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The Future River

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Turbulence in scour holes of sharp bends

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Introduction

Many deep and stable scour holes were recently observed in sharp bends along the Mahakam River in Indonesia (Vermeulen et al., 2015). Understanding where they may develop, how deep they can become and why they remain stable is important for the safety of buried infrastructure (Sawatsky et al., 1998, Beltaos et al., 2011) and buildings near the river banks (Klingeman et al., 1984, Huismans et al., 2016). However, the current knowledge is insufficient to explain the cause of the observed characteristics in scour holes of sharp bends (MacVicar and Rennie, 2012, Vermeulen et al., 2015).

A detailed study of the hydrodynamics in scour holes may elucidate the physical processes that govern the dynamics of scour holes. Here, we explore the possibility to quantify terms in the momentum balance from in situ field measurements (Niesten, 2016) and compare them with the results of a hydrodynamic model (Vermeulen et al., 2015).

Methods

Detailed flow velocity measurements, collected in one of the sharp bends with a scour hole in the Mahakam River, are used for a quantitative study. The scour hole in this sharp bend is representative for other scour holes found in the river (Vermeulen, 2014). The data was collected with an Acoustic Doppler Current Profiler at seven transects around the scour hole (Fig. 1). The data is processed in such way, that most terms in the Reynolds Averaged Navier Stokes equations could be determined. We analyzed the terms in the balances, and determined the relative contribution of accelerations, pressure gradient and the divergence of the Reynolds stresses.

We compared these field based results, with the results obtained from a three-dimensional finite element model (Vermeulen et al., 2014). The model results are evaluated in such way that the terms in the momentum balance can be studied along the whole bend. Therefore, the curved coordinate system is transformed into rectangular coordinates, which makes it easier to compare the processes at different locations along the bend. The results from the hydrodynamic model were calibrated with the data from the flow velocity measurements and show good agreement (Vermeulen et al., 2015) (Fig. 2).

Results

A comparison between the terms in the momentum balance along the bend, reveals, as expected, a large influence of the scour hole. In the streamwise and transverse momentum balance, the dominant terms upstream and downstream of the scour hole are the acceleration and pressure gradient. In the scour hole, the turbulent stress gradient increases and reaches the same values as the other two terms. In the vertical momentum balance, the
pressure gradient and the turbulent stress gradient show a huge increase in the scour hole and become more than 6 times larger than the acceleration (Fig. 3).

A detailed evaluation of the terms in the vertical momentum balance reveals that the large increase of the turbulent stress divergence is mostly caused by an increase in the vertical normal stress. Because there is no vertical flow at the water surface and the river bed, the normal vertical stress also vanishes. The largest variances are found around mid-depth in the deepest part of the scour hole. This may explain why the normal stress gradient in vertical direction shows such a huge increase (Fig. 4).

**Conclusions**

A study of how the terms in the momentum balance change near a sharp bend with a scour hole reveals that the turbulent stress divergence strongly increases in the scour hole and becomes a significant term in the vertical momentum balance. First, this suggests that turbulent stresses are important to consider in improving the understanding of scour hole formation and stability. Furthermore, this result confirms that advanced turbulent models (such as LES) are needed to reproduce the flow through scour holes. This also highlights the need to develop new techniques to measure turbulent stresses in the field, to understand the dynamics of complex three-dimensional flow.

**References**


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