold of width-depth ratio according to bars theory) bars start to completely dominate the behaviour of the bifurcation, imposing an in-time switching character to water distribution and bed setting; (3) as extreme condition bars can drive the bifurcation to the complete closure of one of the distributaries. The quantitative comparison between experiments and theory gives a good correspondence in reproducing the three described behaviours and the condition in which they realize.

The present investigations and model extension, focussed to the dynamic interactions between bifurcation and network processes, give a new, hopefully handy, contribution on one hand to the understanding of bifurcations and on the other hand to the construction of simple but effective predictive models for braided network dynamics.