

A MIXED LAGRANGIAN AND EULERIAN FSI APPROACH FOR SIMULATION OF OVERTOPPING ON EMBANKMENT DAMS

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Abstract. The present work is concerned with some recent advances in FSI simulations with particular emphasis on the simulation of rockfill dams during extreme phenomena. The final objective is the study of the consequences of an overtopping on the stability of such structure and its possible failure mode.

A mixed Lagrangian and Eulerian approach is used. The fluid behavior is described using a modified form of the Navier Stokes equations in order to consider the effect of a variable porosity. A non linear Darcy law is included in the momentum equation. A level set function is chosen to follow the movement of the free surface inside and outside the porous medium.

The structure is described using a purely lagrangian PFEM formulation. The specific features of PFEM make it appropriate to treat the rockfill material and its large deformations and shape changes. A projection technique allows to perform the data transfer between the fluid and the structure non matching meshes.

1 INTRODUCTION

Rehabilitation and safety analysis of existing dams is nowadays an open field of research. The possibility to define a numerical instrument to provide support for analyzing the failure of a dam is a big step ahead for organizing the intervention measures and for optimizing the economic plan. In fact many existing dams have now to be modified due to the revision of previous design criteria in order to increase their safety.

The objective of our work is to develop and validate a new computational method of general applicability that allows treating the above problems. The method will combine advanced finite element and particle techniques. Fluid-structure interaction effects and non-linear geometrical and mechanical effects in the dam material will be considered.

Two different approaches are chosen for the study of the fluid and the structural part:

- An Eulerian formulation to treat the fluid (Section 3);

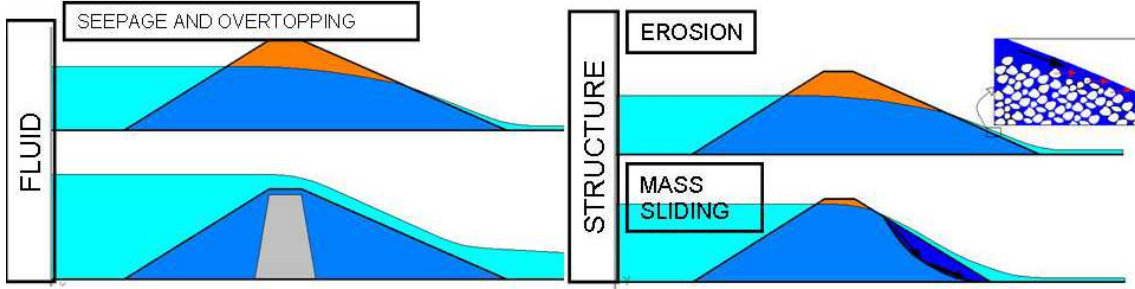


Figure 1: Physical phenomena analyzed.

- The Particle Finite Element Method (PFEM) is the lagrangian technique chosen to study the deformation of the structural part (Section 4);

Two non matching meshes are used during the solution of the problem. The implementation of a projection algorithm is necessary for the coupling of the Eulerian and the PFEM approaches (Section 5).

2 THE MONOLITHIC APPROACH

The problem is characterized by the interaction between water inside the body of the dam and flowing on the downstream shoulder and the rockfill material, which is a non-cohesive porous media.

The variables involved in the mathematical formulation are the following:

- The fluid (\mathbf{u}_f) and the solid (\mathbf{u}_s) velocity fields;
- The pressures in the fluid (p_s) and in the solid part (p_s);
- The densities of the different materials (the symbols are introduced later on);
- Porosity ($\varepsilon := \frac{\Omega_{EMPTY}}{\Omega_{TOT}}$, where Ω is the analyzed domain) that describes the relation between the empty volume domain and the total one;

Porosity is the key variable for coupling the interaction between a flux and a porous medium. The global momentum and mass conservation conditions are imposed together with the fluid ones. Additional equations describing density and porosity behavior are considered in order to complete the formulation.

Given a material volume of the heterogeneous medium composed by the fluid and the structural part, we can define the global density in function of the density of the fluid part and of the structural dry part:

$$\rho = (\varepsilon)\overline{\rho}_f + (1 - \varepsilon)\overline{\rho}_s = \rho_f + \rho_s; \quad (1)$$

where $\overline{\rho_f}$ and $\overline{\rho_s}$ are the free fluid and solid matrix densities respectively, whereas ρ_f and ρ_s are the fluid and the solid densities inside the porous medium, considering the combination of the two materials in a unit volume.

A key point is the definition of the solid and the fluid densities. Being unable to write a close form for the evolution of ρ_s and ρ_f , they are written in rate form.

The variation of the solid densities is analyzed uncoupling the effect due to the forces that are supposed to be taken in charge by $\overline{\rho_s}$ and $\overline{\rho_f}$ from those appearing because of the geometrical effects. The latter are taken into account by the variation of porosity in time.

3 EULERIAN APPROACH FOR THE FLUID

For the study of the fluid behavior both inside and outside the dam an Eulerian approach with a fixed mesh is chosen. A level set technique is used for the identification of the free surface. An edge-based semiexplicit algorithm is implemented for the solution of each time step.

The constitutive law of a Newtonian viscous fluid is used and the effect of porosity is inserted. The classical Darcy equation is not valid here, because the relation between velocity and the gradient of pressure is linear. Non linear effects are taken into account using a quadratic term of the form $\mathbf{D} = (\mathbf{A}\mathbf{u}_f + \mathbf{B}|\mathbf{u}_f|\mathbf{u}_f)$; where \mathbf{D} is the drag vector inserted in the fluid momentum equation representing the interaction forces between the porous medium and water and A and B are defined following Ergun theory.

4 ANALYSIS OF THE STRUCTURAL RESPONSE USING PFEM

The failure of a embankment dam is mainly induced by the hydrodynamic forces acting on the rockfill part in the downstream slope; these forces cause a large loss of material with the consequent instability of the entire dam. Two phenomena play an important role: dragging of rockfill particles due to erosive effects and loss of stability of a part of the downstream region due to the land slide.

The Particle Finite Element Method (PFEM)[1] is chosen for the analysis of the described phenomena. The specific features of the (PFEM) make it appropriate to treat the rockfill material adjacent to the downstream surface where a transfer of momentum occurs between the water running over the dam surface and that moving through the interior due to seepage [2].

The nodes discretizing the solid are view as material particles whose motion is tracked during the solution. In PFEM the domain is discretized using an Updated Lagrangian formulation. A finite element mesh is set up at each time in order to solve the governing equation in traditional FEM fashion [1], [2].

5 THE PROJECTION ALGORITHM

The possibilities of accurately simulate the interaction between the structure and the fluid model is dependent on a good algorithm that allows projecting the different values the fluid Eulerian mesh and the structure Lagrangian one, during the time evolution. Passing

information between non matching meshes needs three different steps: *a)* A *searching algorithm* to identify the neighbor nodes of a given element; *b)* A method to identify if a neighbor point is or not contained into a given element; *c)* A *projection function* that pass the information from an element to a point contained in each element. This is performed both transferring data by direct interpolation between the nodal values of the origin and the destination mesh, or imposing the equality in a weak sense that is, using a weighted residual method.

6 RESULTS

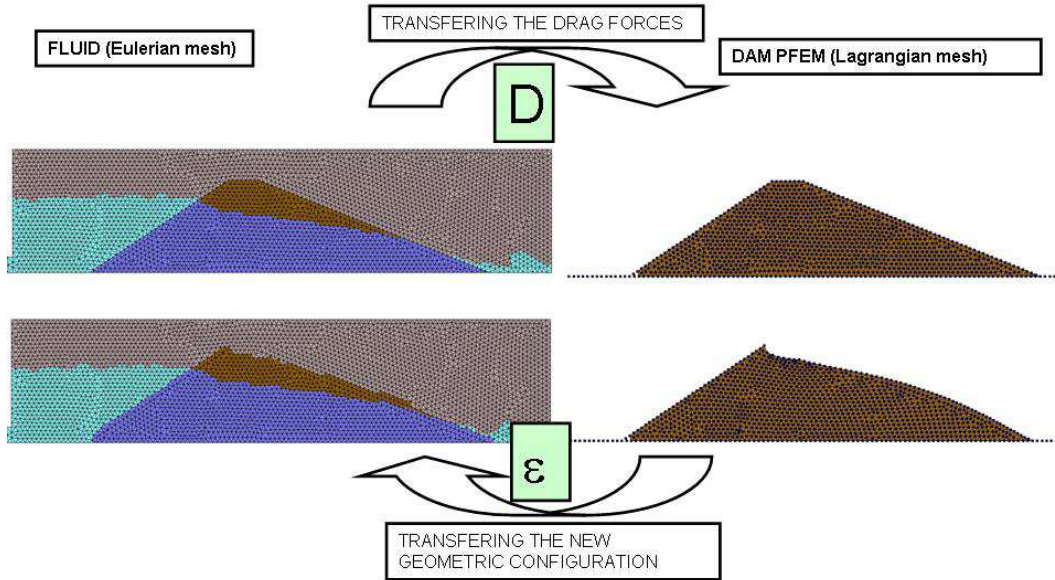


Figure 2: Schematic view of the coupling procedure between the Eulerian and the Lagrangian mesh.

Fig. 2 shows an example of failure of a dam. the porosity is set to be $\varepsilon = 0.5$. From the calculation of the fluid in the Eulerian mesh (left column), the drag force is transferred to the PFEM lagrangian mesh (right column). The deformation of the structure leads to a change in the porosity distribution that affects the fluid calculation.

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REFERENCES

- [1] A. Larese, R. Rossi, E. Oñate, S.R. Idelsohn, Validation of the particle finite element method (PFEM) for simulation of free surface flows, *Engineering Computations*, Vol. **25**,385-425., (2008).
- [2] E. Oñate, S.R. Idelsohn, M.A. Celigueta, R. Rossi, Advances in the particle finite element method for the analysis of fluid-multibody interaction and bed erosion in free surface flows, *Computational methods in Applied Mechanics and Engineering*, Vol. **197**, 1777-1800, (2008).