Pinhole test for identifying susceptibility of soils to piping erosion: effect of water quality and hydraulic head

E. Nadal Romero [(1) (2)], E. Verachtert [(1)], J. Poesen [(1)]

(1) Dep. Earth and Environmental Sciences, Physical and Regional Geography Research Group, K.U.Leuven, Celestijnenlaan 200 E bus 2409, 3001 Heverlee (Belgium).
E-mail: MariaEstela.NadalRomero@ees.kuleuven.be
E-mail: els.verachtert@ees.kuleuven.be
E-mail: jean.poesen@ees.kuleuven.be

(2) Pyrenean Institute of Ecology (CSIC), Campus de Aula Dei, Apdo. 13034. 50080, Zaragoza (Spain).

ABSTRACT

Piping has been observed in both natural and anthropogenic landscapes, in different climates, lithologies and soils, as well as under different types of land uses and vegetation covers. Despite its importance, no standard widely-applied methodology exists to assess susceptibility of soils to piping.

This study aims at evaluating the pinhole test for assessing the susceptibility of soils to piping under different conditions. More precisely, the effects of hydraulic head and water quality are being assessed. Topsoil samples (remoulded specimens) with a small range of water contents were taken in Central Belgium (Heverlee) and the susceptibility of these soil samples are investigated under standardized laboratory conditions with a pinhole test device. Three hydraulic heads (50, 180 and 380 mm) and two water qualities (tap and distilled water) were used, reflecting dominant field conditions.

The results indicate significant differences between different hydraulic heads and water qualities. Maximum flow discharge was recorded at 380 mm, showing small differences between tap and distilled water. Maximum sediment discharges were recorded at 380 mm and significant higher sediment discharges were observed for distilled water compared to tap water. The tests indicate that the tested soil has an intermediate susceptibility to piping.

Keywords: piping, soil erosion, pinhole test

INTRODUCTION

Piping or tunnel erosion is defined as the hydraulic removal of subsurface soil, causing the formation of underground channels in the natural landscape (Boucher, 1990). (1) Field measurements and (2) laboratory experiments have shown that piping can be a very important process associated with runoff, sediment and solute yields in many environments, particularly in humid temperate regions. Despite the widespread occurrence of soil piping erosion in Europe, Faulkner (2006) estimated the areal extent of the land seriously at risk in the EU from piping erosion to exceed 260,000 km^2, quantitative data on the susceptibility of soils to piping and the contribution of piping to sediment yield are scarce. Moreover, quantitative information on the susceptibility of different soils is currently lacking.

The aim of the study is to evaluate the pinhole test device (Sherard et al. 1976) for the assessment of the susceptibility of soils to piping, under three hydraulic heads and two water qualities. In the near future, validation of the findings and methods will be made for typical soil horizons in various regions of Europe.

METHODS

The pinhole test device is an instrument for direct measurements of the dispersibility and erodibility of fine-grained soil, using a flow of water passing through a small hole (1 mm diameter) in a specimen (Sherard et al. 1976), under hydraulic heads (H) ranging between 50 and 1020 cm (Figure 1). Dispersibility is assessed by observing effluent colour and flow discharge through the hole, by visual inspection of the hole after the completion of the test. According to Sherard et al. 1976, the test is highly reproducible and the results of each individual test can be categorized easily.

The methodology and processes are in general identical to these proposed by Sherard et al. (1976), except for the adaptations mentioned below.

Prior to each pinhole experiment the soil was air-dried at room temperature (20 °C) for 3-4 days and sieved at a mesh size of 1.25 cm diameter. Then, to obtain standardized compaction conditions, rainfall simulation was used. The erosion plot (central test area of 0.60 x 0.94 m^2) was filled with the sieved soil. Rainfall was simulated for 60 minutes by a single-nozzle, continuous-spray system (Poesen et al. 1990), with mean rainfall intensity of 67 mm h^{-1}, to slightly compact the topsoil.

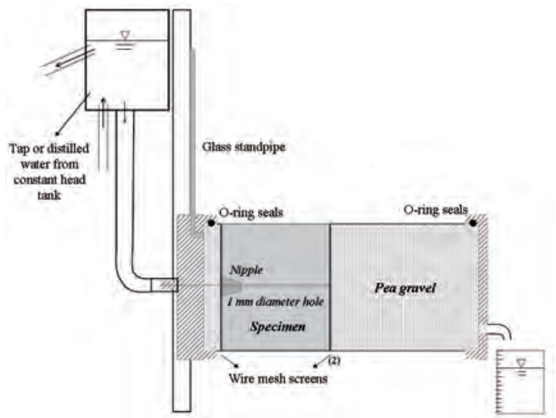

Figure 1. Sketch to illustrate pinhole test measurement set up.

The laboratory pinhole tests were conducted 1, 2, 4, 8 and 15 days after rainfall simulation; six samples (stainless steel rings: 8 cm long and 5 cm diameter) were taken every day in the morning (at the same time), to test the susceptibility to piping with tap and distilled water (EC, 800 and 26 μS/cm, respectively) at three consecutive hydraulic heads (H; 50, 180 and 380 mm), on the same sample. In this study, the pipe flow discharge (Q_w) and sediment discharge (Q_s) was measured continuously. During a time interval of 5 minutes, every minute, the effluent was collected during one minute, with cylindrical measuring flasks and the samples were dried in the oven at 110 °C. This was carried out for every hydraulic head.

Moreover, before the start of the laboratory experiments, three additional cylindrical samples were taken to determine the initial soil moisture content (kg kg^{-1}) and bulk density (g cm^{-3}) (stainless steel rings: 5 cm high and 5 cm diameter).

The analysed silt loam soil is a topsoil from Central Belgium (Heverlee) sampled on a cropland. It consisted of 12% clay, 80% silt and 8% sand and had an organic matter content of 1.9% (Smets, 2009).

RESULTS AND DISCUSSION

The results of several pinhole tests performed on the silt loam samples (in one day) are illustrated in Figures 2 and 3.

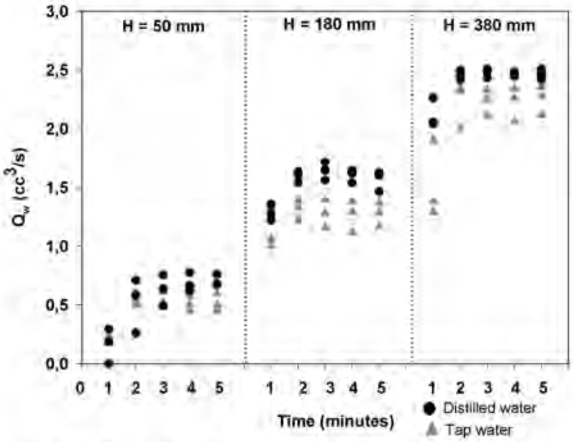

Figure 2. Evolution of pipe flow discharge (Q_w) through a silt loam specimen at different hydraulic heads (50, 180 and 380 mm) and for two water qualities (tap and distilled water).

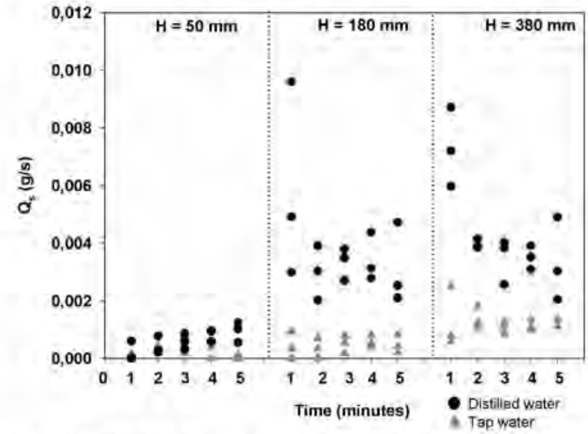

Figure 3. Sediment discharge (Q_S) at different hydraulic heads (50, 180 and 380 mm) and water qualities (tap and distilled water).

Figure 2 shows pipe flow discharge through the specimen (Q_w, cc^3/s) during three replicate samples for tap and distilled water respectively, with a moisture content of 26.5 kg kg^{-1} and a bulk density of 1.22 g cm^{-3}. During a test with a given height, pipe flow increased due to pipe erosion. An increase in mean pipe flow discharge was also observed with increasing hydraulic head. The mean flow discharges were respectively for tap and distilled water 0.46 and 0.54 cc^3/s at 50 mm hydraulic head, 1.25 and 1.54 cc^3/s at 180 mm hydraulic head, and 2.09 and 2.4 cc^3/s at 380 mm hydraulic head.

Figure 3 shows the sediment discharge (Q_s, g/s) for three replicate samples tested with tap and distilled water. Significant differences between tap and distilled water test were observed for the three hydraulic heads. During a test with a given H, Q_s evolved differently depending on the water quality. The mean Q_s values were respectively for tap and distilled water 0.0002 and 0.0006 g s^{-1} at 50 mm hydraulic head, 0.0005 and 0.004 g s^{-1} at 180 mm hydraulic head, and 0.001 and 0.004 g s^{-1} at 380 mm hydraulic head. This is in line with results on susceptibility of silt loam soils to physical degradation under rainfall simulation using distilled and tap water (Boselli et al., 2001).

The results showed that the silt loam soil tested has an intermediate susceptibility to piping based on the classification of Sherard et al. (1976).

CONCLUSIONS

This preliminary investigation indicates that the pinhole test is suitable for assessing the susceptibility of soils to piping in a quantitative way. Moreover, the test gives reproducible results.
The results of this preliminary study (based on 30 specimens and more than 450 data) for one silt loam soil shows significant increasing water and sediment discharge with increasing hydraulic heads (50, 180 and 380 mm) and higher sediment discharge for distilled water than for tap water.

ACKNOWLEDGMENTS
E. Nadal-Romero has benefited from a research contract (Human Resources Mobility, National Plan I-D+I 2008-2011, National Programme), funded by the Spanish Ministry of Education and Science.

REFERENCES

- Borselli, L., Torri, D., Poesen, J. & Sanchis, P.S. 2001. Effects of water quality on infiltration, runoff and interril erosion processes during simulated rainfall. *Earth Surface Processes and Landforms* 26, 329-342.
- Boucher, S.C. 1990. *Field tunnel erosion – its characteristics and amelioration*. Department of Geography and Environmental Science, Monash University, Victoria, 64 p.
- Faulkner, H. 2006. Piping Hazard on Collapsible and Dispersive Soils in Europe. In Boardman, J. and Poesen, J. (Eds) *Soil Erosion in Europe.* John Wiley & Sons, Ltd, Chichester, 537-562.
- Sherard, J., Dunningan, L., Decker, R. & Steele, E. 1976. Pinhole test for identifying dispersive soils. *Journal of the Geotechnical Engineering Division* 11846, 69-85.
- Poesen, J., Ingelmo-Sanchez, F. & Mücher, H. 1990. The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. *Earth Surface Processes and Landforms* 15 (7), 653–671.
- Smets, T. Effectiveness of biological geotextiles in controlling soil erosion by water at a range of spatial scales. Unpublished Ph.D. thesis, Department of Earth and Environmental Sciences, K.U.Leuven, Belgium.