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Effects of rainfall infiltration processes on the stability of surficial covers of fractured swelling soils

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RIASSUNTO

Effetti dei processi di infiltrazione sulla stabilità di coltri superficiali in terreni fratturati e rigonfianti.

L'instabilità di coltri superficiali è spesso collegata alla perdita di resistenza dovuta al decremento della suzione a seguito dei processi di infiltrazione. Il comportamento delle coltri superficiali di terreno soggette a infiltrazione di pioggia è spesso influenzato oltre che dalle proprietà fisico-meccaniche ed idrauliche del terreno anche dalla stratigrafia e dalla presenza di fratture e/o altre discontinuità. In terreni argillosi caratterizzati da fratture subverticali come quelle da ritiro, le fessure facilitano ed accelerano i processi di infiltrazione. Tali fratture possono progressivamente chiudersi durante i processi di infiltrazione in conseguenza di fenomeni di rigonfiamento del terreno. La presenza di livelli di materiali a granulometria fine su terreni a granulometria grossolana o rocce fratturate permeabili può dar luogo a fenomeni di ritenzione in conseguenza del formarsi di barriere capillari.

Nel presente lavoro è stata studiata l'influenza di diversi scenari di pioggia in termini di intensità e durata sulle condizioni di stabilità di coltri di materiali a granulometria fine insature e fratturate poggianti su un substrato a maggiore permeabilità. Lo studio è stato sviluppato sulla base dell'analisi dei processi di infiltrazione in un mezzo fratturato insaturo per mezzo di un modello a permeabilità duale messo a punto dagli autori.

KEY WORDS: *Capillarity barrier, dual permeability*, *fractured soil, infiltration processes, surficial soil slip.*

INTRODUCTION

Slope instability of surficial covers is strongly conditioned by the soil suction, whose decrease leads to the loss of strength, as consequence of rainfall infiltration processes. Stratigraphy, physical and hydraulic properties of the soil, the presence of fracture and other soil state features condition the response of surficial soil cover to rainfall infiltration. In cracked soils, water infiltration is accelerated by fractures (ŠIMŮNEK *et alii*, 2003) that in clayey swelling soil can be subject to progressive closure. In case of a surficial fine-textured soil overlying a more permeable bedrock, at the interface between the two strata during the rainfall the fine soil stores water due to capillary barrier effect (MANCARELLA & SIMEONE, 2007; MANCARELLA & SIMEONE, 2012; MANCARELLA *et alii*, 2012).

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Existing models rarely investigate these phenomena and their consequences on the triggering of surficial landslides. This work presents and discusses the results, with respect to slope stability, obtained analyzing infiltration phenomena in a slope with fine textured surficial cover over a more permeable bedrock by a dual-permeability model, which accounts for fractures, swelling and capillary barrier effect in unsaturated soils. Results show how slope stability conditions can change depending on different scenarios induced by different rainfall events.

THE CASE STUDY

The analyzed case study is a slope with an inclination β of 45° and characterized by a surficial cover of fractured loamy soil with a thickness *s* of 1.5 m, overlying a coarse sand (Fig. 1). The soil weight γ has been assumed 20 kN/m^3 and shear strength parameters c' and ϕ' respectively of 1 kPa and 20°, the initial water content has been assumed quite low, with a degree of saturation of 13% in volumetric term and a corresponding suction of 100 kPa. The fracture network has been assumed squared, with an initial opening δ equal to 1 cm open and a interspacing *L* equal to 80 cm. Hydraulic properties and initial state parameters of the surficial cover are summarized in Table 1.

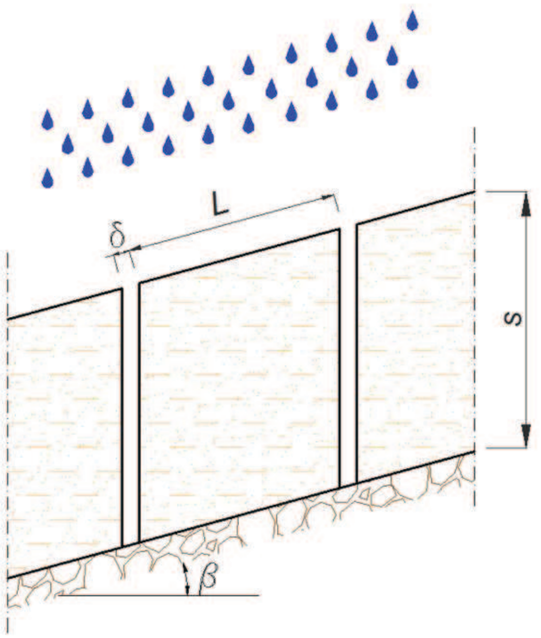

Fig. 1 – Schematic representation of the slope.

To analyze infiltration processes it has been used a dual-permeability model (GALEANDRO *et alii*, 2012, 2013) assuming that rainfall water infiltrates vertically into the matrix and into fractures and it can be laterally absorbed into the soil matrix. Water flowing in cracks is modeled by the continuity equation, while two-dimensional Richards equations are used to describe the flow into the soil matrix. The model implements also a capillary barrier below the base of the surficial fractured soil.

TABLE 1

Features and parameters for the upper soil texture (data from CARSEL & PARRISH, 1988).

Residual water content θ_{res} (m^3m^{-3})	0.078
Saturated water content θ_{sat} (m^3m^{-3})	0.43
Saturated hydraulic condutivity K_{ms} (cm/s)	2.9 10^{-4}
Initial pressure head h_{init} (cm)	-1000
α (van Genuchten 1980) (cm^{-1})	0.036
n (van Genuchten 1980)	1.56

Using the proposed model, 6 rainfall events of different intensity and duration (Table 2) have been simulated: the event A_1-C_1 have a total rainfall height of 20 mm, while the events A_2-C_2 have a total rainfall height of 50 mm.

RESULTS AND DISCUSSION

The stability of the test slope has been evaluated in term of factor of safety according to the infinite slope approach:

$$F(z) = \frac{c' + \left(\gamma \cdot z \cdot \cos^2 \beta - u\right) \cdot \tan \phi'}{\gamma \cdot z \cdot \sin \beta \cdot \cos \beta}$$

Where u is pore pressure, negative if it is suction, and z (m) is the depth of the failure surface parallel to the ground surface. Factor of safety values are different in relation to the depth of the failure surface and in the initial unsaturated condition are quite high due to the effect of suction. The lowest value is at the bottom of the soil cover strata and it is 2.83.

TABLE 2

Rainfall events: intensities, durations and corresponding inflow rate in fractures.

Rainfall event	Rainfall intensity (mm/h)	Duration (h)
A_1	5	4
B_1	20	1
C_1	50	0.4
A2	5	10
B_2	20	2.5
C_2	50	1

For each rainfall scenarios it has been evaluated the water distribution due infiltration processes, at the end of each rainfall event, and then the corresponding pressure head. On the basis of the evaluated pressure head it has been evaluated the new factor of safety value $F_{rs}(z)$ for each rainfall scenarios at the different depths and the results have been expressed in terms of factor of safety variations:

$$\Delta F_{rs}(z) = \frac{F_i(z) - F_{rs}(z)}{F_i(z)}$$

where F_i is the initial factor of safety and F_{rs} is the factor of safety related to a specific rainfall scenario. The results of factor safety variation are summarized in Figures 2 and 3.

Weak and prolonged rains (5 mm/h, A_1 and A_2) can seriously affect safety factor for very surficial failure surfaces much more than high intensity rainfall. During both A events (Figs. 2a and 3a), all the rainfall amount infiltrate into the soil matrix, leading to the saturation of the more surficial layer with a small diffusion in the soil below. So the safety factor decrease in a relevant way just in the first few centimeter of soil. The decrease of the factor of safety in the remaining soil strata is really low (ΔF_{rs} < 20-35 %) because only a small amount of water reaches the deeper portions of the cover and then it does not lead to important variations in pressure heads distributions.

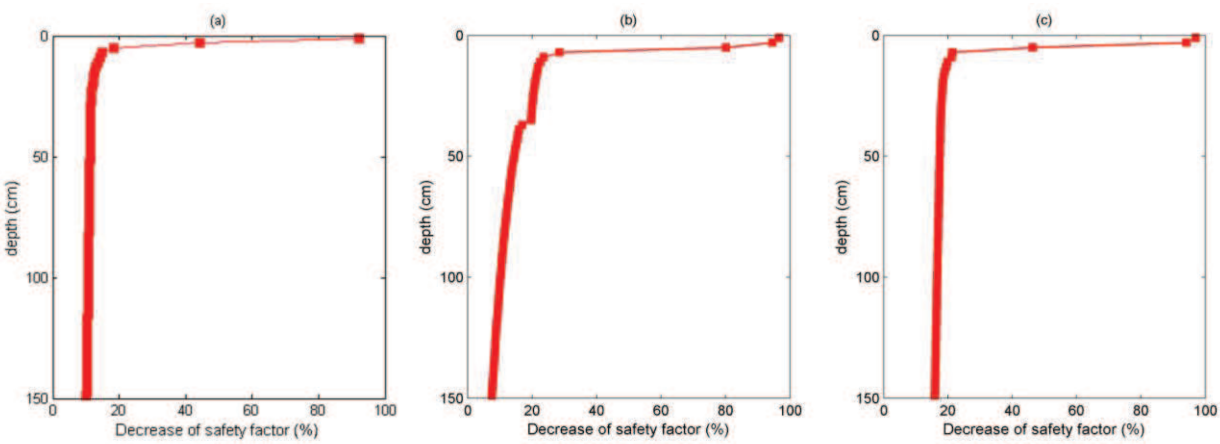

Fig. 2 – Decrease of safety factor versus depth at the end of the considered meteoric events: a) Event A_1 (5 mm/h, 4 h); b) Event B_1 (20 mm/h, 1 h); c) Event C_1 (50 mm/h, 0.4 h).

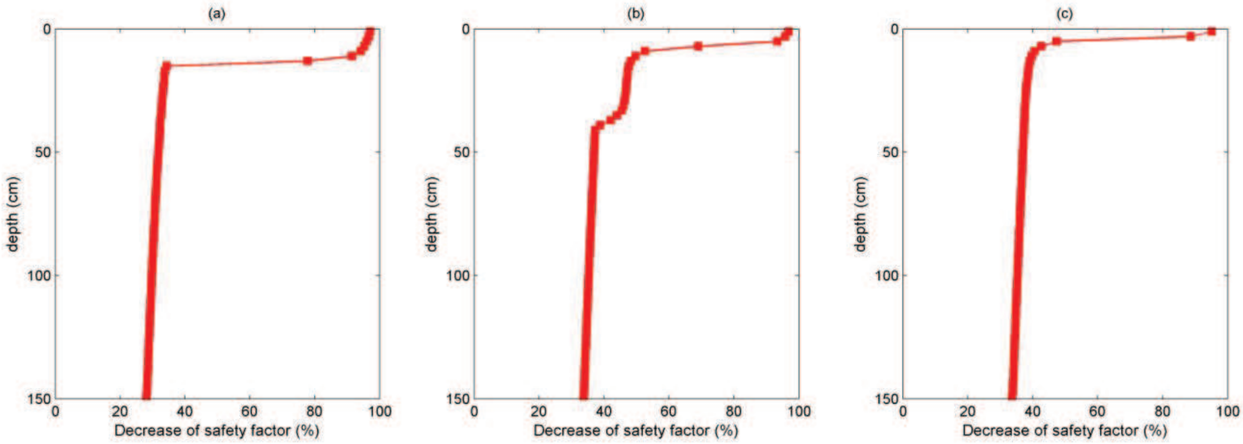

Fig. 3 – Decrease of safety factor versus depth at the end of the considered meteoric events: a) Event A_2 (5 mm/h, 10 h); b) Event B_2 (20 mm/h, 2.5 h); c) Event C_2 (50 mm/h, 1 h).

During the event B_1 (20 mm/h – 1h, Fig. 2b), water flows slowly also through the fracture and activates also the lateral adsorption of water from the fracture to the matrix. However, diffusion process does not involve a great portion of matrix and does not significantly condition the pore pressure distribution. A relevant decrease of the factor of safety involve only in the first few soil centimeters and a lower one affect the soil until a depth of about 25-30 cm. More prolonged rainfall with the same intensity (event B_2) give a factor of safety decrease more relevant, due to the lateral diffusion from the fracture to the matrix. Water diffusion reaches a distance of about 15 cm from the fracture wall. At this condition, the safety factor decrease could be estimated greater than 45 % in the first 35 centimeters of soil (Fig. 3b).

During both more intense rainfall events C_1 and C_2 (50 mm/h) the flow in fracture is fast. The vertical infiltration in matrix saturates only 4-6 centimeters of the top soil. The flow and the capillary barrier breakthrough in fracture is a quick process and do not allow a significant diffusion process from fracture in the matrix (only 4 cm). These intense events do not significantly affect the stability condition of covers. The decrease of the safety factor is always smaller than 40%, except the first 4-6 centimeters of soils (Figs. 2c and 3c).

CONCLUSIONS

The paper discusses results obtained by simulating infiltration processes in a fractured and swelling loamy soil for rainfall events of various intensities and durations, by means of the dual-permeability model proposed by GALEANDRO *et alii* (2013), with respect to slope stability problems. The direct use of the proposed model is quite difficult because it need a lot of parameters about hydraulic soil properties and status. Anyway it made it possible to analyze and compare the effect of different rainfall scenario on theoretically based. So it can contribute to better understand landslide risk for specific rainfall scenarios in particular stratigraphic conditions.

Results show how prolonged weak rainfalls could easily lead to the saturation of the more surficial layers and can trigger instability phenomena of the more surficial strata, being more dangerous for surficial soil fine-grained covers than intense and short precipitations. Then, sometimes prolonged weak rains may be more dangerous in triggering surficial soil slip with all their consequence than more intense one.

REFERENCES

GALEANDRO A. & SIMEONE V. (2012) - *Infiltration processes in fractured and swelling soils and their influence on the stability of surficial covers.* Rend. Online Soc. Geol. It., **21**, 518-520.

GALEANDRO A., SIMEONE V. & ŠIMŮNEK J. (2013) - *A dual-permeability model for simulating water infiltration into unsaturated, fractured and swelling soils.* Rend. Online Soc. Geol. It., present issue.

MANCARELLA D. & SIMEONE V. (2007) - *Analysis of capillary barrier effects in the activation of debris avalanches in pyroclastic cover.* Proc. 4th International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment; Chengdu, China, September 10-13, 2007, C-L Chen & J. J. Major (Eds). 45-53, 2008, Millpress, Rotterdam, ISBN 978-90-5966-059-5.

MANCARELLA D. & SIMEONE V. (2012) - *On capillary barrier effects in unsaturated layered soils, with special reference to pyroclastic covers of Pizzo d'Alvano in Campania, Italy* Bulletin of Engineering Geology and Environment, **71**(4).

MANCARELLA D., DOGLIONI A., & SIMEONE V. (2012) - *On Capillary Barrier Effects And Debris Slide Triggering In Unsaturated Layered Covers*. Engineering Geology, **147–148**, 14-27.

ŠIMŮNEK J., JARVIS N.J., VAN GENUCHTEN M.TH. & GARDENA A. (2003) - *Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone*. J. Hydrol. **272**, 14–35.