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Research paper

Experimental study on the bed topography evolution in alluvial meandering rivers with various sinuousnesses

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Abstract

The bed morphology in alluvial meandering rivers is composed of both alternatively distributed free bars and curvature related point bars. To study the influence of channel sinuousness on the flow and sediment transport, and consequently the bed morphology in meandering rivers, experiments were carried out in a series of curved channels with erodible bed fixed side walls. Measurements on the surface flow field, bed topography evolution and sediment transport rate were performed. Experimental results show a high velocity area near convex bank at a streamwise position a little bit upstream of the apex and the increasing in sinuousness of channel tends to increase the cross-sectional variation of flow velocity at the apex of bends. Point bars and pools appear in the channel bends in all experimental runs the bedform has an obvious tendency of downstream migration as a whole. The quasi-equilibrium bedform in the channel bends are dominated by two independent factors: the influence of curvature and the influence of flow-bed instability inside the channel. The increasing of flow rate leads to a faster development of bars and pools, as well as faster downstream migration of the entire bedform. The increase of sinuousness in channel bends leads to the increase of both the spatial and the temporal fluctuation of bedforms. Bedload is dominant in the sediment transport and the sediment transport rate tends to increase with the increasing of the inlet flow rate but decrease with the increasing of the channel sinuousness. Computational results on the bed topography in river bends was also presented based on empirical models, showing that the highly sinuous channels have more uncertainty in bed morphology and more difficult to be predicted with mathematical models when compared with slightly sinuous channel bends. The coupled interaction of point bars, mid-channel bars, alternative bars and even sand ripples are thought to complicate the mechanism and make the bed morphology difficult to predict. The experiment results can be useful for further theoretical study on the dynamics of river meanders with water depth-width ratio as small as 1/10 to 1/20 and bedload dominated sediment transport.

Keywords: Meandering river; Channel bends; Experimental study; Topography evolution; Sediment transport

1. Introduction

Meandering river is one of the most common river patterns in the nature. It has been one of the most important and interesting topics in geomorphology research for decades. The motivations range from the challenge of explaining a very complex and beautiful physical phenomenon, to practical engineering and environmental concerns (Xu et al., 2011). Meandering rivers shift laterally and migrate longitudinally through a process of erosion (deposition) at concave (convex) banks. The process is extremely complex with many fundamental mechanisms still undiscovered up to now (Seminara, 2006). The complexity comes from both the flow conditions and the erosion process. For the aspect of flow, due to the action of centrifugal force, the flow condition in river bends is much more complex compared with the straight channels. There are structures like secondary current and spiral flow (Blanckaert, 2009; Camporeale et al., 2007; Corney et al., 2006), as well as super-elevation of water surface (McClung, 2001). This kind of flow structure has significant influence

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on incipient motion of sediment, sediment transport mechanism, and river bed morphology. Controlled by the ability of the stream to remove sediments accumulated at the bank foot, Erosion occurs continuously by removal of small particles from the bank surface and intermittently through bank collapse at the flood stage (Seminara, 2006). The bed morphology in alluvial meandering rivers is composed of both alternatively distributed free bars and curvature related point bars (Luchi et al., 2010; Parker et al., 1982). In recent years, there are some successful attempts reported on reproducing river meander dynamics theoretically or numerically. With reasonable simplifications and some assumptions (Blanckaert and de Vriend, 2010; Camporeale et al., 2007; Federici and Seminara, 2003; Khosronejad et al., 2007; Luchi et al., 2010; Xu et al., 2011), the achievements are very encouraging and promising. However, considering the variety and complexity of natural meandering rivers, the details of the bed topography in river meanders is still very difficult to model theoretically or numerically up to now due to the lack of deep understanding of the flow-bed interaction mechanisms.

As one of the most important way to investigate the fundamental mechanisms of river meandering dynamics, laboratory experiments are widely used in recent years. To facilitate a brief summarization of these researches, we hereby classify such experiments into three major categories depending on the mobility of channel boundaries: i) experiment with fixed bed and fixed walls (hereby abbreviated as “FBFW Experiment”, similarly hereafter); ii) experiment with erodible bed and fixed walls (EBFW Experiment) and; iii) experiment with erodible bed and erodible wall (EBEW Experiment). The major purpose of **FBFW Experiments** is to investigate the flow structure inside the channel bends, which ultimately dominate the ability of the stream to remove sediments accumulated at the bank foot (Seminara, 2006). Because both the channel bed and the side walls are fixed, it is possible to accurately measure the flow fields with high precision instruments. The three-dimensional velocities measured in experiments are crucial for the analysis of flow structure in channel bends, including secondary current (Blanckaert, 2009; Corney et al., 2006; da Silva et al., 2006; Termini, 2009; Termini and Piraino, 2011), turbulent structure (Abad and Garcia, 2009a; Liu et al., 2005)and near wall shear stress features (Abad and Garcia, 2009b; Afzalimehr and Singh, 2009). For **EBFW Experiments** with erodible bed and fixed side walls, both flow structures and bed topography become much more complex because of the erosion induced bed deformations and its interaction with flows. The bed deformation usually appears in the form of point bars, free bars and sand ripples (Federici and Seminara, 2003; Luchi et al., 2010; Termini, 2009; Whiting and Dietrich, 1993a, b). There are also mid-channel bars occur in meanders, which may characterize transitional morphologies between pure meandering and braided rivers (Luchi et al., 2010). Different bars may exist simultaneously and combines into extremely complex bed topography structures (Struiksma et al., 1985; Whiting and Dietrich, 1993a). These bars and other bedform structures in channel bends with erodible bed play an important role in both the origin and the maintaining of meandering rivers (Federici and Seminara, 2003; Seminara, 2006; Zeng et al., 2008). **EBEW Experiments** usually adopt self-developed river meanders in an erodible basin in laboratory with both river bed and side walls erodible. As long as the necessary conditions for meandering river pattern satisfied, typical river meanders can develop automatically from an arbitrarily initial planform (either straight or with small sinuosity). Micro-scale meandering rivers have been successfully reproduced in this way in laboratory experiments using various kinds of sediment, including coarse sand, fine sand, cohesive sediment, clay or mixture of non-cohesive sediment and clay and so on (Braudrick et al., 2009; Dulal and Shimizu, 2010; Le Coz et al., 2010; Peakall et al., 2007; Smith, 1998; Zeng et al., 2008). Although these are quite a lot successful attempts in reproducing meandering rivers in laboratory, realistic physical models of meandering rivers have proven extremely difficult to produce, particularly in comparison to the formation of braided rivers in the laboratory. Experiments demonstrate that cohesion is a key variable in the development and maintenance of single-thread channels (Peakall et al., 2007). In particular, cohesion must be sufficient to force the planform away from a braided state but low enough for active migration to continue and for the avoidance of a gradual reduction and eventual cessation of planform ossification (Peakall et al., 2007). Experiments with coarse sediment suggest that sand supply may be an essential control in restoring self-maintaining, actively shifting gravel-bedded meanders (Braudrick et al., 2009). Limited by experimental conditions, such experiments usually have very small scales in dimension (usually as small as 2 m × 1 m). However, these experimental channels offer the opportunity to explore several fundamental issues about river morphodynamics and such experimental channels are needed to explore mechanisms controlling migration rate, sinuosity, floodplain formation, and planform morphodynamics and to test theories for wavelength and bend propagation (Braudrick et al., 2009; Peakall et al., 2007; Smith, 1998). The enhanced realism of the experiments also enables the processes of meander evolution, and critically the resultant alluvial architecture, to be examined in a physical model for the first time (Peakall et al., 2007).

Laboratory experiments on river meanders involved in the above three categories raised intensive interests among researches from areas of both hydraulics and geomorphology. Experimental discoveries based on micro-scale laboratory rivers greatly contribute to our profound understanding of the flow, sediment and consequently bed morphology in meandering rivers. However, most of these experiments were carried out in just one or two specified channels due to the difficulty in building physical models, which makes the analysis of influence from sinuousness difficult. This paper presents a convenient way to make small scale meandering channels in laboratory. Based on this technique, a series of **EBFW** experiments on flow and sediment were carried out inside channels with various sinuousness and discharges in designed channel bends with erodible bed and fixed side wall. The influences of channel sinuousness and flow discharges in alluvial meandering rivers were investigated.