Relative role of bed roughness, bed erosion and channel storage on peak discharge increase in hyperconcentrated floods

W. Li[1], Z.B. Wang[1], D.S. van Maren[1], H.J. de Vriend[1], and B.S. Wu[2]

[1] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands.
w.li@tudelft.nl; Zheng.Wang@deltares.nl; Bas.vanMaren@deltares.nl; Huib.de.vriend@ecoshape.nl
[2] State Key Laboratory of Hydroscience and Engineering, Tsinghua University, Beijing, China.
baosheng@tsinghua.edu.cn

1. Introduction

Normal river floods are featured by a downstream flattening discharge peak while a downstream increasing discharge peak tends to occur at a rate exceeding the tributary contribution during highly silt-laden floods (hyperconcentrated floods) in China's Yellow River. It entails a great challenge in the downstream flood defence and the underlying mechanisms need to be unravelled. Previous study on this issue only focuses on one possible mechanism (Jiang et al., 2006; Qi et al., 2010; Cao et al., 2012), while the present work aims to combine the relative role of bed roughness, bed erosion and their relations to channel storage in the hyperconcentrated flood. First, a relation between the discharge evolution with distance and the time variation of channel storage is introduced based on the mass conservation law. Second, a typical hyperconcentrated flood (with very high concentration occurred in the Middle Yellow River in August 1977) is numerically investigated by a high-resolution fully coupled morphodynamic model of non-capacity sediment transport under the framework of a structured finite volume method. At last, the relative role of bed roughness change, bed erosion and channel storage change will be discussed based on the theoretical analysis and modelling results.

2. Results

2.1 Channel storage analysis

Spatially integrating the mass conservation equation (Eq. (1)) leads to Eq. (2):

$$\frac{\partial \zeta}{\partial t}+\frac{\partial hu}{\partial x}=0 \qquad (1)$$

$$q_2 - q_1 = -\frac{\partial V_{str}}{\partial t} \qquad (2)$$

where ζ is water level, h is water depth, u is velocity, x is horizontal coordinate, t is time, $q_{1,2}$ are discharge at the up (down) boundaries of a reach, V_{str} is channel storage (underneath the water surface) along the reach.

It shows that the simultaneous downstream discharge is higher than the upstream discharge when the channel storage decreases in time. Therefore considerable reduction of channel storage should occur during a flood peak increase event between the occurrence of the upstream and downstream flood peaks.

2.2 Modelling results

The modelling results show that the downstream peak discharge increase can be satisfactorily reproduced when the effects of sediment concentration and flow regime on bed roughness are considered. Only under (unrealistically) extreme bed erosion, this phenomenon can be also reproduced with a constant bed roughness but at less pronounced than the effect of bed roughness.

In cases of both bed roughness reduction and extreme bed erosion, the downstream peak discharge increase occurs accompanied by a considerable channel storage reduction during the period between the upstream and downstream flood peaks, which is in line with Eq. (2). For the former condition, the channel storage reduction is due to flow acceleration by bed roughness reduction. For the latter, it results from a dramatic drop of water surface by strong bed erosion.

3. Conclusions

The effect of bed roughness change in hyperconcentration is demonstrated to play a dominant role in the downstream peak discharge increase for a hyperconcentrated flood of very high concentration and strong bed erosion. The contribution of bed erosion only becomes significant in case of extreme bed erosion which rarely occurs.

Though having distinct mechanisms, both extreme bed erosion and bed roughness reduction result in considerable channel storage reduction and thus intensify the flow propagating downstream during the peak period of the hyperconcentrated flood. As a result, a downstream increasing discharge peak possibly occurs in these two conditions with considerable channel storage decrease.

Acknowledgments

This research is supported by the China Scholarship Council (2008621194) and the Sino-Dutch collaboration project (08-PSA-E-01).

References

Cao, Z. X., Li, Z. J., Pender, G., and Hu, P. (2012). Non-capacity or capacity model for fluvial sediment transport. *Water Management*, 165: 193-211.

Jiang, E. H., Zhao, L. J., and Wei, Z. L. (2006). Mechanism of flood peak increase along the Lower Yellow River and its verification. *Journal of Hydraulic Engineering*, 37(12): 1454-1459 (in Chinese).

Qi, P., Sun, Z. Y., and Qi, H. H. (2010). *Flood discharge and sediment transport potentials of the Lower Yellow River and development of an efficient flood discharge channel (in Chinese).* Yellow River Hydraulics Publisher, Zhengzhou, China.