International Conference on Particle-Based Methods
Particles 2009
E. Oñate and D.R.J. Owen (Eds)

ANALYSIS OF STABILITY OF EARTH DAMS IN OVERTOPPING SCENARIOS WITH THE PARTICLE FINITE ELEMENT METHOD

ANTONIA LARESE*, RICCARDO ROSSI* AND EUGENIO OÑATE*

*International Center for Numerical Methods in Engineering (CIMNE)
Universidad Politécnica de Cataluña
Campus Norte UPC, 08034 Barcelona, Spain
e-mail: antoldt@cimne.upc.edu, web page: http://www.cimne.com/

Key words: PFEM, porous media, fluid dynamics, FSI, CFD.

Abstract. The aim of this work is to study the consequences of an overtopping on the stability of earth dams and its possible failure mode.

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 are considered.

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 [1] and [2]. 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

Embankment dams are very vulnerable to overtopping phenomena because of their particular nature, being made of incoherent material. The failure mechanisms in fact, are mainly due to the hydrodynamic forces acting on the rockfill part in the downstream slope; these forces cause a big loss of material with the consequent instability of the entire dam. They can be resumed by two kind of phenomena, acting in combined or alternative way: dragging of rockfill particles with erosive effects and loss of stability of a part of the downstream region due to the land slide. The loss of a relevant part of the material in the downstream part can carry to the failure of the entire dams.

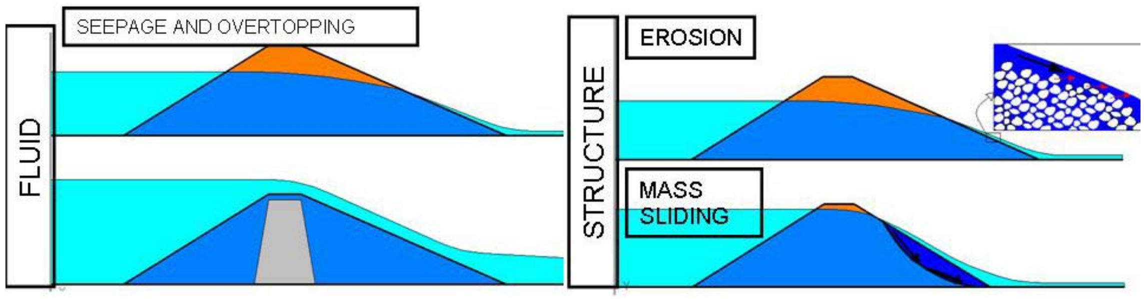

Figure 1: Physical phenomena analyzed.

Therefore the modeling of the onset and evolution of failure process in a rockfill dams due to an overspill implies the analysis and the coupling of many complex different phenomena that are briefly summarized in Fig. 2.

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

- An Eulerian formulation to treat the fluid (Section 2);
- The Particle Finite Element Method (PFEM) is the lagrangian technique chosen to study the response and deformation of the structural part (Section 3);

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 4).

2 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 law 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.

3 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].

4 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.

5 RESULTS

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.

ACKNOWLEDGMENTS

The research was supported by the XPRES project of the National Research Plan of the Spanish Ministry of Science and Innovation I+D BIA2007-68120-C03-01.

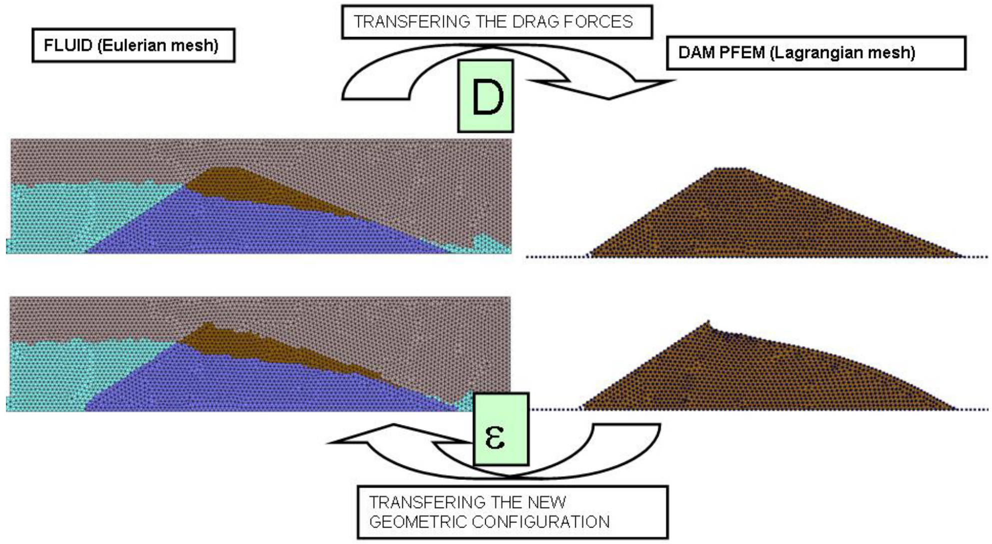

Figure 2: Schematic view of the coupling procedure between the Eulerian and the Lagrangian mesh.

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).