Ph.D. thesis proposal

Title : **Strategy for numerical modeling of bank erosion due to river traffic**

Laboratory : **Roberval Laboratory, University of Technology of Compiègne, France**

Applicant : **CSC-student**

1) Study context

In France, river transport is in full renewal (a new trans-European project for Seine-Nord-Europe large-gauge lanes) as it fully meets the objectives of sustainable development: it reduces the saturation of roads and motorways (reduction of greenhouse gas, Kyoto Protocol); it offers a cost per tonne transported very attractive; Finally, investments in inland waterways offer advantages for spatial planning (electricity production, waste disposal of major industrial and urban centers, creation of sites suitable for industry, housing or tourism). . The intensification of river traffic on certain waterways (and in particular the Oise river which will feed the Seine Seine North-Europe Canal) is accompanied today by the will to limit the recourse to artificial and costly solutions of bank protection. (installation of sheet piles or rockfill, ...). This raises the question of the prediction of the long-term holding of the banks. To our knowledge, few investigations concern the study of riverbank erosion induced by river traffic [1]. At the present time, "pragmatic" approaches based on simplified analytical formulations that do not make it possible to give a satisfactory account of the complexity of the physical phenomena involved are privileged. This phenomenon is the combination of several processes. multi-physics involving fluid flow and its evolution under the effect of the passage of a boat but also its interaction with the porous medium that constitutes the bank and whose saturation level depends on the hydrodynamic flow.

In this context, we propose to put in place a numerical modeling strategy of the behavior of the banks under hydrodynamic flow. The bank can be seen as a porous medium subject to variable loading corresponding to the hydrodynamic flow induced by the passage of boats. Under the effect of the passage of a boat, the level of loading and the level of saturation in the bank evolve possibly inducing local overloads of the solid skeleton of the bank leading to the gradual degradation of the bank. The objective of the thesis is to propose a numerical tool to predict the evolution of the state of the bank and its possible rupture under the effect of fluctuating fluvial flow associated with the passages of the boats.

2) Details of the proposal

In order to give an account of these phenomena, the thesis work will aim to extend, the tools of description of the damage and the rupture developed within the team " Mécanique numérique " of the University of Compiègne [2,3] in the case of saturated and unsaturated porous media. A strategy to link these description tools with the river flow calculation tools used within the NHS will be developed. In particular, will be studied the effect of the establishment of natural protection (planting for example) or artificial protection of the banks. These protections have the effect of damping the waving waves induced by the passage of a boat. The numerical tool developed will enable a parametric study to be carried out on the effect of this damping on bank behavior.

The second objective of the thesis is to study the morphodynamic changes of navigable waterways. In fact, the quantities of eroded materials are transported by the fluvial stream. These quantities must be located to optimize the dredging operations necessary to maintain navigation channels. To answer this problem, the numerical tool developed in the first part of the thesis will then be coupled with a digital model of eroded substrate management to feed a sedimentary transport model (morphodynamics) based on the TELEMAC system available at the our laboratory.

The applicant must contribute to solve the following aspects of the PhD

1- To propose robust numerical methods to solve the nonlinearities.

The multiphysics coupling proposed in this thesis involves several strongly non-linear partial differential equations (PDEs) evolving in different spatio-temporal scales. It is then necessary to propose coupling strategies capable of finely solving the nonlinearities and the multitude of scales inherent to the fluid-structure coupling. On the other hand, the resolution of these equations is very expensive in computing time. It is therefore imperative to conduct a thorough study of the sensitivity of the solution to the mesh (compromise between quality and density) in order to choose the optimal mesh to correctly reproduce the waves and their characteristics.

2- Choice of the finite element ensuring the mechanical coupling of the soil/fluid mechanics

The banks failure brings uses the laws of deformable solids mechanics. These laws will be solved numerically by the finite element method. The applicant will then be confronted with the choices of the appropriate finite element (and even to propose a new element) supporting both the deformation and the constraints of the pressure provided by the fluid model.

3-Management of the amount of the eroded soil.

The displacement of a boat is accompanied by the propagation of the waves of wakes and the increase of the level of the body of water. This increase will modify the nature of the flow in the soil constituting the bank which can lead in the long term (intensified fluvial traffic) to the rupture of the bank. The PhD student will propose a numerical model to manage the fate of eroded soil amounts. The proposed model will then be coupled with a sedimentary transport model to estimate long-term morphodynamic change

3) PhD research plan

1st year) The PhD student will start with a bibliographic study on numerical modeling of flows in porous media. He will take charge of the numerical model developed at the NHS (resolution of the 2D linear nonlinear Richards equation, Hassan SMAOUI [4], [5]). He will then propose robust numerical methods for an extension to the resolution of the forced non linear Richards equation by the change of the level of the water level induced by the passage of the boats. It should be noted that to force the model, we will have access to river traffic data available at VNF (SIF: River Information Service).

2nd year) In the second year, the doctoral student will start with a bibliographic study on the mechanics of deformable solids and fracture mechanics. He will take charge of the rupture model developed at UTC by Delphine Brancherie. He will perform the coupling between this

model and the one solving the non-linear Richards equation. The coupling will require the modification of the law of the behavior implemented in the model of rupture to integrate there the aspect porous medium.

3nd year.) In the third year, the doctoral student will start with a bibliographic study on sedimentary transport and in particular on the techniques of the estimation of long-term morphodynamic change. He will then propose a management strategy for the fate of the quantity of soil eroded by bank failure. This part may seem ambitious, but the doctoral student will not develop the sediment transport model, but will use one already available in the laboratory (TELEMAC system). The second part of the year will be reserved for the writing of the manuscript.

4) References

[1] Yong G. Lai & Blair P. Greimann: Modelling bank erosion in fluvial channels. In "Flow Rivers 2012". R. E. Murillo Muñoz, Editor, pp 709-714.

[2] T. Saksala, D. Brancherie, and A. Ibrahimbegovic: Numerical modeling of dynamic rock fracture with a combined 3d continuum viscodamage-embedded discontinuity model. International Journal for Numerical and Analytical Methods in Geomechanics, 40 :1339–1357, 2016.

[3] D. Brancherie and A. Ibrahimbegovic: Novel anisotropic continuum-discrete damage model capable of representing localized failure of massive structures. part I : theoretical formulation and numerical implementation. Engineering Computations, 26(1-2) :100–127, 2009.

[4] H. Smaoui, S.Kaidi, N. Huybrechts, P.Sergent and F. Daly: Numerical modeling of bank erosion due to fluvial traffic. 34th PIANC-World Congress, Panama City, 11 pages, 2018

[5] H. Smaoui: Résolution numérique de l'éqaution de Richards non linéaire pour des écoulements en milieu poreu saturé-unsaturé , Rapport de recherche, 50 pages, 2017

[6] A. Pizzuto (2009) : An empirical model of event scale cohesive bank profile evolution. Earth Surface Processes and Landforms, Vol 34, pp 1234-1244

[7] H. Piegay, M. Cuaz, E. Javelle and P. Mandier (1997) : Bank erosion management based on geomorphological, Ecological and economic criteria on the Galaure river (France). Regulated Rivers : Research and Management, , Vol 13, pp 433-448.

[8] H. Piegay, S.E. Darby, E. Mosselman and N. Surian (2005) : A review of techniques avalaible for delimiting the erodible river Corridor : A sustainable approach to managing bank erosion. River Research and Applications, Vol 21, pp 773-789.

[9] E. Mosselman, (1998): Morphological modelling of rivers with erodible banks. Hydrological Procsses, Vol.12, 1357-1370.

[10] M. Rinaldi and S.E. Darby (2008) : Modelling river-bank-erosion processes and mass failure mechanisms. In" Gravel-Bed Rivers VI: From Process Understanding to River Restoration". H. Habersack, H. Piegay, M. Rinaldi, Editors, pp 213-239.

5) Profile of the applicant

The applicant should hold an M2 in Fluid (or Solid) Mechanics or Applied Mathematics and skilled in the following area:

- Numerical modelling;
- CFD software;
- Environmental flows;
- Code programming (Fortran90, C, C++).

6) Contacts

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