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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 thankful to the referee for having taken his time to read through our manuscript and for the valuable comments. This is our response to the technical issues raised by the referee. In case it appears that we did not understand the referee's comment, we urge the referee to expound/highlight on those areas. In overall, however, we invite the referee to comment on our response, if possible, before the end of the discussion phase of our manuscript.

2. Volumetric water content and pressure head

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In our manuscript we stated that "while the Richards' equation, and more specifically the embedded hydraulic parameters (e.g. hydraulic diffusivity), sufficiently and adequately applies where change in pressure head is a function of soil water content, it violates the law of conservation of energy, when applied where change in pressure head occurs without change in water content."

The above statement has been rejected on the basis of another one that "even in a saturated soil there is a unique relationship between pressure head and water content: above the air-entry value, a change in pore pressure causes swelling or consolidation of the soil matrix (according to the principle of effective stress) and this changes the volumetric water content of the soil" (Page C675, Paragraph 4).

The above two statements appear to address, respectively, two different (but mutually dependent) physical processes. The two statements, therefore, may not substitute each other.

In our statement we are seeking to explain or understand the cause of change in pore water pressure in a soil profile that is already saturated. We state that, based on the Richards' equation, change in pore water pressure can occur only if there is change in volumetric water content. Therefore, where there is no change in volumetric water content, the Richards' equation cannot help us, or be employed, to predict the change in pore water pressure.

On the other hand, the referee's statement seeks to explain, or highlight, the effects of the change in pore water pressure on the volumetric water content.

In the sequence of the physical processes, we imagine that the referee is ahead of us. While we are still seeking to understand/explain the cause of change in pore water pressure in a saturated soil profile, the referee is already explaining the effects of this change in pore water pressure on saturation. We imagine that it is necessary, first, to understand/explain the cause of change in pore water pressure, then, understand/explain the effect of this change in pore water pressure on saturation.

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In order to understand the cause of change in pore water pressure in a saturated soil profile, we will work backwards from the referee's standpoint. We will then work forward to explain the effects of change in pore water pressure in a saturated soil profile.

The referee's standpoint emphasizes the change in volumetric water content as a result of change in pore water pressure. This emphasis is also apparent in the referee's other statement that, "in a saturated soil, the change in volumetric water content per unit change in pressure head is directly related to the coefficient of volumetric compressibility" (Page C675, Paragraph 4).

3. Rainfall induced pressure head

The referee's standpoint is that in a saturated soil, the change in volumetric water content is caused by compressibility (change in the porosity) of the soil, which is caused by change in pore water pressure. Based on this sequence/order of processes, the question is: "in a saturated soil profile, what causes the change in pore water pressure?" The answer to this question is found in another statement by the referee, and in support of Iverson (2000), that: "in this (saturated) condition the rainfall-induced pore pressure rapidly propagates downward with a diffusive process that can occur with or without much water flux" (page C675, paragraph 4). Therefore, the change in pore water pressure is caused/induced/generated by rainfall. Besides, the above referee statement also generates additional questions.

First, how does rainfall induce pore water pressure in a saturated soil profile? In our manuscript, we argue that, since rainfall occurs on an already saturated soil profile, it is unlikely that the rainfall-induced pore water pressure is as result of rainfall-infiltration. This unlikelihood leads us to question the use of infiltration boundary condition by Iverson (2000) in solving his diffusion equation. On our part, we imagine that the kinetic energy, carried by the intense rainfall, is converted and imparted into pore water as potential energy. It is important to mention here that the spike in rainfall intensity, which triggers the slide, usually occurs when the soil profile is in a state of tension saturation (as also indicated by Iverson, 2000). Since the spike in rainfall intensity is highly transient, the soil's state of tension saturation is very important, because it acts as an intake and temporary storage for the introduced potential energy, which diffuses to the lower horizons.

4. Pressure-head diffusivity coefficient and diffusion of pressure head through pore water

Secondly, what is it that rapidly propagates downward with a diffusive process . . . without water flux? The diffusing element/species is not water; it is the rainfall-induced pressure head. Consequently, the hydraulic diffusivity, which is meant to describe the diffusion of water through unsaturated porous media, cannot be used to describe the diffusion of pressure head through pore water. Certainly, this is where the novelty of our newly proposed model, which contains a newly proposed energy (pressure-head) diffusivity coefficient, becomes apparent. The newly proposed energy (pressure-head) diffusivity coefficient describes the diffusive transmission of pressure head through pore water.

5. Effect of the induced and diffused pressure head

After having explained/understood the cause of change in pore water pressure in a saturated soil profile, and how this induced pressure-head is transmitted down the profile, we can now work forward to address/explain the effect of the change in pore water pressure.

The change in pressure head may affect the soil pore water, as well as the porous media. These effects include, as rightly stated by the referee, the small change in the porosity of the media (compressibility), which results in the correspondingly small change in volumetric water content. Additionally, the change in pore water pressure may also trigger landslides, which is the main focus of our manuscript.

But thinking critically about these two effects, the second one (landslide triggering)

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could be a global manifestation of the first one (swelling). Here, we imagine that the increase (change) in pore water pressure, acting on the soil particles (as stated by the referee) along the line of potential failure in the slope, may result in landslide. However, this subject could be investigated in a separate study.

6. Conclusion

In conclusion, we agree, and are aware, that change in pore water pressure may result in swelling or consolidation of a saturated soil profile. However, change in pore water pressure, especially in a tension saturated soil profile, may also result in landslide triggering, which is the focus of our manuscript, as well as the works of Iverson (2000). The change in pore water pressure in a tension saturated soil profile is induced by the intense rainfall at the surface. The induced pressure head is transmitted through pore water by diffusive process, i.e. without much water fluxes. Our newly proposed diffusion model contains a newly proposed energy (pressure-head) diffusion coefficient, which describes the diffusive transmission of pressure head through pore water.

Our derived model, as mentioned in the manuscript, is mathematically similar to Iverson's (2000) model, except for the diffusivity coefficients. The referee mentioned that we may have misinterpreted Iverson's work. We hereby invite the referee to highlight to us those specific areas that we may have misinterpreted.

Finally, we thank the referee for the list of references provided and we intend to incorporate them, including a discussion on the compressibility issue, in our revised manuscript, after the closure of the discussion phase.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 2355, 2014.