Transverse bed slope effects in an annular flume

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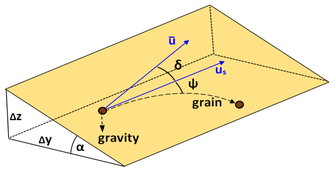
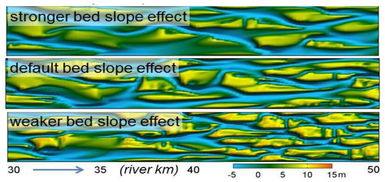
Problem definition

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. 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.



Transverse bed slope effect



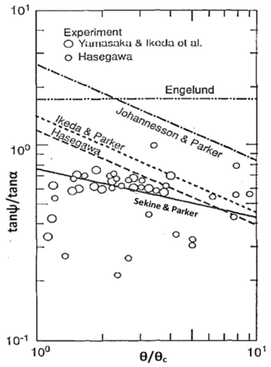
Effect of stronger and weaker transverse bed slope effect on channel morphology

Previous bed slope predictors

Based on experiments with small range of flow conditions & small range of grain sizes (0.01 – 0.8 mm)

- Either bed load or suspension dominated
- Do not account for the presence of bedforms
- No understanding of sediment sorting patterns along a transverse slope

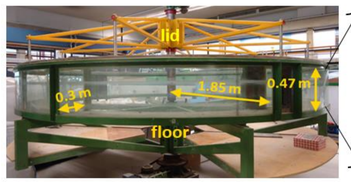
Current models need to be calibrated on existing morphology

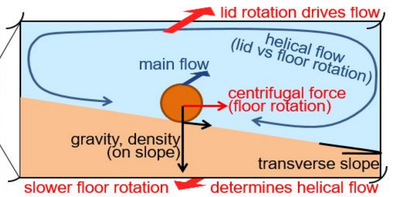


Difference in predicted transverse slope (Sekine & Parker, 1992)

Experiments in annular flume

Objective: quantify the bed slope effect for a large range of flow velocities, helical flow intensities and sediment properties





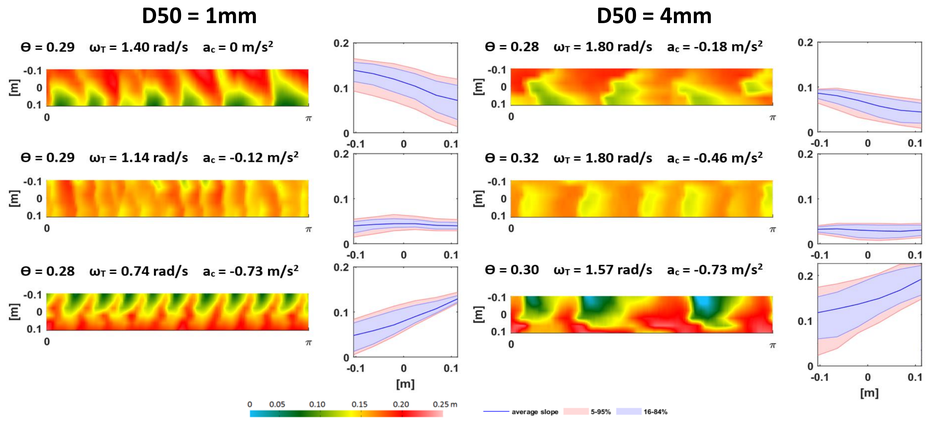
The annular (rotating) flume (Booij & Uijttewaal 1999) allows to control forces on particles

- Uniform sediment: 0.17, 0.26, 0.38, 1, 2, 4 mm
  + 2 series with light weight sediment
- Large range of lid rotation velocities > determines flow velocity & helical flow intensity
- Large range of floor rotation velocities > determines centrifugal force which counteracts helical flow

Resulting morphology and transverse bed slopes

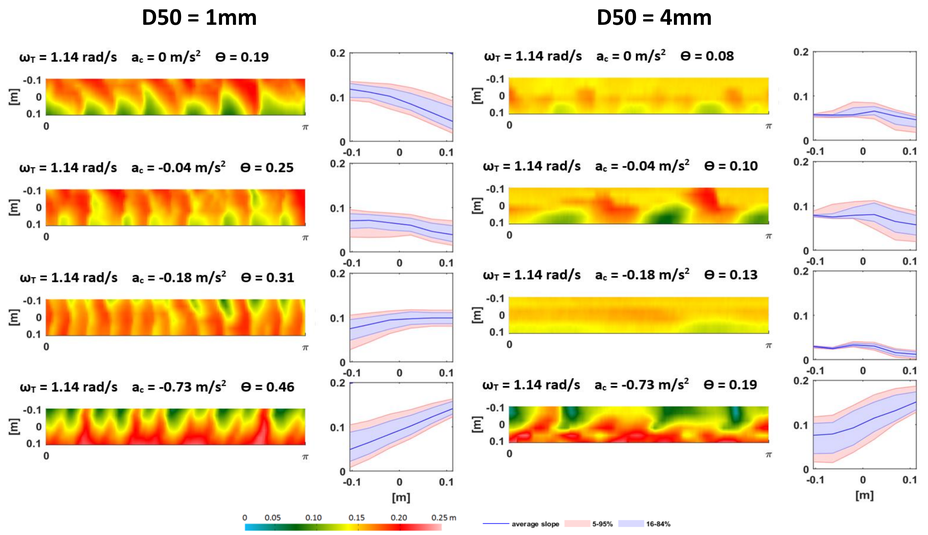
- Increasing helical flow > transverse bed slope increases , until angle of repose is reached
- Increasing centrifugal acceleration > transverse slope decreases
- Centrifugal acceleration equal to helical flow intensity > flat bed
- Dune length and height varies with helical flow intensity and sediment size

Constant sediment mobility (Θ), varying lid rotation (ω_t) and centrifugal acceleration (a_c)



Resulting morphology (top view) of several experiments with similar sediment mobility and corresponding average transverse slopes. The width of the flume is measured relative to the average radius.

Constant lid rotation (ω_t), increasing centrifugal acceleration (a_c)

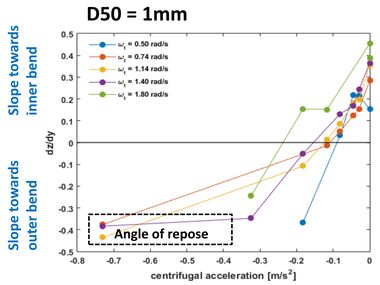


Resulting morphology (top view) of several experiments with constant lid rotation and corresponding average transverse slopes. The width of the flume is measured relative to the average radius.

Data reduction

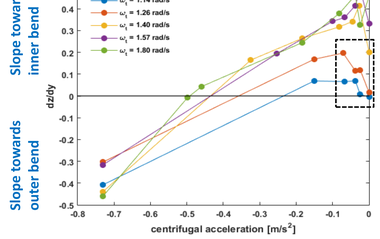
For each experiments the average transverse bed slope (dz/dy) will be determined and compared with corresponding sediment mobility (θ) and a first estimate of the helical flow intensity ($\sin\delta$). The goal of the current experiments is to develop an equation with the form:

$$\tan\psi = \sin\delta - \frac{r}{\sqrt{\theta}}\frac{dz}{dy}$$



Example: Average transverse bed slope (dz/dy) vs centrifugal acceleration (a_c).

When dz/dy = 0, the centrifugal acceleration is equal to the helical flow intensity



Future work

- Study the effect of bedforms with a Large Eddy Simulation model of the annular flume
- Implementing results in Delft3D
- Second set of experiments with poorly sorted sediment, focusing on sorting processes on transverse bed slopes

Conclusions

- Current experiments cover a large range of parameters
- It is possible to express the transverse bed slope that develops in terms of helical flow intensity and sediment properties

Funding

Vici grant (2014), 5 year funding from the Netherlands Organisation of Scientific Research (NWO, STW), Innovational Research Incentives Scheme, www.nwo.nl/vi

ERC Consolidator (2015), 5 year funding from the European Research Council

Collaboration

Deltares

TU Delft University of Technology