Numerical simulation of sediment redynamisation measures in the Old-Rhine

Simulation numérique de mesures de redynamisation sédimentaire sur le Vieux-Rhin

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RÉSUMÉ

Le Rhin entre les barrages de Kembs et de Breisach a été chenalisé par Tulla au milieu du XIX^{ème} siècle, et court-circuité par le Grand Canal d'Alsace, achevé en 1959. Aujourd'hui, le Vieux-Rhin, long de 45 km, présente un lit incisé et armuré, le transport sédimentaire et l'évolution des formes fluviales n'étant que relictuel. Afin d'améliorer l'habitat écologique, le gestionnaire de l'aménagement (EDF) et les collectivités envisagent de développer différentes mesures de redynamisation sédimentaire, notamment à travers le projet Interreg sur la redynamisation du Vieux-Rhin (2009-2012). Ainsi, un essai grandeur nature d'injection de graviers a été réalisé et suivi avant et après la crue de l'automne 2010. Des modélisations physiques du transport de graviers sur lit armuré, ainsi que d'essais d'érosion latérale maîtrisée ont été conduits dans les laboratoires du LWI (Braunschweig, Allemagne) et d'EDF-R&D (Chatou, France), respectivement. A partir de ces expériences et de données de la littérature, des modèles numériques 1D et 2D ont été développés pour reproduire l'évolution du lit et les processus granulométriques entraînés par de telles mesures de redynamisation. En effet, des outils numériques adaptés sont nécessaires pour prédire précisément l'efficience et les risques associés à des opérations de redynamisation sédimentaire extensives. Nous présentons d'abord des résultats obtenus avec le modèle 1D RubarBE sur des expériences en canal reproduisant un dépôt continu (Seal et al., 1997) et du charriage sur la couche d'armure du Vieux-Rhin. Le modèle a ensuite été appliqué à l'essai d'injection grandeur nature et à différents scénarios de redynamisation. Le charriage et les évolutions morphodynamiques ont également été simulés localement à l'aide du modèle 2D Rubar20TS.

ABSTRACT

The Rhine river between Kembs dam and Breisach dam was channelised by Tulla in the mid 1800's and by-passed by the man-made GCA canal (Grand Canal d'Alsace), which was completed in 1959. Nowadays, the 45-km long so-called Old-Rhine exhibits an incised and armoured bed with only relictual sediment transport and bedform evolution. In order to improve ecological habitat, the hydropower scheme manager (EDF) and local authorities are considering to develop a range of sediment redynamisation measures, through the Interreg project for the Rest-Rhine redynamisation (2009-2012). A real-scale gravel injection test was conducted and monitored before and after the 2010 autumn flood. Physical modelling of gravel transport above an armoured bed and of controlled bank erosion tests were also achieved at the LWI (Braunschweig, Germany) and EDF-R&D (Chatou, France) laboratories, respectively. Based on these experiments and on data from the literature, 1D and 2D numerical models were developed in order to reproduce the bed evolution and grain size processes induced by such redynamisation measures. Indeed, appropriate numerical tools are required to accurately predict the efficiency and risks associated with extensive sediment redynamisation operations. First, we introduce simulation results obtained with the RubarBE 1D model against flume experiments of a deposit aggradation (Seal et al., 1997) and of bedload transport above the Old-Rhine armoured layer. Then, the model was applied to the real-scale injection test and to a range of redynamisation scenarii. The local bedload transport and morphodynamic changes were also simulated using 2D hydrodynamic modelling (Rubar20TS code).

MOTS CLES

Charriage, morphodynamique, redynamisation sédimentaire, simulation numérique, Vieux-Rhin.

1 INTRODUCTION

The Rhine river between Kembs dam and Breisach dam was channelised by Tulla in the mid 1800's and by-passed by the man-made GCA canal (Grand Canal d'Alsace), which was completed in 1959. Nowadays, the 45-km long so-called Old-Rhine exhibits an incised and armoured bed with only relictual sediment transport and bedform evolution. In order to improve ecological habitat, the hydropower scheme manager (EDF) and local authorities are considering to develop a range of sediment redynamisation measures, in particular through the Interreg project for the Rest-Rhine Redynamisation (2009-2012). Appropriate numerical tools are required to accurately predict the efficiency and risks associated with extensive sediment redynamisation operations. This paper presents some results obtained using 1D (RubarBE) and 2D (Rubar20TS) numerical simulation.

2 MODEL CALIBRATION AGAINST FLUME EXPERIMENTS

2.1 Continuous deposit aggradation

Seal et al. (1997) reported the comprehensive results of their flume experiment of downstream sediment fining during continuous aggradation. This experiment was used by many authors as a validation test for multi-class morphodynamical models. In contrast, in the RubarBE model the grain size distributions of sediment populations are represented by their median diameter *d* and sorting coefficient *σ*. This simpler representation allows for a robust parameterization of the sediment processes based on usually low-resolution grain size data. The diffusion observed in the sediment transport and grain size processes (evolution of *d* and *σ*) are accounted for using three adaptation length parameters, L_s, L_d, L_σ, corresponding to different space scales.

The simulation of this flume experiment appeared to be very useful to assess the validity of the model assumptions and to define a logical calibration method for L_s, L_d, and L_σ parameters. Fig.1 illustrates the satisfactory results that were obtained as regards the evolution of the gravel deposit during the experiments, using the Meyer-Peter and Müller capacity formula and a sediment transport adaptation length L_s = 3 m (mesh step is 1 m). The observed downstream sediment fining and sorting were also acceptably reproduced, using significantly larger adaptation lengths for grain size processes: L_d = 9 m, L_σ = 100 m. In turn, the calibration of grain size parameters L_d and L_σ improved the morphological results. These calibration results on such a comprehensive dataset are of high interest for further simulations of redynamisation tests and scenarii in the Old-Rhine.

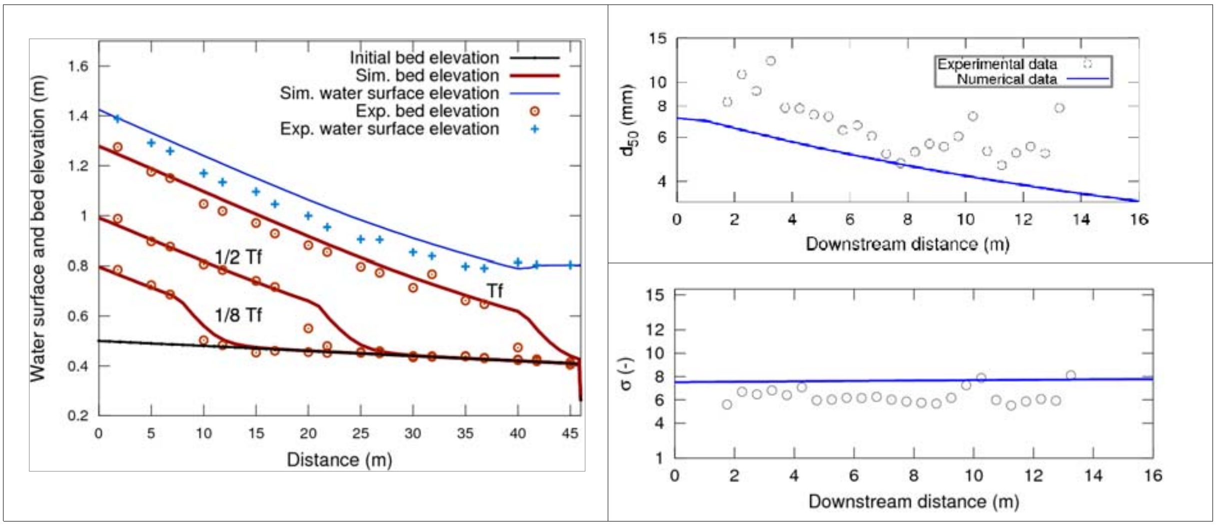

Fig.1 – Simulation of the gravel deposit evolution in Seal et al. (1997) experiments (final time Tf = 16.83 hours): morphological evolution (left) and grain size parameters in the surface layer at final time (right)

2.2 Bedload transport above an armoured layer

Using sediment grain size distributions reduced by a 1/3 scale factor, Koll et al. (2010) conducted flume experiments aiming at assessing the stability of the armouring layer of the Old-Rhine bed when finer gravels are transported above it. Armouring of the bed was carefully reproduced in the laboratory. Then a deposit of colored sediment tracers was introduced and transported above the armour layer.

Their dissemination was monitored using image analysis. Tracers and sediment from the armour layer which were exported out of the flume were weighted and sized. Several of these runs were simulated using the 1D RubarBE model. The formation of the armour layer was difficult to reproduce unless its typical height is specified as a prior related to the size of the largest particles. The transport of the tracers above a stable armour layer was correctly reproduced even if some wall effects could not be taken into account in a 1D model. Simulated sediment exchanges with the armour layer were weak, and all the tracers were finally exported from the flume, whereas at the end of the experiments the isolated tracers were finally hidden and stopped by larger particles of the armour layer.

3 SIMULATION OF SEDIMENT REDYNAMISATION MEASURES

3.1 Real-scale injection test (2010)

In Autumn 2010, the German and French partners of the Interreg Projet conducted a real-scale injection test. Using non-sorted sediment excavated in the German floodplain, an artificial bar was built in the main channel along the right bank. The bar was 620 m long, 11.5 m wide, with edge slope 40°, and total volume 23 000 m³. The topography was monitored by CNRS before and after the flood that occurred a few weeks later (peak discharge 1140 m³/s at Rheinweiler gauging station, WSA). The bar was almost entirely eroded during that flood, and particles were scattered all over the main channel downstream. The individual trajectories of several hundreds of gravel tracers, equipped with passive transponders, were also surveyed. Preliminary 1D and 2D simulations of this real-scale injection test were achieved. As can be seen in Fig.2, 1D modelling predicted a realistic erosion of the artificial bar, along with the dissemination of transported particles in the main channel. Though a 1D model cannot provide accurate information on the deformation of a bar without additional calibration, the test shows that it can be used to assess the long-term evolution of the bed after a reinjection operation. To get a closer view to the local hydrodynamic conditions, sediment transport and deformation of the bar, a 2D model was also built and calibrated. Such simulations appear useful to predict the short-term bar evolution under a given flood magnitude and duration.

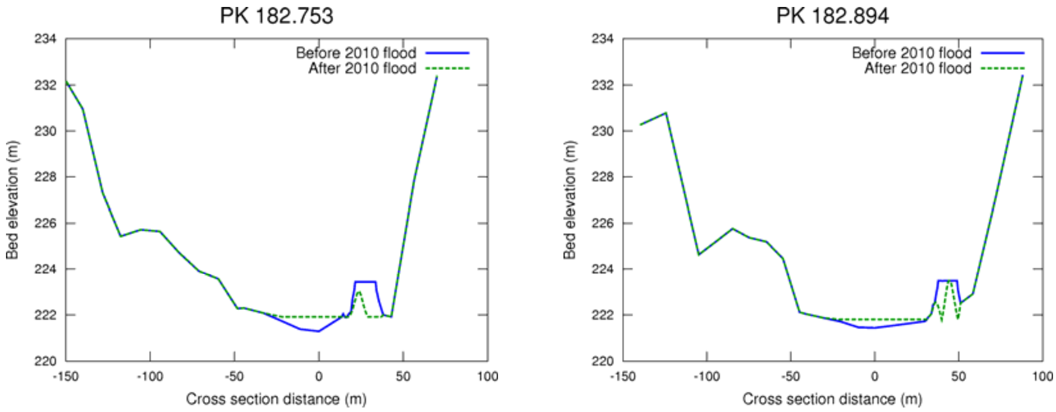

Fig.2 – Simulated morphodynamical evolution of the injected gravel bar after the 2010 flood, in the cross-sections located at kilometer points 182,753 and 182,894

3.2 Sediment redynamisation scenarii

Eventually a set of sediment redynamisation scenarii will also be numerically simulated. In particular, the redynamisation operations planned and studied by EDF include direct injection tests, bed reprofiling with side-arm activation, and bank erosion enhancement (El kadi Abderrezzak et al., 2011). Numerical simulation tools will be helpful for assessing the potential interferences of such a combination of redynamisation measures, in terms of morphological adjustments, erosion or overflooding risks, substratum improvement and bedform reactivation.

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