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INFILTRATION INTO A SWELLING, CRACKED CLAY SOIL

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Transient infiltration into a swelling, cracked fine-textured soil was calculated using the originally designed FRACTURE submodel (version B) of the HYDRUS–ET simulation model. The model permits changes in the dimensions of the cracks during the infiltration process. Modeling results obtained with the new model were compared with those from FRACTURE submodel (version A) assuming a stable crack system. It is shown that deforming cracks lead to higher rates of infiltration during precipitation events as compared with stable cracks. A difference of about 20 percent was estimated in our illustrative example.

KEY WORDS: Swelling Soils, Soil Cracks, Water Infiltration, Mathematical Modeling.

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Práca obsahuje výsledky matematického modelovania infiltrácie vody do pôdy s puklinami, meniacimi svoje rozmery počas procesu, (verzia B) v závislosti na vlhkosti pôdy, ktoré sú porovnané s výsledkami, získanými pomocou modelu s konštantnými rozmermi puklín (verzia A) počas infiltrácie zrážok. Submodel FRACTURE – verzia B, ktorá kvantifikuje infiltráciu vody do pôdy s deformujúcimi sa puklinami je súčasťou modelu HYDRUS–ET. Porovnanie výsledkov modelovania pomocou oboch submodelov ukázalo, že počas zrážkovej udalosti v tomto ilustratívnom príklade rýchlosť infiltrácie do pôdy s deformujúcimi sa puklinami je asi o 20 % väčšia ako do pôdy so stabilnými puklinami. Treba poznamenať, že meranie charakteristík infiltrácie vody do pôdy s puklinami a súčasné meranie deformácií siete puklín nie je v prírode prakticky možné, preto matematické modely môžu byť použité aj ako nástroje vedeckého výskumu v numerických experimentoch.

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KĽÚČOVÉ SLOVÁ: napučiavajúce pôdy, pôdne pukliny, infiltrácia vody, matematické modelovanie.

Introduction

Infiltration of water into fine-textured, low-permeable soils is a slow process, in which precipitation and/or irrigation water enters the soil at a low rate, which in turn often causes surface runoff. The presence of drying cracks in a soil can increase the infiltration rate and increase the soil water content. Negative features often associated with crack infiltration are a) solutes penetrating faster into deeper soil layers and thus contributing to soil and groundwater pollution, and b) nutrients moving out of the range of plant root extraction.

Infiltration rates calculated using classical flow models deviate significantly from those observed in the field for swelling, fine-textured soils. Accurate simulation of infiltration into initially dry, cracked, clay soils remains a weak point of many SWAP (soil-water-atmosphere-plant) models. Such infiltration is usually modeled using the classical Richards' equation for variably saturated flow in a homogeneous soil. Lack of good procedures describing infiltration of water into soil cracks in the SWAP models generally leads to underestimation of infiltration and overestimation of water accumulation at the soil surface, overestimation of runoff, and consequently to unrealistic soil water regime predictions.

A variety of models describing the movement of water and dissolved solutes in soils containing cracks have been developed, most of them based on schematic representation of crack network (Van Genuchten 1991, Ma and Selim 1998, Van Genuchten and Sudicky 1999). Results obtained with these models are relatively poor, in part because of conceptual weakness of the models, and in part because of difficulties in accurately estimating crack input parameters. Flow in structured porous media is frequently also described using dual-permeability models (Pruess and Wang 1986, Gerke and Van Genuchten 1993, Jarvis 1994, 1998). Approaches of this type assume that the soil consists of two regions, one associated with the macropores (cracks) and the other with the less permeable matrix region. The difficulty in applying this approach to cracked soil is that flow in both regions is described using the Richards' equation, an assumption probably not valid for large drying cracks.

Another class of models uses statistical properties of cracks (e. g., depth and width). Such models do not require detailed knowledge of the crack system and/or the spatial distribution of macropores (Slawinski et al. 1996, Van

D a m et al. 1997, N o v á k et al. 2000). An advantage of these types of models is a more realistic description of the physics involved and easier assessment of input data. As an example, the latest version of SWATRE (V a n D a m et al. 1997) adds a source term to the Richards' equation to allow for the infiltration of water from the crack. Lateral infiltration is as to be constant in time, with the infiltration rate changing only as a function of active crack area.

In this study we describe the FRACTURE submodel that quantitatively describes the infiltration of rain water into an initially relatively dry, cracked soil. Variably-saturated flow in the soil matrix is described using the Richards' equation. Excess water at the soil surface that cannot infiltrate because of a relatively low infiltration capacity of the soil, is removed by surface runoff, or allowed to fill the soil cracks from where it can infiltrate laterally into the soil matrix. Lateral infiltration is described using the Green-Ampt approach.

The basic feature of the first version of the FRACTURE submodel (referred to here as version A), as described in N o v á k et al. (2000), is that crack dimensions are constant during the infiltration. This approach makes the calculations relatively simple and saves CPU time. In reality, soil cracks usually change their dimensions depending upon the actual soil water content during the infiltration process. The new FRACTURE submodel (version B) quantitatively describes infiltration of rain into a clay soil containing cracks that can change their dimensions during the infiltration process. The goal of this paper is to evaluate the potential effects of changes in the crack geometry on infiltration using both submodels (versions A and B).

In the previous version of the FRACTURE submodel (Novák et al., 2000), we assumed that the vertical distribution of the crack porosity, P_c, is a function of the vertical distribution of the soil water content, w, at the beginning of the precipitation (irrigation) event. The P_c distribution was estimated from the known soil water content vertical distribution, $w(z)$, before precipitation started, and the relationship between crack porosity and the soil water content, $P_c(w)$. The dimensions of the soil cracks were assumed to be stable during the infiltration event, i. e., we calculated the infiltration of water into the soil assuming constant crack parameters. This assumption was based on field observations that no significant crack geometry changes took place during infiltration of short-term precipitation events. Precipitation during hot summer days occurred by means of relatively short-time rainfall events followed by rapid drying of the surface soil layers due to high evaporation rates, and by subsequent shrinkage of soil peds at and near the soil surface. The perimeters of the soil cracks at the soil surface were not very distinct, which made it difficult to accurately monitor and mathematically describe their changes.

It would be possible to accurately calculate changes in the soil crack dimensions associated with soil water content, if an unambiguous relationship, $P_c(w)$, between the crack porosity and the soil water content existed. Such an approach is an approximation as well because it can be expected that this relationship (i. e., $P_c(w)$) is hysteretic in that it will depend on the history of the soil water content regime.

Conceptual model

A schematic of the conceptual FRACTURE model is shown in Fig. 1. The precipitation or irrigation rate, $q_0(t)$, at the soil surface will be equal to the infiltration rate, $q(t)$, as long as the soil surface is unsaturated. The model assumes that all precipitation water falls directly on the soil surface. Precipitation into cracks is assumed to fall also on the soil surface. After the soil surface becomes saturated, excessive water is first used to form a surface layer at ponding time t_p. It is assumed that the surface run-off or flow into the cracks can start only after surface layer of critical thickness h_s has formed. Water then keeps flowing into the cracks as long as the potential flux is higher than the infiltration flux. When the potential flux becomes smaller than the infiltration rate, water flow into the cracks stops and water in the soil surface layer is used for infiltration until the surface water eventually disappears. According to this model, the infiltration process can be divided into several stages (N o v á k et al. 2000):

1. Unsaturated infiltration when the soil surface is still unsaturated: $q(t) = q_0(t)$, $t < t_p$;
2. The formation (or disappearance) of a surface water layer after the soil surface becomes saturated: $q(t) < q_0(t)$ [or $q(t) > q_0(t)$];
3. Flow into cracks when the surface is saturated and the surface layer has reached some certain critical height h_s: $q(t) < q_0(t)$;
4. Runoff when cracks are either full or not considered: $q(t) < q_0(t)$;
5. Horizontal infiltration from the cracks into the soil matrix.

The influence of soil subsidence on crack development was not considered. Horizontal infiltration of water from the cracks into the soil matrix was assumed to occur only through crack surfaces that are in direct contact with water standing in the cracks. Hence, the model does not consider infiltration of film water flowing along cracks walls.

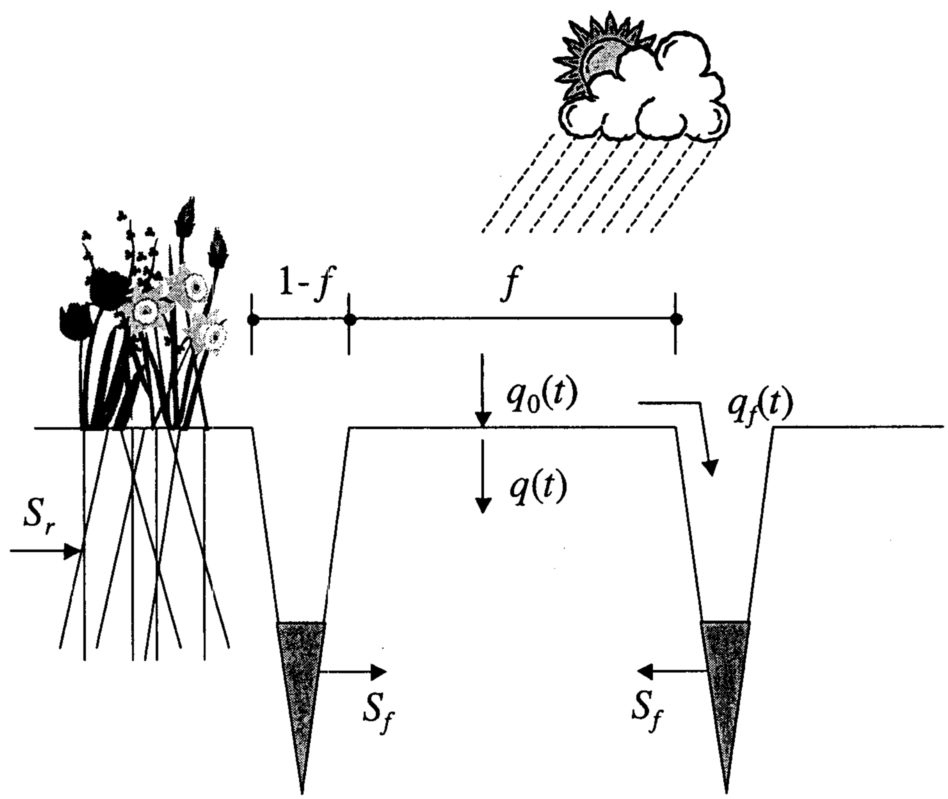

Fig. 1. Schematic of the FRACTURE submodel. The potential infiltration rate (the applied surface flux), $q_0(t)$, is divided between the soil surface infiltration rate $q(t)$ and flow into the cracks $q_f(t)$; $S_f(z)$ is the horizontal infiltration rate from the cracks into the soil matrix.
Obr. 1. Schéma submodelu FRACTURE. Rýchlosť potenciálnej infiltrácie (aplikovaný tok vody na povrch pôdy) $q_0(t)$ sa delí na infiltráciu cez povrch pôdy $q(t)$ a na tok vody do pôdnych puklín; $S_f(z)$ je intenzita horizontálnej infiltrácie z puklín do pôdnej matrice.

We further assume (case A) that soil cracks during a precipitation event do not change their dimensions. This assumption is based on field observations of cracks on the soil surface. Even during a heavy rain, soils generally swell so slowly that crack shrinking is not observable during the first few hours of the rainfall event. This situation was described in our previous publication (N o v á k et al. 2000).

This situation is different for cracks deeper in the soil that are generally invisible to observation. The lower parts of these cracks are filled with water that is slowly infiltrating into the soil matrix. The soil hence can swell in response to this infiltration, and thus considerably change the dimensions and physical parameters of the cracks. Therefore, the second goal of this paper is to evaluate the influence of changing crack dimensions during infiltration on the infiltrating process itself.

Mathematical model

The FRACTURE mathematical submodel is part of the HYDRUS–ET code (Š i m ů n e k et al., 1997). The classical one-dimensional Richards' equation is assumed to describe water flow in the soil matrix. Matrix and preferential flows are mutually linked using an extension of the Richards' equation as follows (F e d d e s et al., 1988):

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h,z)\left(\frac{\partial h}{\partial z}+1\right)\right] - S_r(z) + S_f(z), \tag{1}$$

where h is the water pressure head [L], θ – the volumetric water content [$L^3 L^{-3}$], t – time [T], z – the vertical coordinate [L] (positive upward), K – the unsaturated hydraulic conductivity function [$L\ T^{-1}$], $S_r(z)$ – a sink term (e.g., root water extraction) [$L^3 L^{-3} T^{-1}$] that quantifies the volume of water extracted from soil by roots, and $S_f(z)$ is a source term accounting for the horizontal infiltration of water from the water-filled parts of the cracks into the soil. The latter term $S_f(z)$ is calculated using the Green–Ampt approach:

$$S_f = \left(K_h(z)\frac{h_0 - h_f}{l_f}\right)A_c, \tag{2}$$

where K_h is the saturated hydraulic conductivity of the cracks–matrix interface [$L\ T^{-1}$], h_0 – the positive pressure head at the point of infiltration [L], h_f – the pressure head (negative) at the leading edge of the moisture front at a distance l_f from the infiltration surface [L], and A_c is the specific surface of the cracks [$L^2 L^{-3}$].

Values of K_h and A_c can be measured, while the wetting front distance l_f can be calculated using the Green–Ampt approach as follows:

$$l_f = \sqrt{2K_h \frac{h_0 - h_f}{\theta_s - \theta_i}t}, \tag{3}$$

where θ_i and θ_s are the initial and saturated volumetric water contents, respectively, t is the time interval since the start of infiltration.

T h o m a et al. (1992) experimentally showed that due to coatings at the crack-matrix interface the hydraulic conductivity of this interface can differ significantly from the matrix conductivity. V a n G e n u c h t e n and S u d i c k y (1999) reviewed other evidence indicating that the hydraulic conductivity of the crack–matrix interface can be smaller by several orders of magnitude than the conductivity of the matrix interior. Main reasons for this are the changed physical and chemical properties of the interface resulting from repeated opening and closing of fractures, including coatings of this interface by relicts of roots, other organic matter, and clay particles. Field observations have shown that soil cracks are forming along the same internal soil surfaces, which represent areas of minimum mechanical strength.

The Richards' Equat. (1) was solved numerically subject to the initial and boundary conditions described below.

Initial condition

The initial condition at the beginning of the precipitation event (t_0) is given by the soil water pressure head profile:

$$h_i = f(z) \qquad \text{for } z > 0 \text{ and } t = t_0, \tag{4}$$

where h_i is the initial pressure head and t_0 the initial time.

Upper boundary conditions

The actual upper boundary condition during the infiltration event depends on the state of the soil surface. Three different upper boundary conditions at the soil surface are used to characterize different stages of the infiltration process.

1. A flux boundary condition for the unsaturated soil surface:

$$-K\left(\frac{\partial h}{\partial z}+1\right)=q_0(t) \qquad \text{for} \quad h<0, \tag{5}$$

where q_0 is the potential infiltration rate, i. e., the difference between precipitation and evaporation [$L^3 L^{-2} T^{-1}$].

2. A "surface reservoir" boundary condition (M l s, 1982) is used when the soil surface is saturated and a sub-critical surface layer ($h < h_s$) of water on the soil surface is being formed:

$$-K_s\left(\frac{\partial h}{\partial z}+1\right)=q_0(t)-\frac{dh}{dt} \qquad \text{for} \quad 0<h<h_s, \tag{6}$$

where K_s is the saturated hydraulic conductivity of the soil matrix, and h_s is the critical head, i. e., the thickness of the water layer on top of the soil surface when surface runoff is initiated, or when the water start flowing into cracks [L].

3. When the surface water layer reaches the critical thickness h_s and water flows into cracks (if they exist) or the surface runoff of intensity q_f starts, the following boundary condition is used:

$$-K_s\left(\frac{\partial h}{\partial z}+1\right)=q_0(t)-q_f(t) \qquad \text{for} \quad h_s<h, \tag{7}$$

where q_f is the flow rate into the cracks [$L^3\,L^{-2}\,T^{-1}$].

Boundary condition (6) permits water to build up on the soil surface. The left side represents the actual infiltration rate into the soil profile through the soil surface. The first term on the right side, q_0, represents the potential infiltration rate, i. e., the difference between precipitation and evaporation, and the second term is the change in thickness of the water layer on the soil surface. The volume of water in the cracks V_f is calculated as follows:

$$V_f=\left(\int_t q_f(t)dt-\int_t q_{fs}(t)dt\right), \tag{8}$$

where q_{fs} is the water flux rate from the cracks into the soil matrix.

Lower boundary conditions

A variety of boundary conditions, the same as those used in the HYDRUS-ET model (Š i m ů n e k et al. 1997), can be prescribed at the lower boundary. The conditions include constant or variable pressure heads or fluxes, seepage faces, and deep or free drainage conditions.

Input data

The FRACTURE submodel is part of the HYDRUS–ET model. In addition to parameters needed by HYDRUS-ET, the FRACTURE submodel needs two extra input parameters characterizing the soil cracks:

- The crack porosity P_c as a function of the soil water content expressed in mass units: $P_c=f(w)$. This relationship, also known as the soil shrinkage characteristic curve (M i t c h e l l, 1992), is a soil characteristic and can be estimated in the laboratory using undisturbed soil samples. In this procedure, a soil sample is allowed to dry slowly and its changes in height and diameter are measured together with the soil water content w. It is assumed that deformation of the soil sample will be equal to the soil crack porosity, P_c. From this data the relationship $P_c(w)$ can be established (N o v á k 1999). The crack porosity profile, $P_c(z)$, can be estimated using the soil water content profile $w(z)$, which is output from the HYDRUS–ET model, and the shrinkage curve $P_c(w)$.
- The specific length of cracks l_c is the "length" of cracks in a unit soil surface area. This parameter is assumed to be constant in the region where cracks are expected to exist, i. e., constant along the soil profile with cracks. Value of l_c can be easily estimated in the field by direct measurement or by image analysis of the site under consideration.

Application of the new FRACTURE submodel (version B)

The HYDRUS-ET model with versions A and B of the FRACTURE submodel was applied to the experimental site at Trnava (Western Slovakia). Properties of the silty loam soil at the site are given elsewhere (N o v á k and M a j e r č á k 1992, N o v á k et al. 2000). The saturated hydraulic conductivity was 5 cm/day and the saturated water content 0.407. Experimental $P_c(w)$ data were approximated using a linear function (N o v á k 1999) as follows:

$$P_c = -\, a_f\, w + P_{c0}, \tag{9}$$

where a_f is a slope of the $P_c(w)$ function and P_{c0} is the maximum crack porosity corresponding to a zero soil water content (dry soil).

Experiments conducted by T h o m a et al. (1992) and others showed that the saturated hydraulic conductivity of the cracks–matrix interface K_h can be much smaller than the matrix conductivity K_s. This decrease in K_s can be expressed as follows:

$$K_h = r_k\ K_s, \tag{10}$$

where r_k is a reduction factor accounting for hydraulic resistance across the crack–soil matrix interface. As mentioned earlier, this decrease in the hydraulic conductivity at the interface is probably due to coatings resulting from changed physical and chemical properties.

The following crack characteristics were used in our numerical experiment: z_c = 40 cm, a_f = 0.178, P_{c0} = 0.0429, r_k = 0.1, where z_c is the depth of soil cracks. The precipitation rate q_0 was assumed to be 25 cm/day during a period of 2 hours. Flow into cracks was assumed to start when the thickness of the surface water layer reached 0.1 cm.

Results and discussion

In our previous paper (N o v á k et al. 2000) we showed the importance of soil cracks in determining infiltration rates during a precipitation and/or irrigation event. As is demonstrated in Fig. 2, infiltration from cracks into a soil with stable crack dimensions increased the total infiltration rate significantly during the infiltration event. Having stable cracks may not be very realistic. In reality, the soil water content during infiltration will change and the soil will swell correspondingly, thus decreasing the crack dimensions. The question is what we can expect when using the FRACTURE submodel with crack dimensions changing due to soil swelling during infiltration (version B) contrary to the submodel with constant crack dimensions (version A).

1. The soil water content should increase in both cases (in comparison to a soil without cracks) due to infiltration through the soil surface, as well as infiltration through the crack surfaces. Because of soil swelling, cracks should be narrower when using version B of the FRACTURE submodel since their dimensions are constantly reevaluated based upon the actual water content. This as compared with version A, which assumes that the cracks remained constant during the infiltration process.
2. The water level (pressure height) in the soil cracks should be higher for the version B submodel in comparison to version A since the volume of cracks diminishes as time progresses, and hence less water is needed to fill the cracks up to some given level. Water storage in the cracks during infiltration in a soil whose cracks change dimensions was found to be lower in

comparison to the soil with stable cracks. This is shown to be the case in Fig. 3. Notice, that the amount of water stored in the cracks also decreased significantly.

3. Higher instantaneous and cumulative infiltration rates were calculated as well for soils with changing crack dimensions (version B) in comparison to the submodel with stable cracks (version A) (see Fig. 4 and Fig. 5); this because larger crack surfaces are exposed to infiltration in the former case. However, the effects are not as significant as those pertaining to water storage in the cracks.

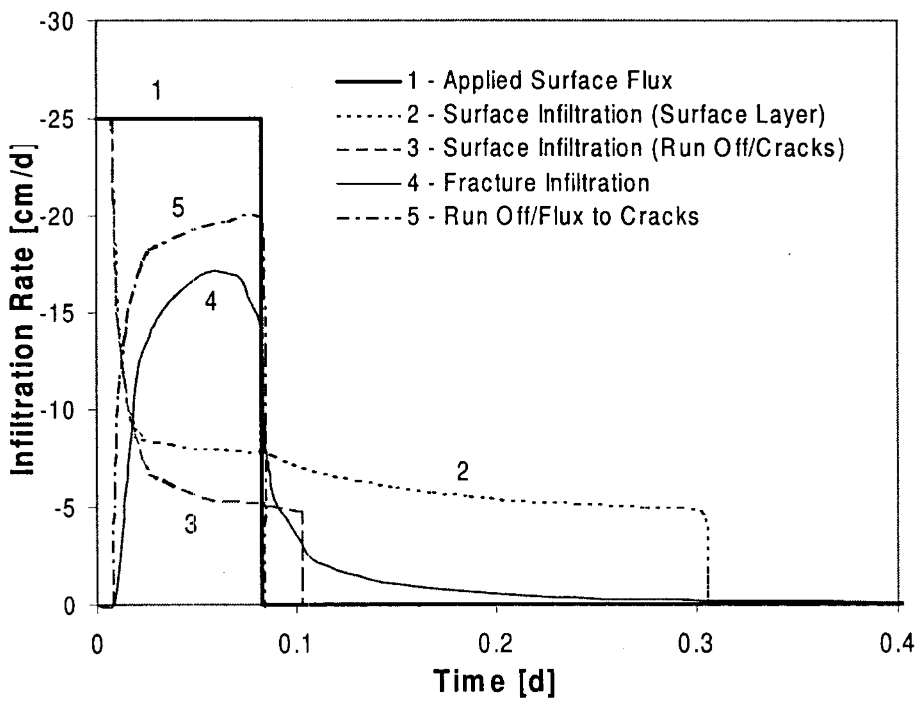

Fig. 2. Infiltration rate versus time calculated using the FRACTURE submodel (version A) with soil cracks not changing their dimensions during infiltration: 1 – potential infiltration rate (irrigation rate), 2 – infiltration into the soil without cracks, with water accumulating on the soil surface, 3 – infiltration into the soil through the soil surface without cracks, but with surface runoff, 4 – infiltration rate from cracks into the soil, and 5 – flow into the cracks.

Obr. 2. Rýchlosť infiltrácie v závislosti na čase, vypočítaná pomocou submodelu FRACTURE (verzia A) s pôdnymi puklinami, ktoré nemenia svoje rozmery počas infiltrácie: 1 – rýchlosť potenciálnej infiltrácie (rýchlosť závlahy), 2 – infiltrácia do pôdy bez puklín, voda sa akumuluje na povrchu pôdy, 3 – infiltrácia do pôdy cez jej povrch, bez puklín, ale s povrchovým odtokom, 4 – infiltrácia z puklín do pôdy a 5 – prítok vody do pôdnych puklín.

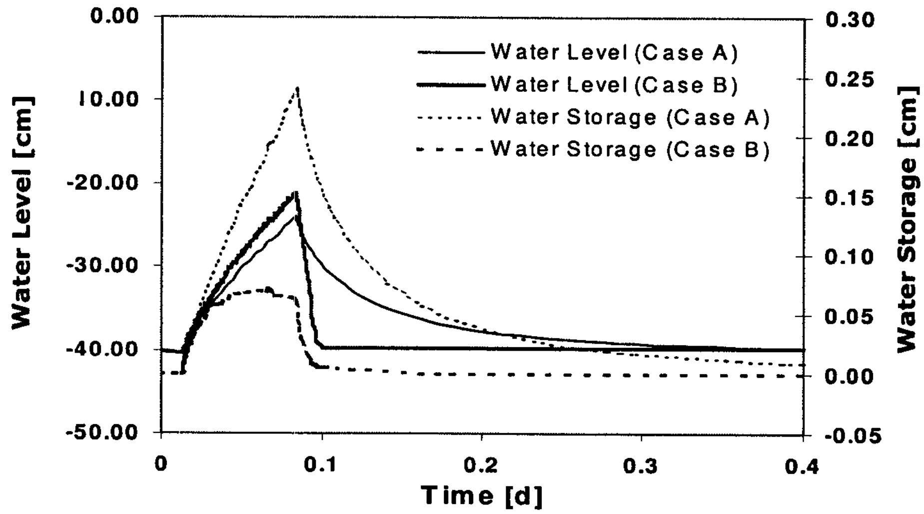

Fig. 3. Water level and water storage in cracks during infiltration for soil cracks with constant (case A) and changing (case B) dimensions during the infiltration event.
Obr. 3. Hladina vody v pôdnych puklinách a ich obsah vody, ak sú rozmery pôdnych puklín stále (prípad A) a ak pukliny menia svoje rozmery počas infiltrácie (prípad B).

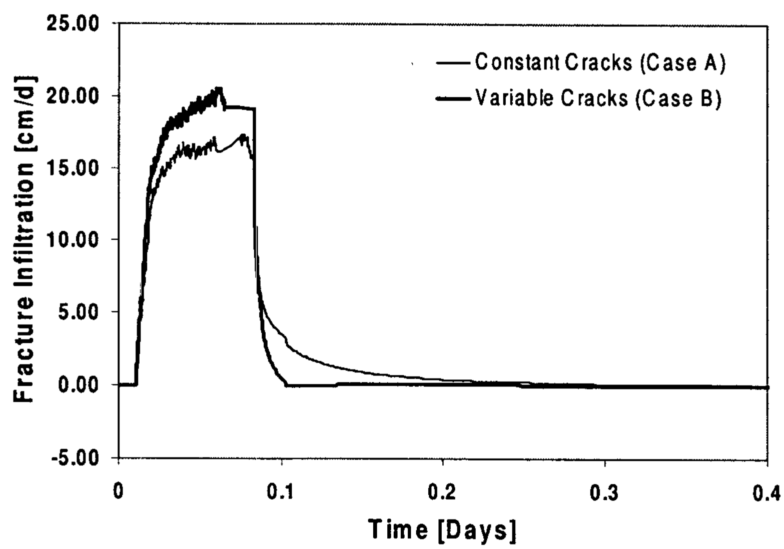

Fig. 4. Infiltration rate versus time for soil cracks being constant (case A) and changing during infiltration (case B).
Obr. 4. Intenzita infiltrácie v závislosti na čase pre pôdne pukliny so stálymi rozmermi (prípad A) a pre pukliny meniace svoje rozmery počas infiltrácie (prípad B).

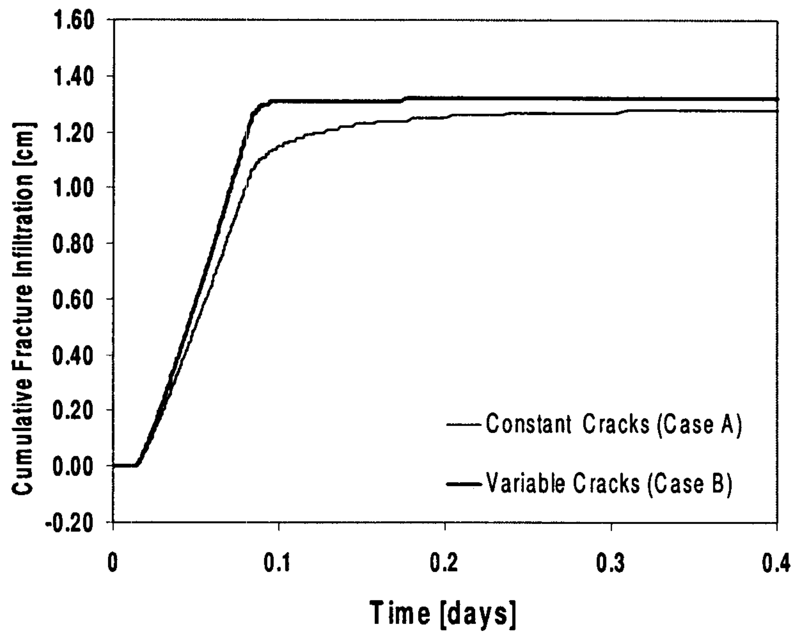

Fig. 5. Cumulative infiltration versus time for soil cracks being constant (case A) and changing during infiltration (case B).
Obr. 5. Kumulatívna infiltrácia v závislosti na čase pre pôdne pukliny so stálymi rozmermi (prípad A) a pre pukliny meniace svoje rozmery počas infiltrácie (prípad B).

Conclusions

The effects of changing soil crack dimensions during infiltration were quantified by comparison of infiltration characteristics as modeled by two versions of the FRACTURE submodel. Version A assumed non-changing cracks dimensions during the infiltration event, while version B assumed that the cracks dimensions can change during the infiltration event depending upon soil water content changes. The results of our numerical experiments are as follows:

1. The ratio of the maximum infiltration velocities into the soil with changing crack dimensions during infiltration, $v_{max,v}$, and with stable cracks, $v_{max,c}$, was 1.23 for the illustrative example presented in this contribution.
2. The ratio of cumulative infiltrations (I_v/I_c) as estimated by both submodels (versions B and A) for a given precipitation event was 1.20.

3. By comparing both modeling approaches (stable cracks and cracks changing their dimensions), it is shown that the crack "retention capacity" (i. e., the ability of cracks to accumulate and infiltrate "in-flowed" water) is increased in case of the cracks changing their dimensions. Although the soil is swelling and cracks are becoming narrower during infiltration (i. e., smaller crack volumes), the larger exposed wetted crack surface area due to a higher water level in the cracks increases the actual infiltration rates. The increased pressure heights in the deforming cracks, in comparison to the stable cracks, also increases the infiltration velocity.
4. The many complex processes affecting infiltration into a soil with cracks are difficult to measure, especially when the cracks change their dimensions. Modeling such an event greatly helps to understand the importance of the various processes involved, and ultimately in determining the effects of cracks on infiltration.

Acknowledgements. This work has been carried out under the support from the Slovak Grant Agency (VEGA), Project 2 – 1084 – 21.

List of symbols

a_f – slope of the $P_c(w)$ function [–],
A_c – specific surface of the cracks [$L^2 L^{-3}$],
h – pressure head [L],
h_0 – positive pressure head at the point of infiltration [L],
h_i – initial pressure head [L],
h_f – pressure head (negative) at the wetting front at a distance l_f away from the crack surface [L],
h_s – critical head, i.e., thickness of the water layer on the soil surface when surface runoff is initiated, or when water starts to flow into soil cracks [L],
K – unsaturated hydraulic conductivity [$L T^{-1}$],
K_h – hydraulic conductivity of the crack-matrix interface [$L T^{-1}$],
K_s – saturated hydraulic conductivity of the soil matrix [$L T^{-1}$],
l_c – specific length of cracks per unit soil surface area [$L L^{-2}$],
l_f – distance of the wetting front from the infiltration surface [L],
P_c – crack porosity [$L^3 L^{-3}$],
P_{c0} – maximum crack porosity corresponding to a zero soil water content w [$L^3 L^{-3}$],
q – actual infiltration rate [$L^3 L^{-2} T^{-1}$],
q_0 – potential infiltration rate [$L^3 L^{-2} T^{-1}$],
q_f – flow into soil cracks, or surface runoff [$L^3 L^{-2} T^{-1}$],
q_{fs} – water flux rate from the cracks into the soil matrix [$L^3 L^{-2} T^{-1}$],
r_k – reduction factor for the saturated hydraulic conductivity of the crack–soil matrix interface [–],
S_r – sink term quantifying the volume of water extracted from soil by roots (the root extraction term) [$L^3 L^{-2} T^{-1}$],
S_f – horizontal infiltration rate of water from cracks into the soil matrix [$L^3 L^{-3} T^{-1}$],
t – time [T],

t_0 – initial time [T],
t_f – time interval since the start of infiltration [T],
t_p – ponding time [T],
V_f – volume of water in the cracks [$L^3 L^{-2}$], under a unit square area of soil surface,
w – soil gravimetric water content [$M^3 M^{-3}$],
z – vertical coordinate [L], (positive upward),
θ – volumetric water content [$L^3 L^{-3}$],
θ_i – initial volumetric water content [$L^3 L^{-3}$],
θ_r – residual soil water content [$L^3 L^{-3}$],
θ_s – saturated soil water content [$L^3 L^{-3}$].

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INFILTRÁCIA DO NAPUČIAVAJÚCEJ PÔDY S PUKLINAMI

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Pomocou dvoch verzií submodelu FRACTURE sme kvantifikovali vplyv zmien rozmerov výsušných puklín v pôde počas infiltrácie vody do pôdy. Verzia A predpokladá nemeniace sa rozmery puklín počas infiltrácie, verzia B umožňuje výpočet rozmerov puklín – vyvolaných zmenami vlhkosti počas infiltrácie – a zahrnutie týchto zmien do výpočtu charakteristík procesu infiltrácie. Výsledky numerických experimentov sú takéto:

1. Pomer maximálnych rýchlostí infiltrácie do pôdy s premenlivými rozmermi puklín $v_{max,v}$ v porovnaní s rýchlosťami infiltrácie do stabilných puklín $v_{max,c}$ pre použitý ilustratívny prípad bol 1,23.
2. Pomer kumulatívnych infiltrácií (I_v/I_c), určený oboma modifikáciami submodelov (verzie A a B) pre daný prípad bol 1,20.
3. Z porovnania výsledkov modelovania s využitím oboch verzií submodelov vyplýva, že tzv. retenčná kapacita (schopnosť akumulovať v puklinách vodu, ktorá do nich vtečie a infiltrovať ju) sa zväčšuje, ak sa menia – zmenšujú rozmery puklín. Pôda počas infiltrácie vody do nej napučiava, pukliny sa zužujú, avšak zvyšuje sa infiltračná plocha puklín a tlaková výška vody v nich, čo spôsobuje v porovnaní so stabilnými puklinami zvýšenie rýchlosti infiltrácie.
4. Mnohé zložité procesy ovplyvňujúce infiltráciu do pôdy s puklinami sú ťažko merateľné, predovšetkým v prípade meniteľných rozmerov puklín. Modelovanie

takýchto prípadov umožňuje pochopiť význam prebiehajúcich procesov, ale aj určenie vplyvu puklín na infiltráciu vody do pôdy.

Zoznam symbolov

a_f – sklon funkcie $P_c(w)$ [–],
A_c – merný povrch puklín [$L^2 L^{-3}$],
h – tlaková výška [L],
h_0 – kladná tlaková výška na infiltračnom povrchu [L],
h_i – počiatočná tlaková výška [L],
h_f – tlaková výška (záporná) na čele omáčania, vo vzdialenosti l_f od povrchu pukliny [L],
h_s – kritická výška, t. j. hrúbka vrstvy vody na povrchu pôdy na začiatku povrchového odtoku, alebo na začiatku prítoku vody do puklín v pôde [L],
K – nenasýtená hydraulická vodivosť pôdy [$L\, T^{-1}$],
K_h – hydraulická vodivosť rozhrania puklina – matrica pôdy [$L\, T^{-1}$],
K_s – nasýtená hydraulická vodivosť pôdnej matrice [$L\, T^{-1}$],
l_c – merná dĺžka puklín, pripadajúca na jednotku plochy povrchu pôdy [$L\, L^{-2}$],
l_f – vzdialenosť čela omáčania od infiltračného povrchu [L],
P_c – puklinová pórovitosť [$L^3 L^{-3}$],
P_{c0} – maximálna puklinová pórovitosť, zodpovedajúca nulovej vlhkosti pôdy [$L^3 L^{-3}$],
q – skutočná rýchlosť infiltrácie [$L^3 L^{-2} T^{-1}$],
q_0 – potenciálna rýchlosť infiltrácie [$L^3 L^{-2} T^{-1}$],
q_f – rýchlosť vtoku vody do puklín, alebo povrchový odtok [$L^3 L^{-2} T^{-1}$],
q_{fs} – rýchlosť vtoku vody z puklín do matrice pôdy [$L^3 L^{-2} T^{-1}$],
r_k – redukčný faktor pre nasýtenú hydraulickú vodivosť rozhrania puklina – pôdna matrica [–],
S_r – odberový člen, charakterizujúci objem vody odobraný koreňmi rastlín [$L^3 L^{-2} T^{-1}$],
S_f – horizontalna rýchlosť infiltrácie vody z puklín do matrice pôdy [$L^3 L^{-3} T^{-1}$],
t – čas [T],
t_0 – počiatočný čas [T],
t_f – časový interval od začiatku infiltrácie [T],
t_p – čas výtopy [T],
V_f – objem vody v puklinách, pripadajúci na jednotku plochy povrchu pôdy [$L^3 L^{-2}$],
w – hmotnostná vlhkosť pôdy [$M^3 M^{-3}$],
z – vertikálna súradnica [L], (pozitívna smerom hore),
θ – objemová vlhkosť pôdy [$L^3 L^{-3}$],
θ_i – počiatočná objemová vlhkosť pôdy [$L^3 L^{-3}$],
θ_r – reziduálna objemová vlhkosť pôdy [$L^3 L^{-3}$],
θ_s – nasýtená objemová vlhkosť pôdy [$L^3 L^{-3}$].