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Discussions

Interactive comment on "A model of landslide triggering by transient pressure waves" *by* G. W. Waswa and S. A. Lorentz

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1. Introduction

We are grateful to the referee for taking his precious time to read and understand our manuscript. We thank the referee for the comment, because it questions some of the important issues raised in our manuscript and might help us understand the processes better.

Since the deadline for discussing our manuscript is very close, our response here is very brief and with reference to only a few issues raised by the referee. This is in order to allow the referee to comment on our response, if possible, before the closure of the discussion period of our manuscript (that is just effectively a few hours away).

2. Hydraulic diffusivity

We read in many text books and journal articles that transmission of water through soil is described by the hydraulic conductivity parameter, specifically unsaturated hydraulic conductivity (K-unsat) for flow of water through unsaturated soil and saturated hydraulic conductivity (K-sat) for flow of water through saturated soil.

K-unsat is usually expressed as a function of soil-water content or pressure head. This is because in unsaturated soil, a relationship exists between soil-water content and pressure head. It is this relationship, moreover, that enables us to convert the water-content (the mass picture) Richards' equation to pressure head (the energy picture) Richards' equation (Swartzendruber, 2003; Buchan, 2003). K-sat is usually expressed, neither as a function of soil-water content nor of pressure head. K-sat is usually taken as a constant. This is because in a saturated soil, water content is invariant.

However, expressing K-unsat as a function of pressure head does not mean that it (K-unsat) describes the transmission of pressure head. Note that, one can only express K-unsat as a function of pressure head if the relationship between pressure head and soil-water content is available. This is to say that, if we know the behavior of pressure head in relation to soil-water content at any point within a soil, we can predict K-unsat as a function of pressure head. In other words, a change in pressure head without a change in water content cannot help us to predict K-unsat, because there is no movement and change in soil-water content. This phenomenon, of change in pressure head without change in soil-water content, we imagine, was the case in Rasmussen et al.'s (2000) laboratory observations, which we described in our manuscript.

Having stated that K-unsat does describe the transmission of water through soil, and not pressure head through pore water, we now would like to explain our understanding of the physical significance of the hydraulic diffusivity parameter.

Wu (2003) has stated that "since hydraulic diffusivity is defined as the ratio of the hydraulic conductivity to specific water content, it can be viewed as the ratio of the flux to the soil-water content gradient when gravitational and hysteresis effects can be neglected. Thus hydraulic diffusivity provides a measure of the rate of water movement through soil." This statement is in agreement with the basic definition of diffusion and diffusivity. Diffusion is the process that involves the net movement (flux) of a substance from a region of high concentration to its adjacent region of low concentration. Diffusivity is the constant of proportionality between the net movement (flux) and the concentration gradient. Consequently, a process that involves only flux (movement) of a substance without concentration gradient of that substance (for instance transmission of water through saturated soil) can neither be described as diffusion nor yield a diffusivity coefficient. It is for these reasons that diffusivity coefficient, in Richards' equation, only appears in matric-suction dependent term and not in gravity dependent term. Note that, the matric-suction dominates the flow of water in dry soil (in unsaturated state, when there is concentration/water-content gradient). This dominance becomes remote as the soil becomes wet (saturated state, when the concentration/water-content gradient diminishes), in which case the gravity force dominates the vertical flow. Note that the Richards' equation consists of both the matric-suction-dependent and gravity-dependent terms. Consequently, if we neglect the gravity term, we will come up with a purely diffusion equation, and this is only physically true for unsaturated soil. It is on this basis that we imagine that the derivation of Iverson's equation is erroneous (as described in our manuscript) and, if left unexplained, might be confusing to soil physicists and hydrologists.

Therefore, the referee's statement that the hydraulic diffusivity does not describe the diffusion of water mass, it does describe the diffusion of pressure head through the soil matrix, may not be true. And for clarification, our manuscript is not focusing on the water content dependent pressure head (which of course only occurs in unsaturated soil), it is focusing on pressure head transmission through pore water and not soil matrix.

Furthermore, even in the unsaturated soil, pressure head on its own cannot be transmitted through soil matrix; a change in pressure head occurs because of transmission and change in soil-water content. Therefore, to state that hydraulic diffusivity does not describe the diffusion of water mass, but diffusion of pressure head through soil matrix, might be not only physically incorrect but illogical as well.

3. Intense rainfall and infiltration in landslide triggering

Our review of literature indicated that most rainfall-triggered shallow landslides occur when the soil mass is in a state of saturated (or nearly saturated). In fact, Iverson (2000) described observations made from some of his earlier experiments that, a higher-intensity rainfall was used to elevate the pressure heads and trigger landslides after the soil mass was pre-wetted to the state of tension saturation by low-intensity rainfall. Iverson's observations are in agreement with the documented field observations, which indicate that the higher-intensity rainfall that triggers landslide usually occurs in the latter part of the critical storm, which also occurs in the latter part of the rainfall season, i.e. after the soil mass is pre-wetted.

The question is: how can infiltration occur on a saturated (pre-wetted) soil profile? And particularly from even a higher-intensity rainfall, after the soil has been pre-saturated by a low intensity rainfall?

The referee has explained that almost all the higher-intensity rainfall that falls on a saturated soil mass, in slopes prone to shallow landslides, infiltrates the soil and for the entire event. This, on our part, is very difficult to imagine. We hereby urge the referee to help us understand the physical processes that might be involved here. Is it that the water initially held in the soil (the water that pre-saturates the soil), before the intense rainfall, is quickly released to give way/space for the one that intensely arrives at the ground surface? If this is so, what is the mechanism of this self quick release? Or is it that the intense rainfall pushes the initial soil water (the one that pre-saturates the soil) out of the soil matrix for it (the new water) to infiltrate? If this is so, what is the displacement mechanism?

4. Way forward

We will respond fully to the referee's comment after the discussion period. But we hereby request the referee, if possible, to comment on our above short response. This will indeed help us understand the processes better and revise our manuscript accordingly.

We also wish our referee and the entire HESSD community a happy Easter.

5. References

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