Free surface effect on dune morphology and evolution

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Abstract

Our aim in this paper is to illustrate the importance of free water surface effects and sediment transport mode in the morphological evolution of sand dunes to upper stage plane beds. We have analyzed a large number of bed form data, 414 experiments from flumes and field, showing significantly different evolution of dune height and length in shallow (high Froude numbers) and in deep flows (low Froude numbers). In shallow flows, dune heights are observed to grow only in bed load dominant transport regime and start to decay for Suspension numbers greater than 1. Dunes in this case are not observed for Suspension number greater than 2.5. For low Froude numbers, dune heights continue to grow from bed load to suspended load dominant transport regime. Dunes in this case are not observed for Suspension number greater than 5. Furthermore, dunes in shallow flows reach significantly greater heights compared to dune heights in deep flows and dune lengths are generally larger in shallow flows

Introduction

Dunes are common bedforms in sand bed rivers and estuaries and are of central interest for water management purposes. Due to the flow separation and associated energy dissipation, dunes form the main source of hydraulic roughness of the river bed. During floods in several rivers (e.g. Elkhorn, Missouri, Niobrara, Rio Grande), initially dunes are observed to grow rapidly as flow strength increases, undergoing an unstable transition regime after which they are washed out what is termed as upper stage plane beds. This morphological evolution of dunes to upper stage plane beds (D-USPB) is the strongest bedform adjustment during time-varying flows and is associated with a significant change in hydraulic roughness and water levels.

Hydraulic roughness due to the presence of bedforms is directly related to flow and sediment parameters, and bedform height and length. Therefore, during time-varying flow reliable predictions of bedform regimes (e.g. dune regime, dune transitional regime, upper stage plane bed USPB) and bedform dimensions are of great importance in determining hydraulic roughness and water levels for flood management purposes (Best, 2005).

From literature, we find repeatedly that dune morphology and evolution to upper stage plane beds are mainly controlled by two processes: free water surface effects and high suspended sediment transport rates of bed material. However, for the prediction of the dimension of dunes during the D-USPB regime, in literature we find predominantly empirical relations based on a limited number of mainly flume data sets with relatively high Froude numbers. These predictors relate dune dimensions to sediment transport capability of the flow and not explicitly considering free water surface effects or high suspended sediment transport of bed material. As a result, these predictors may not be suitable for the prediction of dune dimensions and the occurrence of USPB under relatively low Froude numbers in large rivers (e.g. Julien and Klaassen, 1995, figure 6 and 7).

Our aim in this paper is to illustrate the importance of free water surface effects and sediment transport mode in the morphological evolution of dunes to upper stage plane beds. We focus on the evolution of dune height and length for a large range of Froude numbers and sediment transport rates.

Method

To examine the influence of sediment transport mode and Froude number in determining dune dimensions in the D-USPB regime, we have analyzed a large number of bed form data from flumes and rivers. Based on several criteria for the classification of dunes reported by (Venditti et al., 2005: Table 1), a total of 414 data points, 187 flume and 227 field experiments, were selected, which is quite

unique compared to the number of experiments used by former authors while deriving empirical dune dimension predictors. Van Rijn's (1984c) predictor is based on 84 flume and 22 field experiments, while Karim (1995) used 71 flume and 21 field experiments for his dune height predictor in the D-USPB regime. For our analysis, we focus on dunes where ripples are excluded from the data sets as ripples scale with the grain size where dunes scale with the water depth. Furthermore, we have selected dune data such that a wide range of Froude numbers is well represented and that the flow regime is hydraulically rough.

Results and main conclusions

1. Morphological evolution of sand dunes to upper stage plane beds is controlled by the magnitude of Froude and Suspension numbers. Therefore, applying dune dimension predictors, which are mainly derived from experimental data in shallow flows (high Froude numbers), may not be suitable for the prediction of dune dimensions and the occurrence of USPBs under relatively low Froude numbers in large rivers (deep flows).
2. In shallow flows, upper stage plane beds occur for lower values of Suspension number compared to deep flows.
3. Dunes in shallow flows reach significantly greater heights compared to dune heights in deep flows.
4. Dune lengths are generally larger in shallow flows than in deep flows.

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References

Best, J. (2005) The fluid dynamics of river dunes, a review and some future research directions. J. of Geophysical Research 110, F04S02.

Julien, P. Y., and G. J. Klaassen (1995) Sand-dune geometry of large rivers during floods. J. Hydr. Engrg., ASCE, 121(9), 657–663.

Karim, F. (1995) Bed configuration and hydraulic resistance in alluvial channel flows. J. Hydr. Engrg., ASCE, 121(1), 15–25.

Van Rijn, L. C. (1984c) Sediment transport, part III: bed forms and alluvial roughness. J. of Hydraulic Engineering 110 (12), 1733–1754. DOI: 10.1061/(ASCE)0733–9429(1984)110:12(1733).