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TAKING ACCOUNT OF LANDSLIDES IN 2D HYDRODYNAMICS MODELING

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Abstract: Riverbanks are subject to geotechnical instabilities, which are often difficult to consider during hydraulics modeling since the available software doesn't take account of riverbanks instabilities. This paper proposes an approach combining a slope stability module, BISHOP, with a 2D hydraulic model, SRH2D, to have a completely two-dimensional river modeling. After generating the river's mesh, BISHOP can be launched through an input data file containing the riverbank profile defined from the pre-established mesh. If a riverbank fails, all the mesh nodes belonging to the sliding area, defined as a slip cone, whose characteristics will be fixed based on geotechnical observations, will be automatically updated, allowing a newly defined geometry of the river and its banks. The Ha!Ha! River, in Quebec, will be used to test the proposed approach. A comparison between the predicted and observed results will be presented and discussed.

Keywords: Two-dimensional modeling; SRH-2D; 2D riverbank sliding; automatic coupling; BISHOP; stability analysis.

1 Introduction

Currently, multidimensional simulation models are increasingly used to predict channel responses. During violent floods caused by heavy torrential rainfalls or dam failures, the flood risk area is not restricted to the rising floodwaters simulated by hydraulic models, but also includes the riverbank failure area. The proposed approach involves coupling the channel hydraulic and the geotechnical responses, to achieve an accurate definition of the areas of potential risk.

Herein, a section of the Ha! Ha! River will be modeled with nine bank profiles. The two-dimensional model SRH-2D developed by the US Bureau of Reclamation (Lai, 2008) is used for the hydraulic and sedimentation part, and the BISHOP module developed by Mahdi (2003) will be used for the geotechnical part. The coupling of the two models will be done automatically at each chosen time step to update channel topography on SRH-2D in case of a potential bank failure.

2 Methodology

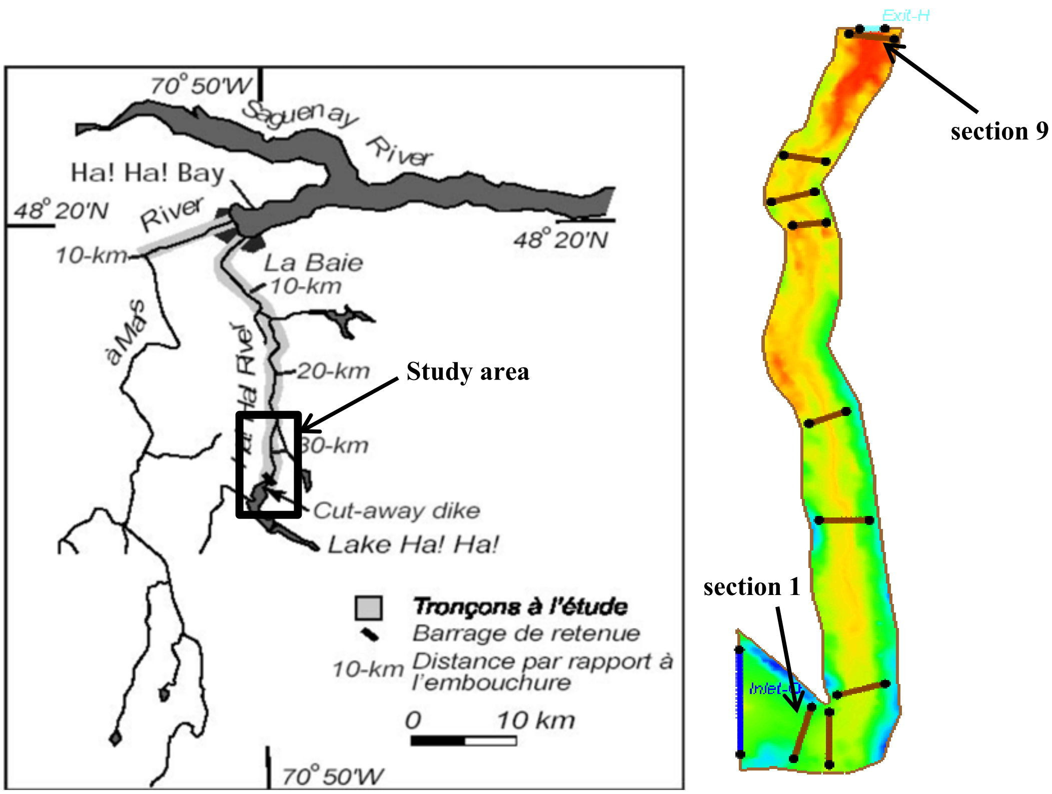
To take account of the riverbank failures during the simulation, the method adopted couples a two-dimensional flow and a sediment transport model ,SRH-2D, which provides the channel adjustments due to erosion, with a module stability analysis ,BISHOP, to assess stability of the chosen cross-sections. At each time step, the algorithm automatically utilizes the bed topography supported by SRH-2D to update the geometry of the cross-sections in the input files of BISHOP. The module tests their geotechnical stability before continuing simulation with SRH-2D.

3 Models presentation

3.1 SRH-2D model

The SRH-2D (Sedimentation and River Hydraulics - Two-Dimensional) model is a two-dimensional model for flow simulation and sedimentary computation. Besides its mesh flexibility, SRH-2D is an efficient and robust model that adopts an implicit numerical scheme based on the finite volume method.

A complete analysis with SRH-2D might be done with SMS (Surface water Modeling System), a mesh generator developed by Aquaveo. SMS offers the possibility to defining the initial solution domain, by introducing the channel's topographic and bathymetric data, before fixing the channel's materials and boundary conditions. Then exports all the simulation data into files that can be used by SRH-2D. The results of simulations can be obtained, in several forms, for the chosen time step. In the current research we are interested by the results obtained on the mesh nodes, which will be used to renew the information on each bank node in the input files of the BISHOP module.



(a) (b)

Figure 1: (*a*) Ha!Ha! River and domain area (Adapted from Mahdi and Marche, 2003); (*b*) Modeling of the domain area on SMS within the 9 cross-sections

3.2 BISHOP module

BISHOP is a geotechnical analysis module developed by Mahdi (2003) based on Bishop's modified method (Philipponnat and Hubert, 1979) for calculating the minimum factor of safety. Stability analysis is carried out based on the approach of circular failures; a type of riverbank fails often noticed *in-situ* (Philliponnat and Hubert, 1979).

BISHOP takes into account the bank geometry, geotechnical properties as well as pore water pressure conditions, through text files, defining the characteristics of each bank separately (two banks per hydraulic section). BISHOP has been tested and compared previously to other commercial software (Mahdi, 2003) and proved its ability to accurately evaluate the force equilibrium factor of safety for circular failures. Interested readers can refer to Mahdi (2003) for further details. For all its capabilities, the BISHOP module was employed in this study, especially, to make the coupling between the two models completely automatic.

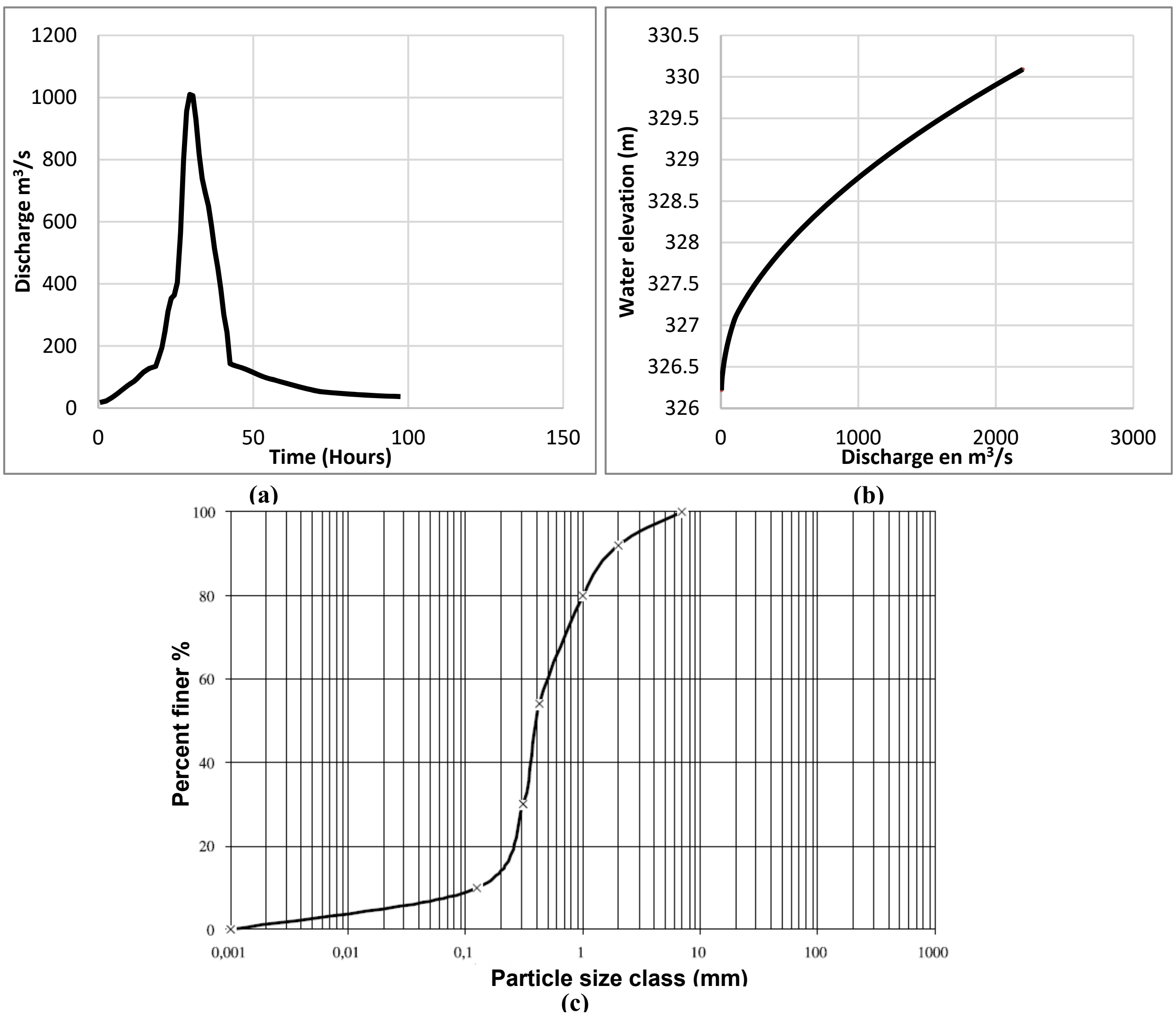


Figure 2: (*a*) Flood hydrograph at the upstream; (*b*) Rating curve at the downstream; (*c*) Bed and bank material size distribution (Adapted from Mahdi and Marche, 2003)

3.3 SRH-2D with BISHOP

After defining the cross-sections and preparing the simulation on SMS, the files containing all the information about the simulation can be exported, and the SRH-2D can be launched. At each time step chosen to test the stability, which can be different than the time step for SRH-2D, the SRH-2D's bed elevation results are obtained at the mesh nodes of the banks' profiles. From these results, the automation algorithm will update cross-sections geometry in the input files, of the BISHOP stability analysis module.

After geotechnical analysis, in case of failure (the driving forces exceeds the stabilizing ones) the bank profile will be reshaped, and the mesh on the bed topography on the input file of the SRH-2D processor will be updated automatically to accommodate bank failure before moving to the next time step.

In this paper, the sliding bank area will be considered in the form of a cone, having its top as the upper point of intersection between the riverbank and the slip circle, and its slope is defined by the user through *in-situ* observations. By adopting this approach, the bed elevation of all nodes located inside the sliding cone area will be automatically interpolated to ensure a two-dimensional bank slip, and thus a wholly two-dimensional hydrodynamic simulation accounting for riverbank failures.

4 Application

The proposed methodology will be applied to the rupture of the "Cut-away" dike located on the Ha! Ha! River in Quebec due to the exceptional rainfall of 1996. The flood wave caused a major change in the morphology of the river as result of heavy erosion.

The study area extends over a distance of 9 km from the dike to the first falls (Figure 1*a*). The study area was modeled with nine cross-sections irregularly spaced to better take into account the hydraulic features of the channel (Figure 1*b*).

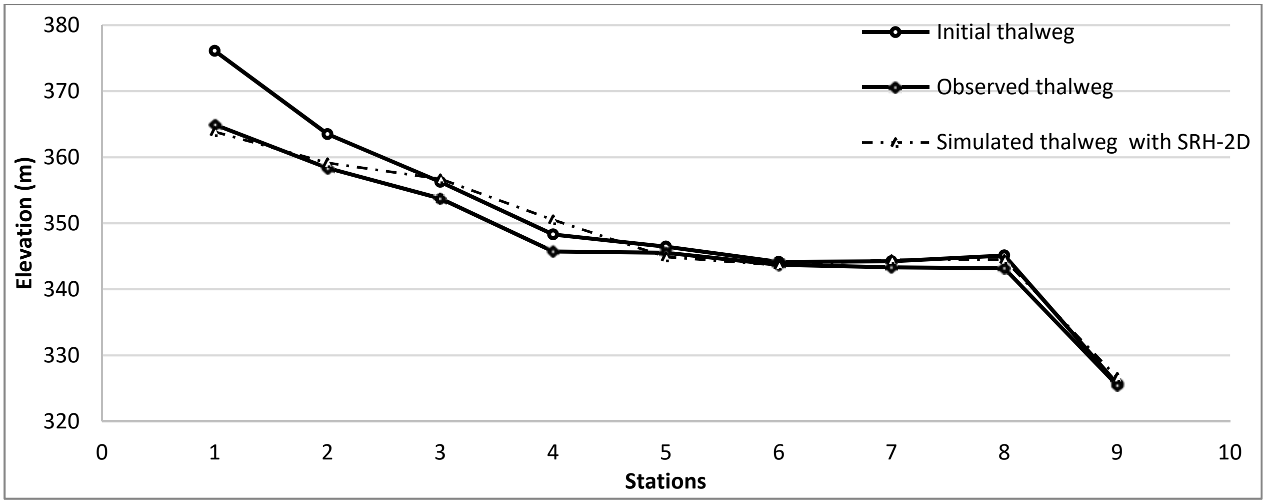
To start the simulation, a flood hydrograph was imposed at the upstream (Figure 2*a*) and a developed stage-discharge rating curve at the downstream (Figure 2*b*), the Manning's roughness coefficient is 0.013 and the bed material size distribution given by Mahdi and Marche (2003) (Figure 2*c*) is used for the entire river reach. The riverbanks consists of a single homogeneous cohesive layer, with a low effective cohesion of 9 kPa due to the riverbank's slope ranging from 30° to 85° (Mahdi, 2003), a friction angle of 32°, a saturated unit weight of 18.6 KN/m^3 and a 45% soil degree of saturation, caused by the heavy rainfall during the event.

4.1 Results and Discussion

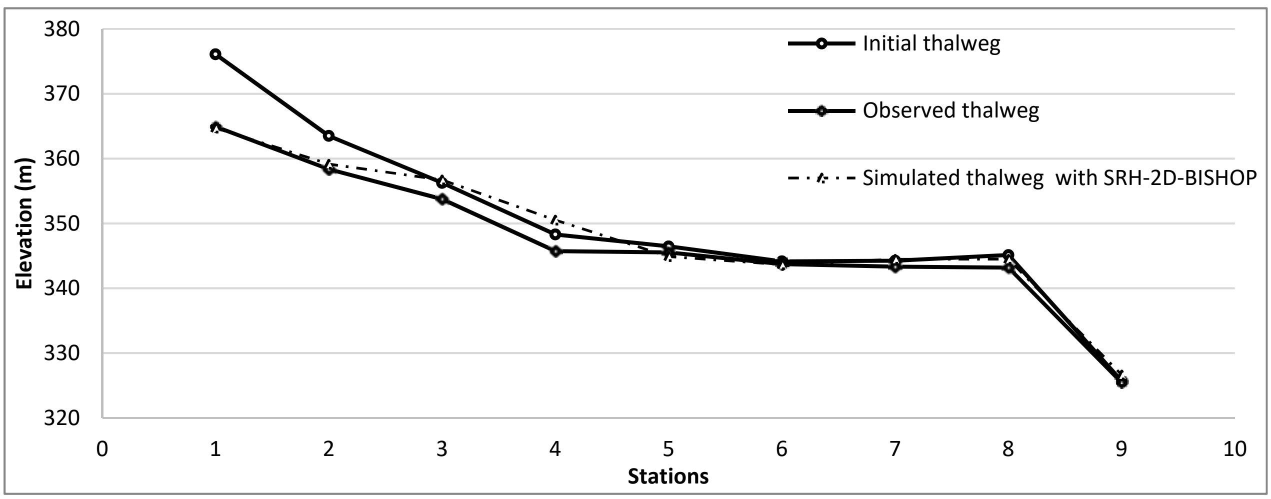
The proposed coupling between SRH-2D and BISHOP was applied for 48 hours of the event, with a 6 hours' time step, to test the stability. In this paper, we've considered two processes: First, modeling the flood with SRH-2D only, and second using the model's coupling.

The Figure 3*a* shows the longitudinal profile obtained with SRH-2D regardless of the riverbank failures. It is noted that the erosion is strong for the first sections and decreases towards the end due to a decrease in the flow velocity. From the same Figure, we can notice an agreement between the model results and the observed data, that highlight the capabilities of the model predicitions.

Once we've included the bank movements we found almost the same profile, except for cross-section 1, where we've noticed the bank failure at the last time step of the geotechnical analysis within BISHOP (Figure 3*b*), which is also 42 hours of simulation with SRH-2D. At this station, the algorithm renewed the mesh nodes of the slipped bank, before continuing with SRH-2D. Hence, we've noted that in the last 6 hours of simulation, SRH-2D eroded less at this cross-section, about 1m less (Figure 4*b*), which can be attributed to the widening of the stream channel.

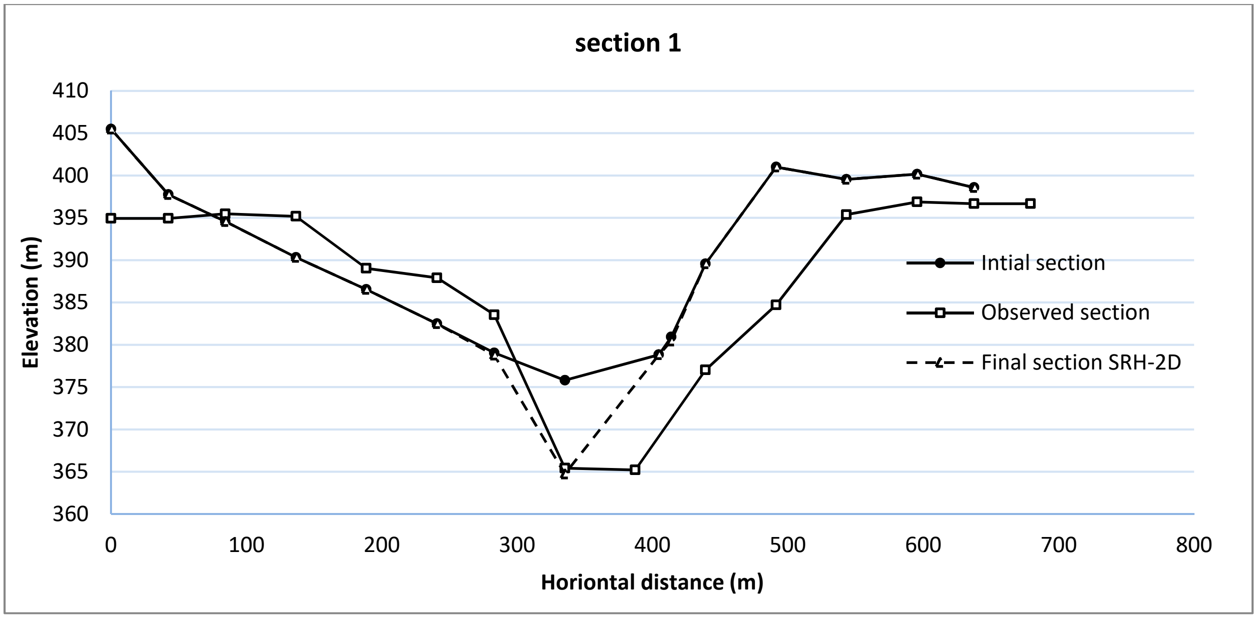


(a)

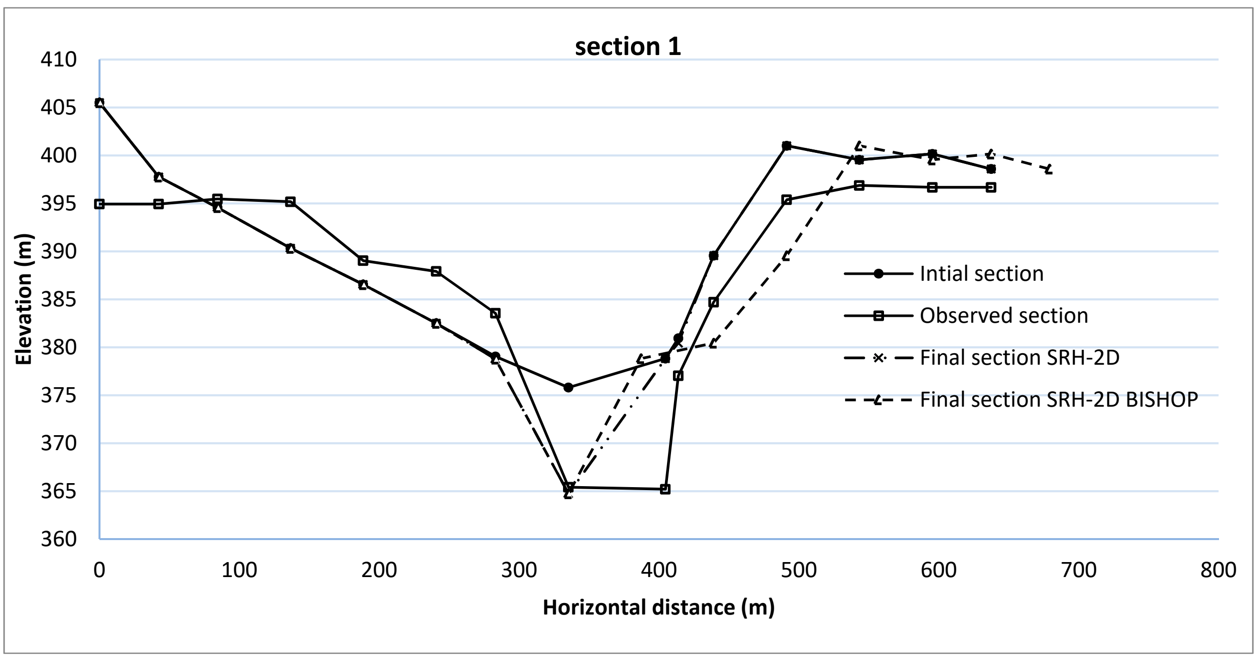


(b)

Figure 3: (*a*) Evolution of the thalweg using only SRH-2D; (*b*) Evolution of the thalweg using SRH-2D-BISHOP coupling



(a)



(b)

Figure 4: (*a*) Evolution of the cross section 1 using only SRH-2D; (*b*) Evolution of the cross-section 1 using SRH-2D-BISHOP coupling

The results obtained from the simulation seem appropriate, as we noticed a similarity between the observed and simulated data. During this flood event, it appears that the geomorphology changes, of the channel, are mainly due to erosion. The erosion at cross-section 1 is more significant in the case of simulation with only SRH-2D. However, when we've included bank failures by using the coupled model, the thalweg is closer to what was observed at cross-section 1. On the other hand, the bank profile in the same section is slightly different from what was observed in the field (Figure 3*b*), hence the interest of using a model for sediment redistribution after riverbank failure.

Despite success of the proposed coupling between the two models, the study can be further enhanced. In this field application, a mesh width of 50 m was used, and a slope of 20° was assumed for the slope failure cone. It has been noted that the interpolation of bed elevation on the sliding area occurs only at the cross-section due to the small chosen angle. Thus, the study can be improved by reducing the mesh size and redefining the failure cone angle based on *in-situ* data. Finally, the number of cross-sections can be increased to represent more accurately the channel characteristics and BISHOP's time step decreased to better predict the time of stream bank failures.

5 Conclusion

In this paper, we present our first results of the proposed coupling approach of a 2D mobile bed modeling software, SRH-2D, and a geotechnical analysis, BISHOP's module. Considering a cone failure area seems to be a good approach as it allows taking into account the two-dimensional character of bank sliding, but it requires *in-situ* data and mesh refining. The application of this approach to a Ha! Ha! River reach showed encouraging results. In case of bank failure, a sediment redistribution module, REDISSED developed by Mahdi (2003) could be coupled to the previous models, thus allowing a two-dimensional flow simulation including bank failure and sediment redistribution fully automatic.

Acknowledgment

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