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Automatic calibration of a 3-D morphodynamic numerical model for simulating bed changes in a 180° channel bend

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ABSTRACT

Sediment transport in meanders is a complex phenomenon due to its three-dimensional behavior (i.e., the presence of secondary currents). As a result, in river bends, sediments are eroded from the outer bank, resulting in depositions at the inner bank. In order to describe the complexity of flow characteristics and sediment transport mechanisms in river bends, the use of three-dimensional numerical models is essential. Nevertheless, these models are highly parameterized; therefore the model calibration process becomes demanding. Model calibration has been traditionally accomplished manually by trial-and-error adjustment of parameters until reaching a satisfactory agreement between simulated and measured values. This method can become time- and cost-consuming owing to the high number of model runs. Using optimization methods for model calibration can diminish the manual effort and avoid users' subjectivity. Besides, it helps to decrease errors caused by wrong assumptions and unrealistic combinations of involving parameters.

In this study, the 3-D numerical model SSIIM 2 (Olsen 2014), which solves the Reynolds-averaged Navier-Stokes (RANS) equations on an adaptive three-dimensional non-orthogonal grid is used to simulate the flow field as well as morphological bed changes in a U-shaped bend. The model uses a finite-volume approach for the spatial discretization and an implicit scheme for the temporal discretization. Concerning the RANS equations, the Reynolds stress term is computed by the standard k–ε turbulence model. The semi-implicit method for pressure-linked equations (SIMPLE) is used to evaluate the pressure term, and the convective term is modeled by using the second-order upwind (SOU) scheme. A Dirichlet boundary condition is defined for the inflow, whereas regarding the outflow, a zero gradient boundary condition is applied. Wall laws are used for the sides and the bed. The free water surface is calculated according to the computed pressure field using the Bernoulli equation. The computation of the sediment transport is carried out by four different formulae (i.e., Einstein, Engelund-Hansen, van Rijn and Wu).

The model calibration is performed using the model-independent parameter estimation software PEST (Doherty 2016); applying the gradient-based Gauss-Marquardt-Levenberg (GML) algorithm for iterative progress refinement by minimizing the sum of the squared errors between the model-generated values and the corresponding measured data. Bed roughness, active layer thickness and the volume fraction of compacted sediments in the bed deposit in comparison to the water content were investigated as calibration parameters against the experimental data. Figure 1 shows the normalized bed deformations (by means of the bed level changes and the initial water level $\Delta Z/h_0$) regarding the best numerical model (i.e., using the Wu's bed-load formula) and the measured bed level changes.

The results of this study reveal that the use of PEST can considerably expedite and facilitate the model calibration procedure by reducing the user-intervention. The general characteristics of the bed deformations as well as the magnitude of the deposition heights and erosion depths are well reproduced by the numerical model in most parts of the investigated domain. The formula by van Rijn using the hiding-exposure approach of Wu also provides reasonably acceptable results.

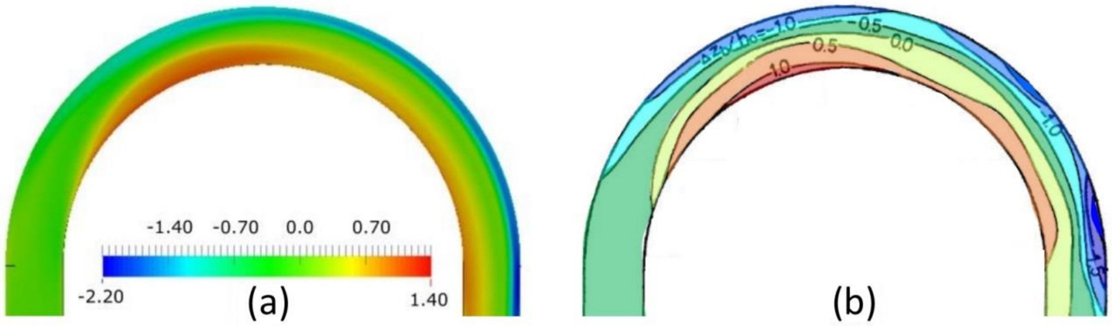

Fig. 1. Plan view of the normalized bed deformation; (a) simulation results using Wu's formula, (b) experimental data from the physical model.

REFERENCES

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