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River meandering: linear versus non linear models

G. Seminara

Department of Civil, Environmental and Architectural Engineering

Via Montallegro 1, 16145, Genova, Italy (sem@dicat.unige.it Fax +39 010 3532546)

In the last few decades the interaction between fluid dynamicists and geomorphologists has allowed to develop a rational framework for the quantitative understanding of the origin and dynamics of a rich variety of patterns shaped by the action of water in sedimentary environments. The nature of most patterns is strictly related to fundamental instabilities whose peculiar character lies in the mobile interface between a fluid and an erodible boundary driving the instabilities. *Meandering* is a most fascinating example of such patterns. Meanders are ubiquitous: they develop in sandy rivers wandering through flat valleys, in narrow incisions constrained through rocky hill slopes or earlier terraces, in sandy tidal channels as well as in vegetated cohesive salt marshes, in submarine fans at the base of the continental slope generated by turbidity currents.

Our attempt, here, is to provide a brief, yet systematic, overview of the fundamental aspects of the mechanics of meandering.

We start recalling the three main tools constructed to understand how meandering rivers evolve in space and in time: a *nonlinear integro - differential plan form evolution equation* obtained by stipulating that the centreline of erodible channels moves in the lateral direction with some lateral migration speed, an *erosion rule* relating this erosion speed to the near bank hydrodynamics and some *model of flow and bed topography* in sinuous channels required to predict near bank flow.

Next, we summarize the fairly established results of *linear theories*, the actual implications of a linear approach being that flow, bed topography and channel alignment undergo ‘small’ perturbations: i) the linear *bend theory* shows that meanders behave as linear oscillators which resonate at some distinct values of the aspect ratio of the channel and of meander wavenumber, in that, at resonance, some natural mode of ‘spatial oscillation’ of bed topography (the so called stationary *alternate bars*) is excited; ii) crossing the *resonance* barrier leads to reversing the directions of *meander migration* and of the dominant *morphodynamic influence*; iii) meanders, in their mature stage, typically develop a characteristically *skewed shape* and possibly *compound loops*, they also *slow down* and reach eventually the stage of the so called *neck cut-off* : the latter features emerge in models which ignore flow nonlinearities as long as *geometric nonlinearity* is allowed.

We then investigate the effects of *flow nonlinearities*. On the basis of an asymptotic model which is valid for a meandering river with arbitrary (yet not too sharp) distribution of channel curvature, we are able to show that flow nonlinearities have a number of effects.

1. Firstly, the peak in the response (velocity and bottom deformations) is *finite*.
2. It occurs at a *preferred wavelength*, which is typically smaller (hence closer to field observations) than predicted by classical linear theories.
3. On the contrary, the wavenumber at which the direction of meander migration is reversed, does not differ significantly from the *resonant wavenumber* of the linear theory.
4. The *phase of the velocity peak* is significantly modified, a feature which has important consequences on plan form evolution.

Finally, we discuss qualitatively the mechanics of meanders observed in different environments and conclude with some thoughts on the issue of the actual predictability of long term meander evolution.