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Effect of curvature and width variations on the morphodynamics of meandering rivers

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Abstract

The present work analyzes the key dynamical role of the interactions between channel width and channel curvature in shaping the plane-altimetric patterns in natural meandering streams.

Traditionally, most studies on meander morphodynamics have focused on the direct role of channel curvature in the deformation of bed topography and of the flow field, as well as on the feedback mechanism whereby curvature is modified by the near-bank flow and altimetric patterns through the process of planimetric evolution. Channel width has been assumed constant in most meandering simulation models, and the effect of cross-section aspect ratio has rather been considered scarcely.
This notwithstanding, the role of channel width on meander dynamics can be relevant as suggested by both field observations as well as by modelling approaches. First, several field observations (Brice, 1974; Knighton, 1972; Richards, 1976; Hooke, 1986) suggest that spatial width variations can have a relevant dynamic role in single - thread meandering rivers. Moreover, recent modelling approaches have shown the crucial role of the half channel width to-depth ratio in determining different classes of morphodynamic behaviors (Zolezzi and Seminara, 2001) and have pointed out the forcing effect of spatial width variations on the flow -bed topography field of single thread channels (Repetto et al., 2002).

The present research aims to provide a comprehensive insight into the dynamics of spatial width variations in river meanders combining mathematical modeling with field investigations. While the main body of the present PhD thesis concentrates on width variations, the work is integrated by some novel comparison between constant-width meander models and field data to investigate the dynamic effect of channel width, in particular of

the width to-depth ratio, to control the morphodynamic regime of a meandering stream.

Observations and measurements in a natural, free evolving meandering river, the River Bollin (Cheshire, UK), have been carried out in order to increase the knowledge concerning the definition of width variations in a meandering river. The analysis of the free surface width along the river at different flow stages shows opposite behaviors in correspondence of the bend apexes and of inflection points. Field investigations suggest that two different mechanisms can be responsible of generation of width variations: an *"asymmetric driven mechanism"* in correspondence of the bend apexes where width variations are the result of an asymmetric behavior of erosion and deposition of the two banks; a "*symmetric driven mechanism*" where width variations are associated with the development of incipient mid channel bars in correspondence of riffle position where both banks are subject to erosion.

The depth averaged mathematical model consists of newly derived steady momentum and continuity equations for flow and sediments for the morphodynamics of meandering rivers with the presence of width variations. The model is solved with a perturbation scheme based on a two parameters (denoted with ν and δ) perturbation expansion. These two parameters quantify the intensity of the longitudinal variability of the two planimetric forcings, curvature and width variations respectively. The structure of the governing systems inherently contains the information that the wavelength of periodic width oscillations is half that of channel curvature and that the oscillation of the width can present a phase lag respect to the distribution of channel curvature.

The solution at the different orders of approximation has allowed to quantify: (i) the tendency of a meandering river to produce the plane-altimetric pattern mid channel bars-width variations and (ii) the effect of channel width oscillation on meander growth through a modified bend stability analysis.

The first nonlinear self-interaction of the curvature-forced linear solution ($O(\nu^2)$), associated with nonlinear effects within the flow-bed topography field, is used to investigate how and where an initially equiwidth meander may tend to produce mid channel bar in relationship with its reach-averaged hydraulic conditions and its geometry.
Mid-channel bars seldom locate in correspondence of bend apexes, as it can be often thought on an intuitive basis. The location of mid-channel bars with respect to the bend apex depends on the intrinsic wavelength for relatively long meanders, and reduces for shorter bends. Central bars tend to symmetrically divert the flow against the two banks, a process which is proposed as a *symmetric driven mechanism* of width variations. At the same time, induced longitudinal width variations (i.e. for the *asymmetric driven*

mechanism at the bend apexes) can force mid channel bars close to the widest cross-section through a symmetric linear altimetric response of the system ($O(\delta)$). The results are in qualitative agreement with several field and experimental observations.

The effect of spatial width variations on meander stability is instead reproduced at the first nonlinear interaction between the linear solutions separately forced by curvature and by width variations ($O(\nu\delta)$). The analysis allows to detect possible conditions leading to a modified channel response with respect to classical meander models, and to understand the role of width variations to inhibit or enhance the growth of channel curvature. Width variations tend to destabilize shorter meander wavelengths with respect to the classical linear theory, thus providing a better qualitative comparison with field observations. Given ranges of linearly stable meander wavelengths can become unstable and grow in time provided the channel is subject to large enough spatial oscillations of its width.

The second part of the work attempts to link theoretical and experimental findings on the issue of two-dimensional morphodynamic influence with field data from natural single-thread rivers.

Morphodynamic influence consists of the propagation of a transverse (scour-deposition) bed deformation triggered by a geometric disturbance such as a discontinuity in channel curvature. Two-dimensional planform and bed deformation waves can propagate both upstream and downstream within single-thread meandering rivers. The existence of upstream influence is controlled by the value of channel aspect ratio with respect to a threshold that is determined by reach-averaged characteristics and by the evolutionary state of a given river section.

The mathematical model employed in the present work is basically made of two main ingredients: a flow bed topography model for single-thread meandering channels with given distribution of channel curvature, and a planimetric evolution equation (Seminara et al., 2001), whose time integration assumes that the flow and bed topography instantaneously adapt to planform changes occurring on longer time scales. The flow-bed topography model is needed to compute the morphodynamic regime of a stream given its reach-averaged characteristics ($O(\nu)$). The planimetric evolution model allows investigation of the extent to which a meandering stream can modify its own morphodynamic regime in dependence of its planimetric evolution stage.

The analysis of model predictions has been done based on the input of field data referring to more than 100 gravel bed rivers, in order to quantify the regime of morphodynamic influence that can be expected in these streams. The analysis points out how the predicted morphodynamic regime of a given reach can be controlled by the bankfull aspect ratio and the Shields stress. Differences within the dataset suggest an autogenic tendency of gravel bed rivers to behave super-resonantly, while environmental factors like denser vegetation and reduced gravel supply tend to promote the sub-resonant regime. Moreover the autogenic tendency of developing meanders to continuously modify their sinuosity and to consequently reduce the downchannel slope almost invariably promotes transition from the super-resonant to the sub-resonant regime.

References:

J. Brice. Stream channel stability assessment. Report no. fhwa/rd, Federal Highway Administration, Offices of Research and Development, 1982. 42p.

J. Hooke. The significance of mid-channel bars in meandering channels. Sedimentology, 33:839–850, 1986.

Knighton. Changes in a braided reach. Geological Society of America Bulletin, 83: 3813–3822, 1972.

R. Repetto, M. Tubino, and C. Paola. Planimetric instability of channels with variable width. Journal of Fluid Mechanics, 457:79–109, 2002.

K. Richards. Channel width and the riffle-pool sequence. Geological Society of America Bulletin, 87:883–890, 1976.

G. Zolezzi and G. Seminara. Downstream and upstream influence in river meandering. Part 1. general theory and application of overdeepening. Journal of Fluid Mechanics, 438:183–211, 2001.