E3S Web of Conferences **40**, 02056 (2018) https://doi.org/10.1051/e3sconf/20184002056
River Flow 2018

Experimental investigation of low-angle dune morphodynamics

Suleyman Naqshband[1,*], *Bas* Wullems[1], *Timo* de Ruijsscher[1], and *Ton* Hoitink[1]

[1]Wageningen University and Research, Department of Environmental Sciences, P.O. BOX 47, 6700 AA, Wageningen, the Netherlands

Abstract. Dunes commonly dominate the bed of sandy rivers and they are of central importance in predicting flow resistance and water levels. In the present study, we show that by using light-weight polystyrene particles as substrate in a laboratory setting, promising morphodynamic similarity is obtained between dunes in shallow flow (flume) and deep flow (field) conditions. In particular, results from our flume experiments show that dune lee-side angles, which are crucial in turbulence production and energy dissipation, better approximate dune lee-side angles observed in natural channels. Furthermore, dune height evolution towards upper stage plane bed observed in the present experimental study, closely follows dune height evolution as observed in world's large rivers.

1. Introduction

River bedforms arise from the interaction between flow and the underlying sandy river bed. Dunes are the most common bedforms observed in rivers. Due to their large dimensions relative to flow depth and the formation of turbulent flow separation zones, dunes are the main source of flow roughness and they are the essential ingredient for accurate predictions of water levels during floods [1]. Particularly under increasing river discharges, dunes grow rapidly and reach heights up to several meters, resulting in a significant rise of water levels and, consequently, increase flood risk.

Dunes are traditionally studied in sand-bedded flumes, in which Froude numbers are relatively high due to limited flow depths [e.g., 2, 3, 4]. Dunes under these conditions are asymmetric and possess lee-side angels at the angle of repose of sand (~30°). Consequently, most of our understanding of dune morphodynamics, kinematics, flow resistance, and sediment transport originates from shallow flows with high Froude numbers. However, field studies over the past decades have illustrated that dunes in natural rivers are predominantly symmetric with much lower lee-side angles (~10°) and more complex lee-side morphology [5, 6, 7]. These low-angle dunes (LADs) are associated with intermittent flow separation zones, whereas laboratory generated, high-angle dunes (HADs) show a permanent zone of flow separation [8, 9, 10]. Such difference in dune morphology and lee-side flow separation zone has major implications for flow resistance and water levels.

* Corresponding author: suleyman.naqshband@wur.nl

https://doi.org/10.1051/e3sconf/20184002056

Using light-weight polystyrene particles as a substrate, in this study, we were able to generate low-angle dunes under shallow laboratory flow conditions. By limiting the Froude number, low-angle dune morphodynamics were studied for a wide range of flow and sediment conditions.

2. Methods

Experiments were conducted in the Kraijenhoff van de Leur laboratory for Water and Sediment dynamics of Wageningen University & Research. A tilting flume of 14.4 m long and 1.20 m wide was used (Figure 1). At the downstream end of the flume, a sediment trap is connected to a sediment recirculation pump. At the upstream point where the sediment-rich water re-enters the flume, a diffuser is placed to distribute the inflow over the full width of the flume. Furthermore, turbulence is suppressed by a laminator located at the upstream end of the flume.

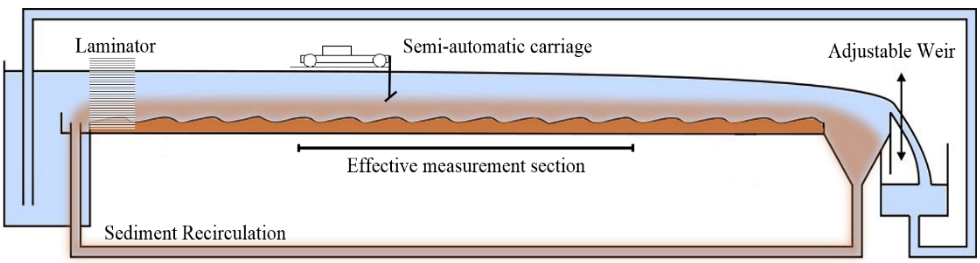

Fig. 1. Side view of the flume used, adapted from [11].

A 15 cm thick layer of light-weight polystyrene particles was installed at the flume bed with a D_{50} of 2.1 mm and a D_{90} of 2.9 mm, and a specific gravity of 1.1. A filter was installed at the end of the flume to prevent loss of polystyrene particles over the flume edge and to make sure that all particles were fully recirculated. Flow conditions were chosen such to represent the natural variability of observed suspension numbers and Froude numbers in large rivers (u_*/w_s range of 0.50 to 3.2, Fr number up to 0.15).

Flow discharge was measured continuously with an electromagnetic flow meter. Flow depths along the entire flume were measured using stilling wells. Water levels in the stilling wells were continuously recorded using magnetostrictive linear position sensors. Bed morphology was measured during certain phases of the experiment, being the initial dry-bed condition, the initial submerged condition and after reaching dynamic dune equilibrium. A line laser scanner mounted on a semi-automatic carriage was used for this purpose (Figure 2, for details see [12]). The entire flume bed was scanned with a streamwise resolution of 2 mm and a crosswise resolution of 3 mm, in four parallel partly-overlapping swipes, within a period of 2 minutes. Three transects, evenly distributed from the centre of the flume towards both side walls, were selected to monitor dune morphology (height and length statistics, together with lee-side angles) using bedform tracking tool of [13]. Average and standard deviations of dune height and length were determined over the effective measurement section of the flume.

https://doi.org/10.1051/e3sconf/20184002056

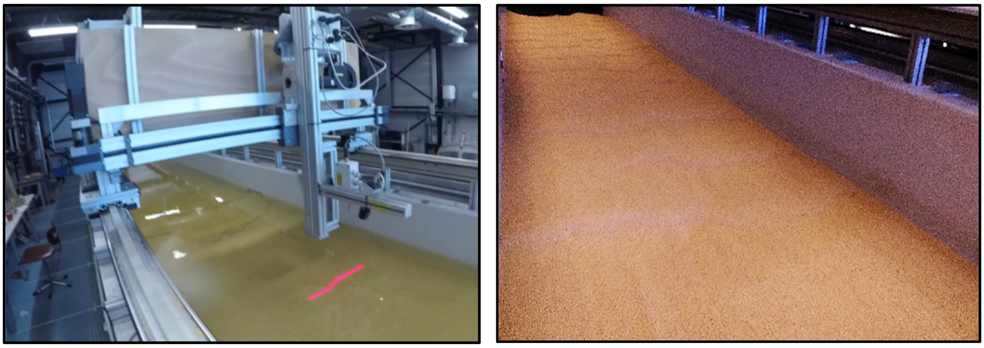

Fig. 2. Line laser scanner mounted on a semi-automatic carriage (left), and developed dune field (right).

3. Results and Discussion

Flume experiments with light-weight polystyrene particles show that dune lee-side angles considerably vary across the width of a dune, and also between successive dunes downstream as recently observed in world's large rivers, including the Amazon, Mississippi, Parana, Mekong, Columbia and Jamuna rivers [7]. Furthermore, for a wide range of flow and sediment conditions, dune lee-side angles are predominantly lower than the 30° angle of repose found under traditional flume experiments with sand (see Figure 3).

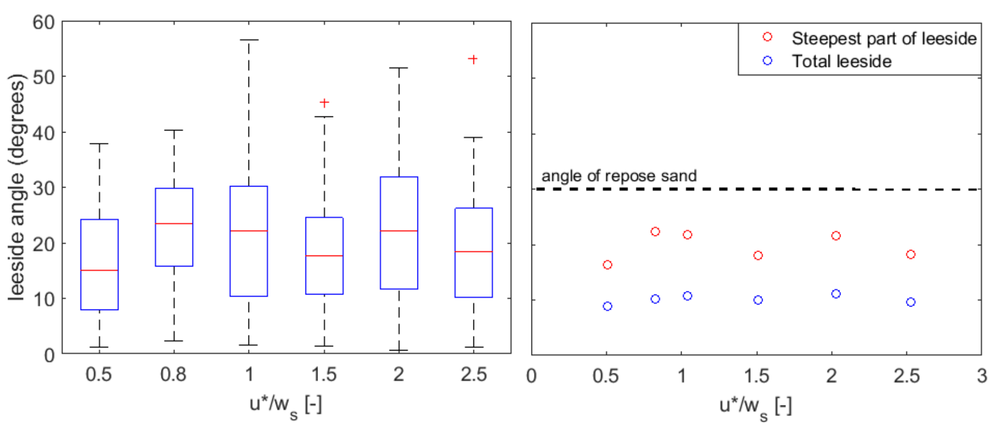

Fig. 3. Distribution of lee-side angles for the investigated range of suspension numbers, boxplot with median lee-side angles indicated with red line (left), and mean lee-side angles (right).

In addition to the promising dune dynamic similarity observed between shallow flow (flume) and deep flow (field), using light-weight polystyrene particles further result in a more realistic dune height evolution towards upper stage plane bed. By compiling and analysing a large data set (414 flume and field experiments), [2] showed that dune heights under shallow laboratory flow conditions (high Froude number) decay and dunes reach upper stage plane bed at much lower suspension numbers compared to dunes under deep flow in natural channels (low Froude number). For the investigated range of suspension numbers, average dune heights observed in the present study closely follow dune height evolution as observed in the field (see Figure 4). Figure 4 further illustrates a sequence of dune development over time, for the effective measurement section of the flume, corresponding to a suspension number of approximately 2.5.

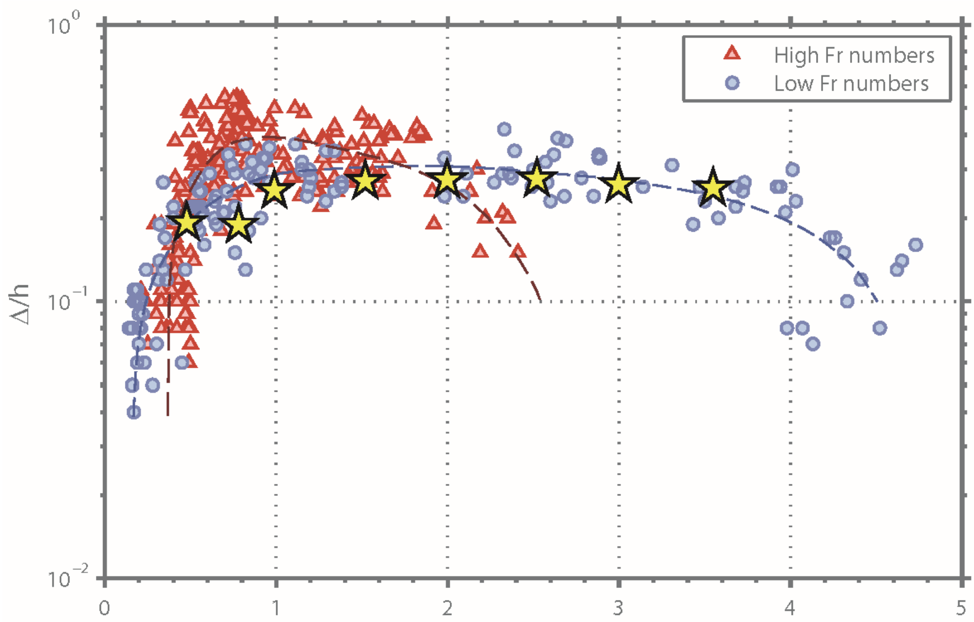

Fig. 4. Dune height evolution for shallow laboratory flow (high Froude numbers) and deep field flow (low Froude numbers) conditions, adapted from [2]. Yellow stars indicate mean dune heights observed in the present flume experiments.

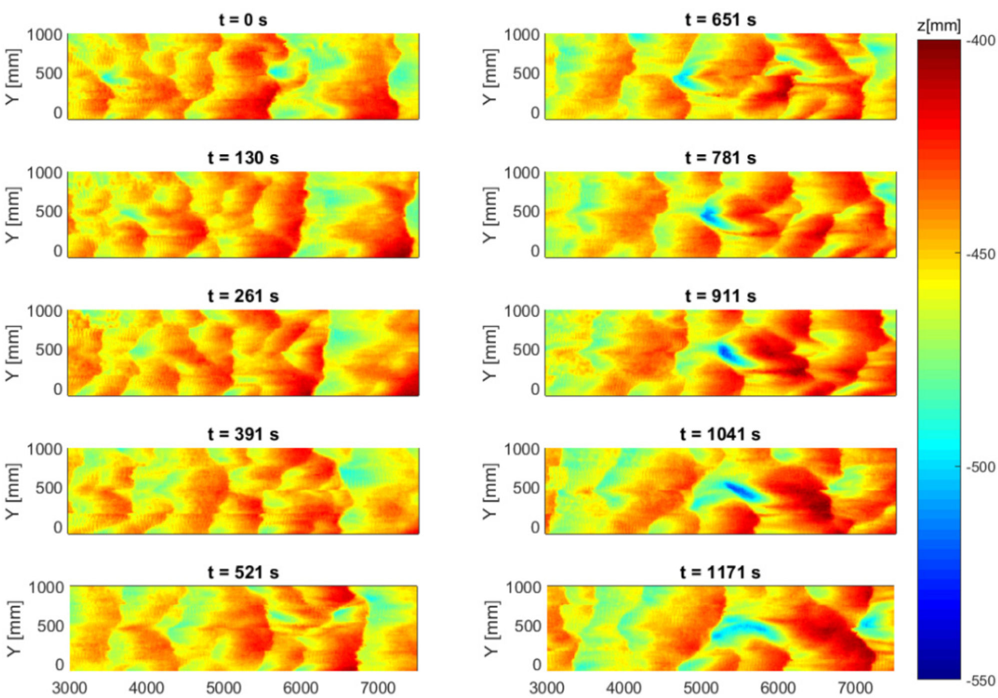

Fig. 5. Sequence of dune development over time for the suspended load dominant experimental condition ($u_*/w_s = 2.5$). X is the streamwise direction, Y is the cross-stream direction, and z is the vertical distance with respect to the mean bed elevation.

4. Conclusions

In the present study, we showed that by using light-weight polystyrene particles as substrate in a laboratory setting, promising morphodynamic similarity is obtained between dunes in shallow flow (flume) and deep flow (field) conditions. In particular, for a wide range of flow conditions, lee-side angles obtained in the present flume investigations better approximate dune lee-side angles observed in natural channels. Furthermore, dune height evolution towards upper stage plane bed observed in the present experimental study, closely follows dune height evolution as observed in world's large rivers.

Partial funding for this research was provided by the Department of Environmental Sciences at Wageningen University, and the Dutch Ministry of Infrastructure and Environment (Rijkswaterstaat, Fund 5160957319).

References

[1] J. J. Warmink, Adv. Geosci., **39** (2014).
[2] S. Naqshband, J.S. Ribberink, D. Hurther, S.J.M.H. Hulscher, J. Geo. Phys. Res., **119** (2014)
[3] J.G. Venditti, C.-Y.M. Lin, M. Kazemi, Sed., **63** (2016)
[4] S. Naqshband, A.J.F. Hoitink, B. McElroy, D. Hurther, S.J.M.H. Hulscher., Geo. Phys. Res. Let., **44** (2017)
[5] J.L. Best, P. Ashworth, H. Maminul, E. Roden, *Geomorphology and Management* (John Wiley and Sons, 2007)
[6] M.L. Hendershot, J.G. Venditti, R.W. Bradley, R.A. Kostaschuk, M. Church, M.A. Allison, Sed., **63** (2016)
[7] J. Cisneros, J. Best, *Marine and River Dune Dynamics* (MARID V, 2016)
[8] J. Best, R.A Kostaschuk, J. Geophys. Res., **107** (2002)
[9] R.W. Bradley, J. G. Venditti, R. A. Kostaschuk, M. Church, M. Hendershot, M. A. Allison, J. Geophys. Res. Earth Surf., **118** (2013)
[10] E. Kwoll, J.G. Venditti, R.W. Bradley, C. Winter, J. Geo. Res., **121** (2016)
[11] B. Vermeulen, M.P. Boersema, A.J.F. Hoitink, J. Sieben, C.J. Sloff, M. Van der Wal, J. Hydro. Res., **8** (2014)
[12] T.V. de Ruijsscher, S. Dinnissen, B. Vermeulen, P. Hazenberg, A.J.F. Hoitink, A. J. F. *NCR days 2017* (Wageningen, 2017)
[13] C.F. van der Mark, A. Blom, S.J.M.H. Hulscher, J. Geophys. Res., **113** (2008)