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River Bar Downscaling with Bed Sills and Bottom Groynes: A Numerical Study

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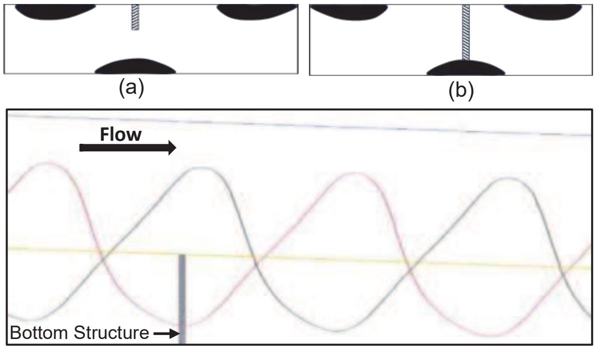
Introduction

Alluvial low land rivers are often characterized by the presence of bars. These are large sediment deposits that affect the river cross-section by creating shoal and pool areas. The existence of bars in a river can lead to undesired effects on human activities and structures, such as hindering of navigation, blockage of water intake, and endangering the safety of the existing hydraulic structures as a result of flow concentration in some parts of the river cross-section, i.e. pool areas (Teraguchi, et al., 2011). Suppression or downscaling of bars can be possibly obtained by using bottom structures like bed sills, (structures across the entire river width with a level equal to the average elevation of channel bed) and bottom groynes (Figure 1). The advantage of using this type of structure to manage bars lies in their low level, which does not hinder river navigation and fish passage.



(a) (b) (c)

Figure 1 a) Plan view of Bottom Groyne, b) plan view of Bed Sill, c) Longitudinal profile. Blue line: water level, black line: right bank bed level, red line: left bank bed level, yellow line: average bed level.

This study investigates the effects of using bottom structures with various configurations (length, location, and number) on alternate bar-size reduction.

Methods

To achieve the goals of this research, a 2DH morphodynamical model of a straight alluvial channel with alternate bars was set up using the Dleft3D code, version 4. To have a realistic virtual river, characteristics of the Waal River, in the Netherlands, were imposed to the model, starting from the work of Duró (2014).

The virtual river has a uniform discharge of 1600 m³/s (bankfull discharge of the Waal River), a Chèzy coefficient of 55 $m^{1/2}/s$, a longitudinal slope of approximately 10 cm/km, and uniform grain size with D_{50} of 1 mm.

These morphodynamic characteristics lead to the formation of alternate bars close to resonance (Crosato and Mosselman, 2020). The model grid consists of 16 and 384 cells covering a (250 m wide) and 15 km long river reach, the cell dimensions being about 15 m and 39 m in the transverse and longitudinal direction, respectively.

Preliminary model runs allowed selecting the numerical representation of bottom structures using Delft3D. Various scenarios are studied with the model:

- Two base-cases without any instream bottom structures represent cases of steady bars (hybrid alternate bars, as in Duró, et al. (2016)) or migrating bars (free alternate bars).
- Various scenarios with numerical structures representing bed sills or bottom groynes.
- Different configurations regarding structure's location, length (in the transverse direction), and number.

Preliminary Results

Two-base cases were generated. Hybrid bars were obtained by placing, a permanently emerging groyne obstructing 50% of the channel width near the upstream boundary (Figure 2). The groyne was enough to generate both morphodynamic instability, leading to the formation of alternate bars, and forcing, stabilising the bars while making them longer and steady.

Figure 2 Plan view of bed level in steady bars base case

Free migrating bars were obtained by introducing a small random perturbation in the transverse distribution of the inflow at the upstream boundary. This was enough to create morphological instability leading to the formation of migrating bars (Figure 3).

Figure 3 Plan view of bed level in migrating bars base case

The results of the preliminary runs to establish the best numerical representation of the structures clarified that the combination of inserting a numerical sub-grid structure called “2D Weir” and “non-erodible bed layer” does not alter the geometrical characteristics of the bars that form further downstream, which is according to theoretical expectations (Crosato and Mosselman, 2020) since these structures cause some extra forcing to the system without altering its morphodynamic characteristics.

The numerical “2D weir” computes the energy dissipation due to the presence of the structure and the “non-erodible bed layer” allows reproducing the morphological response to the rigid structure having a given top level.

About the scenarios with structures, preliminary trials were done to study the effects of different configurations on bar formation:

Location

Figure 4 shows that placing a bed sill at the pool deepest point of a hybrid steady bar affects the downstream bar amplitude more than placing the structure at other locations with respect to the same bar. The effect extended to a distance of approximately 1.5 times the bar wavelength and to a much lesser extent also upstream.

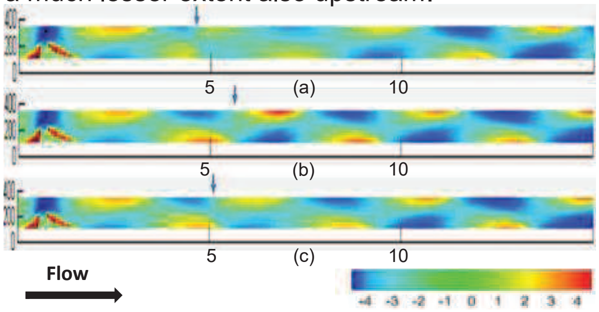


Figure 4 Plan view of bed level with different location of bed sills for hybrid alternate bars, a) pool deepest point, b) cross-over section, c) pool end section. The original hybrid bars are shown in Figure 2.

Length in transverse direction

Three different lengths (100%, 50%, and 33% of the width) were tested. Figure 5 shows that the bottom groyne covering 33% of the width maximizes downstream bar reduction. The bar amplitude decreased by 70% of the initial base-case scenario for a distance of 1 to 1.5 bar wavelength downstream and locally also upstream.

Number

Placing two structures at distances of 0.5, 1, 1.5 bar wavelengths does not increase the effectiveness in reducing downstream bar amplitude.

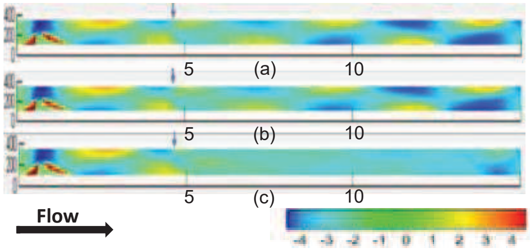


Figure 5 Plan view of bed level with different structure lengths, a) 100% of channel width, b) 50% of channel width, c) 33% of channel width.

Conclusions and recommendations

In Delft3D, the effects of bottom structures can be simulated using the combination of a sub-grid structure “2D Weir” and a “non-erodible bed layer”.

Preliminary results indicate that bottom structures might be effective in reducing alternate bar amplitude for a certain length downstream and can therefore be used to locally mitigate the negative consequences of bars. However, the investigation requires further studies, for instance by considering different bar regimes.

It is recommended to carry out additional physical experimental studies to clarify the feasibility of using this research outcome and obtain the required effects on real cases.

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