Transverse bed slope experiments in an annular flume

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Introduction

A crucial part of morphodynamic models is the transverse bed slope effect, which determines the deflection of sediment transport on a transverse sloping bed due to gravity. Overestimating this effect leads to flattening of the morphology, while underestimating leads to unrealistic steep bars and river banks (Fig. 1). Therefore, incorrectly estimating the transverse bed slope effect could also have major consequences for the predicted large-scale morphology, as it influences the development of river bifurcations, meander wave length and the degree of braiding in rivers and estuaries.

In current models, the prediction of the magnitude of sediment transport is based on a situation of a flat bed with a single grain size, and only the direction is afterwards corrected for transverse gradients (e.g. Ikeda, 1982; Talmon et al., 1995). However, in reality sediment transport is also affected by grain size distribution, bedforms and suspension rate. The angle of sediment deflection is therefore often calibrated on measured morphology afterwards.

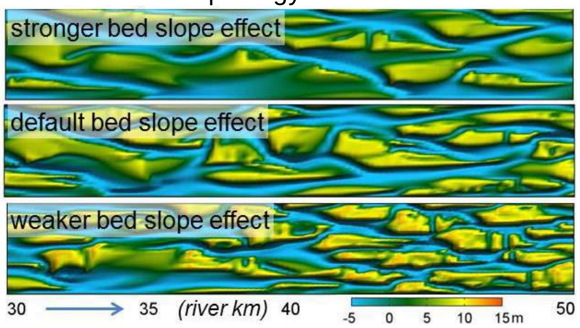

Figure 1. The effect of stronger and weaker transverse bed slope effect on channel morphology (Schuurman et al., 2013)

Previous research

Current transverse bed slope predictors are based on theoretical model studies (e.g. Odgaard, 1981; Sekine & Parker, 1992) and laboratory experiments. Experimental studies focused on experiments with bended flumes (e.g. Zimmerman & Kennedy, 1978; Struiksma et al., 1985; Ikeda & Nishimura, 1986), or straight flumes initiated with a transversely sloped bed that relaxed to a horizontal bed, to avoid secondary currents (e.g. Ikeda, 1982; Talmon et al., 1995; Talmon & Wieseman, 2006). However, in bended flumes the transverse bed slope effect cannot be isolated from the effect of helical flow, and in the experiments with a straight flume it is not possible to measure the equilibrium slope. Also, all previous transverse bed slope experiments were performed with a small range of flow conditions and mostly uniform grain sizes, varying from 0.09mm (e.g. Talmon & Wieseman, 2006) to 0.79mm (e.g. Talmon et al., 1995). Therefore, existing predictors can only apply for a certain range of conditions, as they depend on either bed load or suspension dominated conditions, and do not account for the presence of bedforms (Talmon et al., 1995, Wieseman et al., 2006). Odgaard (1981) also discusses that grain size and flow conditions vary along the transverse slope, and therefore understanding of sediment sorting patterns along a transverse slope is needed to accurately predict the transverse slope effect.

Aim and methodology

The aim of the current research is to experimentally quantify the bed slope effect for a large range of flow velocities, helical flow intensities and particle sizes (0.1-4mm), while taking into account the effect of bed forms and suspension. The experiments are being executed in the annular flume of Delft University of Technology (Fig. 2). This flume functions as an infinitely long bended flume, which therefore avoids boundary effects. Flow is generated by rotating the lid of the flume, which can be controlled to create a large range of flow conditions. Also, the intensity of the helical flow can be controlled by counter-rotating the bottom of the flume (Booij & Uijttewaal 1999).

The equilibrium transverse slope that develops during the experiments is a balance between the transverse bed slope effect, the bed shear stress caused by the helical flow and the centrifugal force caused by the rotation of the bottom of the flume (Fig.3). This balance depends on particle size, size range and density, and the rotation velocities of the lid and the bottom of the flume. All these parameters are systematically varied during the experiments in order to determine the separate effect on the equilibrium slope. Also, the effect of bedforms and suspension can be studied by the large range in flow conditions and grain sizes. For the first set of experiments only uniform sediment is being used. At a later stage, also poorly sorted sediment will be used in order to focus on sediment sorting processes. By systematically varying all these parameters, we aim to develop a more physical based transverse bed slope predictor that is applicable in a wide range of model simulations.

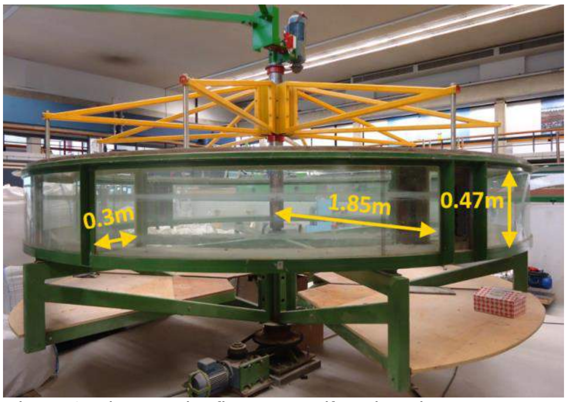

Figure 2. The annular flume at Delft University.

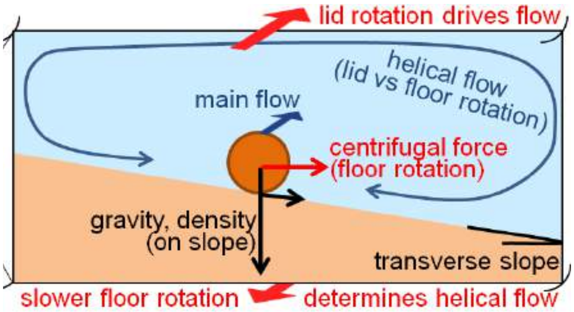

Figure 3. Forces acting on particles that can be controlled in the annular flume (after: Booij and Uijttewaal, 1999).

Preliminary results

In Fig 4. The morphology of several experiments with a grain size of 4 mm is visible, as well as the corresponding maximum transverse bed slope that developed. During this set of experiments the rotation velocity of the lid of the flume (ω_l) is kept constant, while the rotation of the bottom of the flume in the opposite direction (ω_b) increases. The average flow velocity therefore increases, as the difference between both rotation velocities increases. By increasing the bottom rotation, the centrifugal force on the sediment also increases, which counteracts the helical flow driving sediment inwards. Therefore, the transverse slope decreases with increasing centrifugal force, as is visible in Fig. 4B. When the centrifugal force is larger than the helical flow intensity, a steep slope develops towards the outside wall of the flume. Next to variations in transverse slopes, variations in dune length are also observed.

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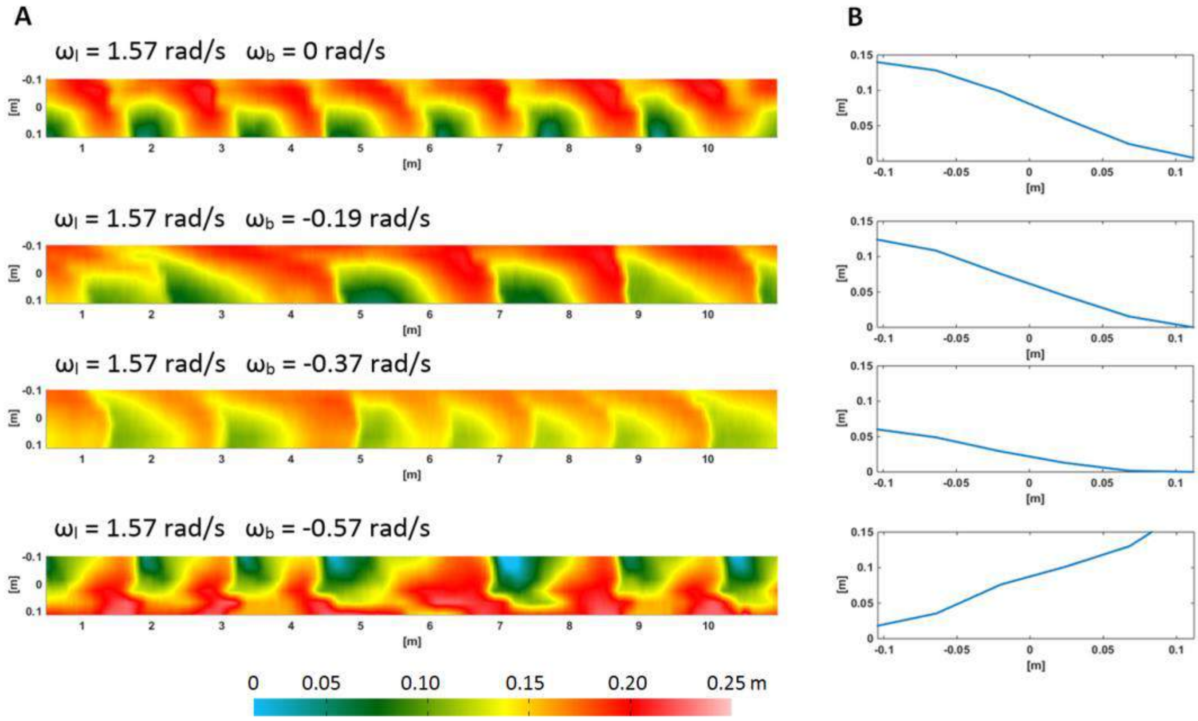

Figure 4. (A) Resulting morphology (top view) of a series of experiments with a constant rotation velocity of the lid of the flume (ω_l) and varying counter-rotating bottom velocities (ω_b), and (B) corresponding maximum transverse slopes. The width of the flume is measured relative to the average radius.