

# Local mechanisms of cohesive soil erosion

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## Introduction

Soil erosion concerns several domains of agriculture, ecology and engineering. According to Girard *et al.* (2005) there are 25 billion of tons of annual sediment losses due to water erosion worldwide, while Syvitski *et al.* (2005) identified 20 billion of tons of the same sediments delivered annually by rivers into the oceans. For civil engineering, erosion is a central problem for many infrastructures located next to erodible areas or which are themselves directly erodible. According to Foster *et al.* (2000), 90% of embankment failures are caused by erosion. Furthermore, the International Commission Of Large Dams (ICOLD) estimates that 75% of dams are built in sand, clay or muddy sediments and are consequently subject to erosion.

## Surface erosion

For the general case of a soil exposed to the flow of water, the surface erosion takes place at the solid-liquid interface. The solid phase (the soil) is generally a cohesive material where internal forces are primarily due to Van der Waals attractive forces and electrostatic forces in balance with repulsive forces (Lick *et al.*, 2004). The water flowing on the surface constitutes the liquid phase and is the eroding agent. In terms of quantification, the most common erosion model is probably the linear threshold model firstly proposed by Partheniades (1965) and Ariathurai and Arulanandan (1978). According to this law, if the average stress  $\tau$  due to turbulent flow surpasses a certain critical stress  $\tau_c$ , it can cause erosion. Beyond this threshold, the rate of removed material, which can be defined either in terms of eroded mass or volume, is proportional to the distance to the threshold through an erosion coefficient  $k$ . These two parameters can be used to calculate the erosion rate depending on an average hydrodynamic stress. However, in practice the average magnitude of the stress is often insufficient for a precise quantification, since the fluctuating flow creates instantaneous local peak stresses which can significantly exceed the average stress and result in particles dislodgment (see e.g. Diplas *et al.* (2008) for the case of non-cohesive grains). For cohesive material, the fluctuations have a similar role but the mechanism of material removal is different from the non-cohesive case. Winterwerp and Van Kesteren (2004) distinguish four modes of cohesive particles dislodgment: entrainment (fluidization), floc erosion (disruption and break up of flocs), surface erosion (drained process where eroded particles were replaced by water) and mass erosion (undrained process, local failure within the bed).

To evaluate the soil's resistance to erosion, several erosion tests have been developed. The Jet Erosion Test (JET) is a circular impinging vertical turbulent jet introduced by Moore and Mash (1962) and later used e.g. by Hanson and Cook (2004), who measured the deepening of a soil scour hole as a function of time. The Hole Erosion Test (HET), firstly introduced by Lefebvre *et al.* (1985) and further developed by Bonelli *et al.* (2006), is used to modelling piping erosion by measuring variation of the radius of an initial pipe, eroded by a permanent flow. The Erosion Function Apparatus proposed by Briaud *et al.* (1999) consists in measuring the velocity by which a 1mm thick circular section of soil sample (76.2mm diameter) is completely eroded when it is placed inside a flow field in a pipe with rectangular cross-section. Another apparatus developed by Le Hir *et al.* (2008) consists in a sample of sediment placed inside a pipe with rectangular cross-section where the erosion rate is estimated by measuring sand accumulation in a sand trap and by measuring turbidity.

## Present contribution

Our contribution will focus on the elementary mechanisms involved during the surface erosion of a cohesive soil by a fluid flow in order to improve the local modelling of erosion. An experimental approach enables us to develop model materials, which then can be subjected to given hydrodynamic stresses and controlled mechanic stresses. Preliminary results will be presented on the following points. Firstly, the development of materials for which it is possible to adjust specifically and continuously certain characteristics of the soil and then to identify the soil properties having a strong incidence on the resistance to erosion. Secondly, the local analysis of erosion mechanisms by using transparent medium and adapted optical equipment. This makes the time-space monitoring during erosion possible and allows to see the mechanisms by which a fluid flow leads to the removing of elementary particles in cohesive material. The two optical techniques, which are the refractive index matching between the matrix and the grains and the planar laser-

induced fluorescence already used by Philippe and Badiane (2013), made possible to model a cohesive medium with transparent cohesive medium.

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