A finite element method for piping erosion in levees

A.F. Rotunno[1,2]
[1]University of Rome "Tor Vergata"; Via del Politecnico 1, Rome, Italy,
[2]École Centrale de Lyon; 36 Avenue Guy de Collongue, Lyon, France

C. Callari[3] & F. Froiio[2]
[3]University of Molise; Via De Sanctis, Campobasso, Italy

Keywords: levees, backward erosion piping, multi-phase porous media, finite elements.

We present an innovative finite element approach to simulate backward erosion piping (Rotunno et al., 2017a). Such mechanism consists of the upstream-oriented propagation and simultaneous transverse enlargement of erosion pipes in granular media (e.g. in dams, levees and cofferdams) (Rotunno et al., 2017b).

We consider problems at the scale of the civil engineering works, and the pipe is thus treated as a one-dimensional entity, that is, a propagating line of localized erosion in a multi-phase porous medium. A turbulent flow is considered in the erosion line and, to account for the fluid mass exchanges through the pipe walls, a discontinuity of the Darcy flow in the porous medium is assumed across the erosion line. Further terms of mass exchange between porous medium and pipe are due to the pipe tip propagation and to the enlargement of the pipe. The evolution of these crucial mechanisms is governed by kinetic laws which model the erosion induced by the Darcy flow normal to the erosion front (propagation) and the erosion due to the turbulent flow tangential to pipe walls (enlargement). The finite element methods presented in Callari and Abati, 2009 and in Abati and Callari, 2014 have been extended to integrate also the equations governing the problem illustrated above. Several numerical simulations in two- and three dimensions are presented to show the ability of the proposed formulation in reproducing available results of real-scale experimental tests (De Rijke, 1991, van Beek et al., 2011).

Acknowledgements
Research supported by GIS VOR 2012, LTDS 2012 and PRIN 2010 - 2011 (2010BFXRHS 004) projects as well as by one PhD fellowship (MIUR). The research also benefited from several invitations of C. Callari at the École Centrale de Lyon - LTDS and of a VINCI mobility program (Italian-French University).

Abati, A. and Callari, C. (2014). Finite elements formulation of unilateral boundary conditions for unsaturated flow in porous continua. *Water Resources Research* **50**:5114-5130.

Callari, C. and Abati, A. (2009). Finite elements methods for unsaturated porous solids and their application to dam engineering problems. *Computer and Structures* **87**:485-501.

De Rijke W.G., (1991). *Verificatie piping model: proven in de Deltagoot.*Technical Report.

Rotunno, A.F., Callari, C. and Froiio, F. (2017a). A finite element method for localized erosion in porous media with applications to backward piping in levees. *In preparation*.

Rotunno, A.F., Callari, C. and Froiio, F. (2017b). A computational method for backward erosion piping. *Models, Simulations and Experimental Issues in Structural Mechanics* 225-234.

van Beek, V.M., De Bruijn, H.T.J., Knoeff, J.G., Bezuijen, A., Forster, U. (2011), Levee failure due to piping: a full-scale experiment. *In: Scour and Erosion,* 283-292