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Reduction of bend scour with an air-bubble screen - morphology and flow patterns

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Abstract

The interplay between streamwise flow, curvature-induced secondary flow, sediment transport and bed morphology leads to the formation of a typical bar-pool bed morphology in open-channel bends. The associated scour at the outer bank and deposition at the inner bank may endanger the outer bank's stability or reduce the navigable width of the channel. Previous preliminary laboratory experiments in a sharply curved flume with a fixed horizontal bed have shown that a bubble screen located near the outer bank can generate an additional secondary flow located between the outer bank and the curvature-induced secondary flow and with a sense of rotation opposite to the latter. This bubble-induced secondary flow redistributes velocities and bed shear stresses. The reported study investigates the implications of a bubble screen on the flow and the morphology in configurations with mobile bed. Velocity measurements show that the bubble-induced secondary flow shifts the curvature-induced secondary flow in inwards direction and reduces its strength. The bubble screen considerably reduces morphological gradients. Maximum bend scour is reduced by about 50% and occurs further away from the outer bank where it does not endanger the bank stability anymore. The location of maximum scour coincides with the junction of the curvature-induced and bubble-induced secondary flows. At this same location, the maximum streamwise velocities and maximum vertical velocities impinging on the bed also occur, which indicates their importance with respect to the formation of bend scour. The bubble screen also substantially reduced deposition at the inner bank. These preliminary experiments show the potential of a bubble screen to influence and modify the bed morphology.

Key Words: Bubble screen, Erosion, Scour, Morphodynamics, Open-channel bend

1 Introduction

Low-gradient rivers often develop a meandering morphology, whereby each individual bend of the meander is characterized by a particular morphological profile. Outer banks are vulnerable to scouring, whereas deposition occurs near the inner bank. This so-called bar-pool morphology is related to the existence of a curvature-induced secondary flow, where secondary flow is defined as flow perpendicular to the streamwise axis. This secondary flow redistributes the velocities and the boundary shear stresses, and hence also the sediment transport and the morphology (Rozovskii, 1957; Blanckaert and de Vriend, 2003, 2004, 2010; Blanckaert and Graf, 2004).

The formation of the typical bar-pool morphology in open-channel bends leads to adverse impacts, such as increased risk of erosion at the outer bank or reduced navigable width. Several techniques exist to reduce these adverse impacts, but they generally imply substantial constructive works. Techniques reported in literature include bottom vanes (Odgaard and Spoljaric, 1986; Odgaard and Wang, 1991), fixed layers (Roca et al., 2007), submerged groynes (Przedwojski, 1995) and bandal-like structures (Teraguchi et al., 2011). However, these techniques have the disadvantage of being fixed constructions on the bed that represent a possible threat for navigation. This paper describes an innovative technique that consists in indirectly manipulating the morphology by provoking changes in the flow pattern.

Previous preliminary laboratory experiments in a sharply curved flume with a fixed horizontal bed have shown that a bubble screen, which originates from a porous tube located on the bed near the outer bank, can generate an additional secondary flow located between the outer bank and the curvature-induced secondary flow and with a sense of rotation opposite to the latter (Blanckaert et al., 2008). In these previous preliminary experiments, the additional bubble-induced

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secondary flow was efficient in redistributing velocities and boundary shear stresses. The cores of maximum descending vertical velocities and of maximum streamwise velocities, which are assumed to play an important role with respect to the development of the bend scour, were shifted away from the outer bank and situated at the junction of both secondary flows.

Contrary to "hard" engineering techniques, bubble screens have the advantage of being controllable, ecological (oxygenation), reversible and non-permanent. Bubble plumes and screens have already been applied in a wide range of applications, such as aeration and destratification of lakes and reservoirs (Schladow, 1992; Wüest et al., 1992), or venting of aerosol mixtures into water pools in nuclear power plants (Smith, 1998). However, bubble screens have not yet been investigated or applied in shallow river morphodynamics.

Following the promising results of the previous preliminary study over a fixed horizontal bed (Blanckaert et al., 2008), similar experiments with mobile bed have been performed with and without the bubble screen in order to understand its influence on the interplay between the morphology and the flow field. Morphologic and hydrodynamic comparisons are provided in this paper with the aim to answer the following questions:

- Can the bubble screen technique be applied to manipulate the morphology in open-channel bends ?
- How does the bubble-induced secondary flow redistribute the velocities and the morphology ?

This paper briefly describes the laboratory flume and the experimental conditions, presents the results for the reference and bubble-screen experiments and discusses the impact of the bubble screen on the morphology and hydrodynamics of the bend.

2 Experiments and measurement techniques

2.1 Experimental set-up

Experiments were performed in a sharply curved laboratory flume (Fig. 1a) at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. This flume has vertical PVC sidewalls and a width that is constant at B = 1.3 m. From upstream to downstream, the flume consists of a 9 m long straight inflow reach, a 193° bend with centerline radius of curvature R = 1.7 m, and a 5 m long straight outflow reach which includes a sediment deposition basin. The same flume was used in the previous preliminary experiments by Blanckaert et al. (2008) to investigate the influence of the bubble screen on the flow in a configuration with fixed horizontal bed.

Measurements will be reported in an orthogonal curvilinear (s, n, z) reference system, with downstream s axis along the flume's centerline, transverse n axis pointing outward, and upward vertical z axis. Quartz sand of nearly uniform diameter 1.6 mm < d < 2.2 mm with a mean diameter of 2 mm was used as bed material. When conducting experiments with sediment feeding, the same sand was continuously introduced near the flume entrance.

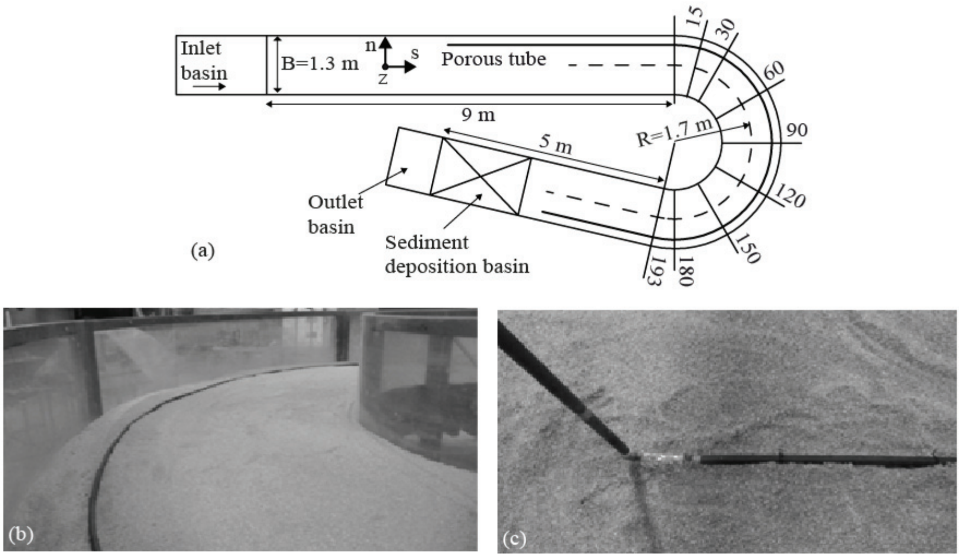

Fig. 1 (a) Plan view of the curved channel with the porous tube. (b) and (c) Porous tube with the connection to the pressurized air system existing at the two sides of the tube

A porous tube, with an inner diameter of 0.01 m (high-pressure tube of porous rubber, Multivis Waterbehandeling B.V.), placed on the bed of the flume generated the air-bubble screen. It was ballasted with a chain submerged in the sand to impede its movements, and connected at both ends to a pressurized air system to guarantee the same air pressure over the entire length of the tube (Figs. 1b, c). Microscopic holes in the tube were located on opposite sides of the diameter with a longitudinal spacing of 3 mm. The size of the bubbles was estimated to vary between 0.002 m to 0.015