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Effect of unsteady flow on the dynamics of forced alternate bars

Shashank GUPTA, Céline BERNI, Benoit CAMENEN

INRAE, UR RiverLy, Lyon-Villeurbanne, France

Introduction

Forced alternate bars:
- ❑ large-scale bed-forms
- ❑ observed in embanked rivers but not too narrow: *B/2h* > 6 (*B:* River width, *h:* water depth)
- ❑ formed due to persistent forcing such as bridge piers or river bend
- ❑ reducing channel navigability, trapping fine sediments, inducing side bank erosion, increasing flood risk
- ❑ prediction of geometrical features under unsteady flows is crucial for river managers and engineers

Fig. 1: Forced alternate bars with vegetation in the River Arc, France. Source: www.geoportail.gouv.fr/ (2021).

Objective

- ❑ To study the dynamics of forced alternate gravel bars under unsteady flow.

Materials

- ❑ Titling flume of the Hydraulic and Hydromorphology Lab, INRAE, Lyon
- ❑ Uniformly graded gravels with median grain size of 3.5 mm

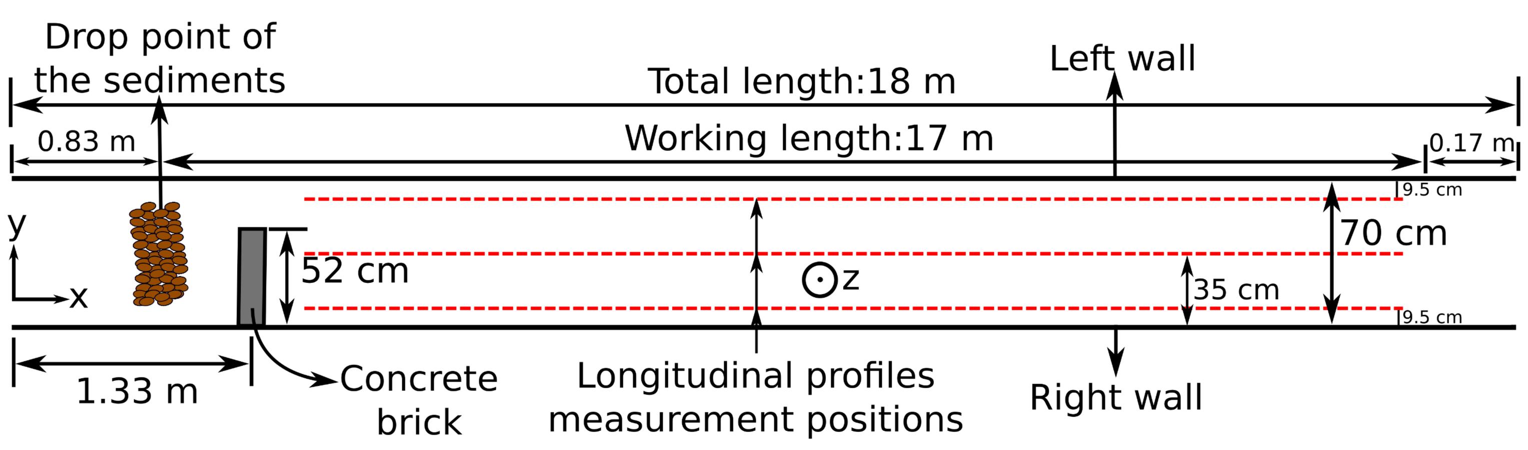

Fig. 2: Sketch of the experimental flume with concrete block to force the system persistently.

Experimental methodology

1. Created an initial state of forced alternate bars with steady water discharge (Q_w = 15 L/s)
2. Launched a triangular shaped symmetrical hydrograph over the initial state

Constant sediment supply rate = Event averaged expected sediment rate

$$Q_s = \frac{\int_0^T Q_{s,T}\,dt}{T}$$

✓ Bed slope remained nearly constant

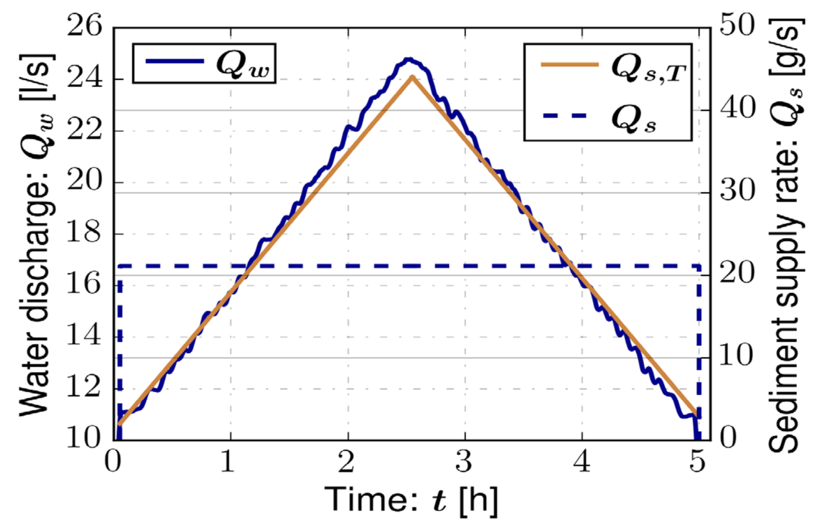

Fig. 3: Time series of the water discharge (Q_w), sediment transport capacity ($Q_{s,T}$) corresponding to the hydrograph and the constant coarse sediment supply rate (Q_s).

Forced bar characteristics before and after the flood event

State	Wavelength: λ_b [m]	Height: H_b [cm]	Relief: R_b[cm]	Length of first forced bar: L_1 [m]	Length of second forced bar: L_2 [m]
Initial	12.52	9.6	1.6	6.42	6.1
Final	13.71	10.5	1.7	7.36	6.35

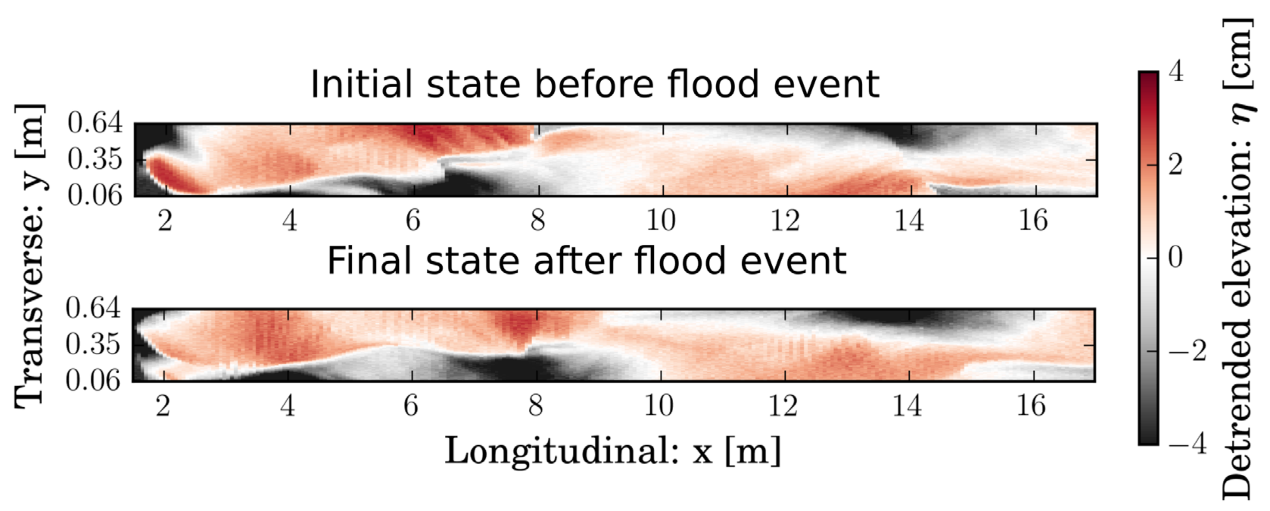

Fig. 4: Detrended bed topographies recorded before and after the flood event.

Key results:

- ❑ First forced bar shifted downstream by 1 meter and extended upstream due to overfeeding of the system at the end of the flood
- ❑ Second forced bar shifted downstream by approximately 1 meter
- ❑ Wavelength of the forced alternate bars increased by 1.2 m after the flood event

Evolution of the forced bar characteristics during unsteady flow

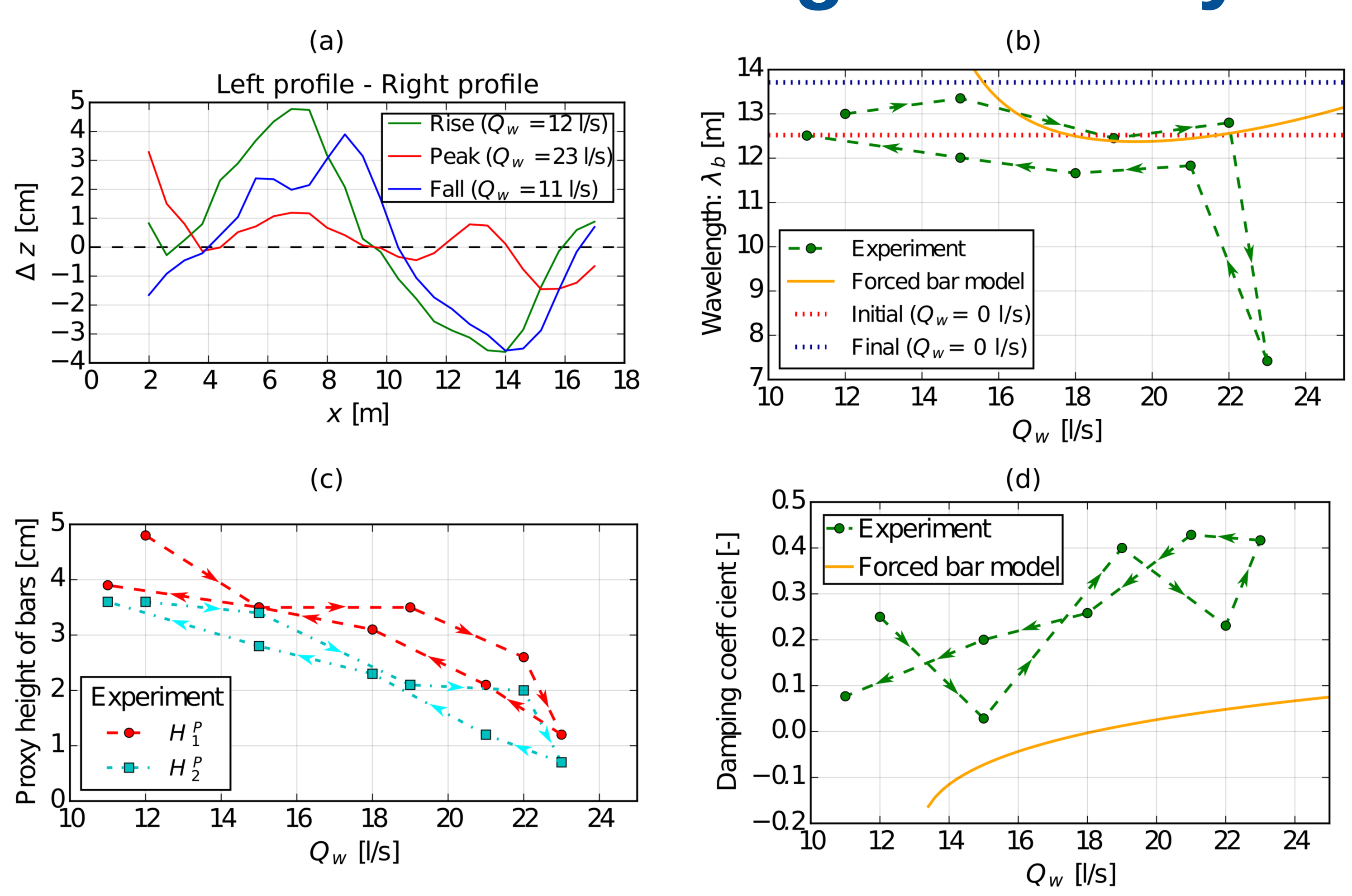

Fig. 5: (a) Difference between the left and right-side bed elevations, (b) wavelength of the forced alternate bars (distance between 2 zero-upcrossings of Δ*z*), (c) proxy heights , and (d) damping coefficient of the forced alternate bars. Lanzoni (2000) forced bar model is used to compute the theoretical values.

Key results:

- ❑ Rising limb : height ↘, damping coefficient ↗
- ❑ Falling limb : height ↗, damping coefficient ↘ leading back to initial values.
- ❑ At the peak of the flood, free bars were observed in the second half of the flume (lower wavelength and damped Δ*z*, Fig. 5a)

Conclusions

- ❑ The first forced bar was damped in the first half of the flume, and free bars were observed in the second half of the flume at the peak of the flood.
- ❑ The two forced bars re-emerged during the falling limb of the hydrograph and eventually redeveloped by the end of the flood event with a similar wavelength except at the end of the hydrograph when sediment transport capacity drops below the input, leading to upstream deposition and a larger bar length.
- ❑ The flow unsteadiness seems not to affect the dynamics of the forced alternate bars compared to steading conditions:
  - ➢ The forced bar characteristics (length, height, damping coefficient) are quite similar during the rising and falling limb of the flood event
  - ➢ The observed bar characteristics (length, damping coefficient) during the experiment matched with the theoretical values of the forced bars computed for steady discharges

Principal references

Lanzoni, S. (2000). Experiments on bar formation in a straight flume: 1. Uniform sediment. *Water Resources Research*, 36, 3337-3349.

Redolfi, M., Welber, M., Carlin, M., Tubino, M., and Bertoldi, W. (2020. Morphometric properties of alternate bars and water discharge: a laboratory investigation. *Earth Surface Dynamics.* 8, 789-808.

Acknowledgements

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