Hydrol. Earth Syst. Sci. Discuss., 10, C453–C458, 2013
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Hydrology and Earth System Sciences Discussions

Interactive comment on "Characterization of groundwater dynamics in landslides in varved clays" *by* J. E. van der Spek et al.

J. E. van der Spek et al.

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Received and published: 22 March 2013

General comments.

We thank the reviewer for his constructive review and the compliments. Here we will address the specific points mentioned by the reviewer.

Specific comments.

1. The text is perhaps a little too concise in some respects. For example, there is little indication of scale for the reader to understand the nature of the system. How thick are the silt lenses, and how thick are the clay layers that separate them? How large are the landslides (length? typical width?) and how are the major fissures aligned with respect to the geometry of the landslide and its slope context? How steep are the

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Interactive Discussion

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slopes, and is there any possibility that surface runoff from large rainfall events may contribute directly to the water in the fissures?

Indeed we tried to keep the manuscript as focused as possible. We will add some topographic information about the length, surface area, steepness etc of the landslides we used in our study. The scale of the silt and clay lenses is mm – cm (p.298 line 12-13). We will add that the silt and clay laminae are assumed to be equal in thickness with reference to Huff 1989. We described the fissures in the Trieves on p.298 Line 24 to p.299 Line 14. This is what we collated from all published information available. We did not try to model one specific landslide in the Trieves but rather put effort in building two generalized landslide geometries (deep fissures and slip surface, with rather large fissure distance, and a more shallow, smaller system with also shorter fissure distance) from the scattered data available. Furthermore, we discuss the sensitivity of our fissure conceptualization in section 7.2. It is possible that surface runoff will flow directly into the fissures in practice, but this was not taken into account as a separate hydrological process. Surface water flow infiltration could especially be an issue during the snowmelt period. We will indicate this in the revised version of the manuscript.

2. The main problem is the lack of clarity regarding the connections between fissures that permit downslope drainage, and how these connections relate to the shear surface. Indeed, the precise mechanism by which the pore water pressures at the shear surface between fissures are being affected by the changing head in the fissures. Are the shear surfaces all contained within clay layers, and if so, how easily/quickly can water penetrate along the shear surface from the base of a fissure? The paper refers to 'infiltration from fissures at the level of the slip surface', but this phrase implies infiltration into a layer of material rather than possible preferential seepage into and along the weakness that is the shear surface. The effectiveness of the changing head conditions within the fissures for driving the reactivation of movement will depend on the mechanism by which the effect(s) of those conditions are transmitted to the failure surface.

The reviewer stresses an important point that we will clarify further. From the colluvium

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top layer water flows into the fissure which basically is a water balance bucket. From here water can infiltrate horizontally into the silt laminae of the varved clays (in area below water table in fissure) or will be drained away from the landslide laterally. This is modeled using a (black box) linear reservoir approach (see also section 3.3) We do not have any detailed information about fissure connectivity. We do not conceptualize the slipsurface itself as a preferential flow path. . On the contrary we show that with a relatively modest water flux from the fissure to the varved clays (figure 3) the measured water level fluctuations in different varved clays landslides could be explained. Also Van Asch et al. (1996), Nieuwenhuis (1991) and Vuillermet et al. (1994) assume infiltration into the silt laminae of the varved clays, rather than preferential flow along the slip surface. -Preferential flow along the slip surface could be modeled by an increased permeability of the varved clays around the slip surface. The influence of a larger saturated permeability in the varved clays can be seen in eq. 8 and is quantified in the sensitivity analysis shown in figure 4. A higher saturated permeability will allow faster pore water pressure response in the varved clays, thus on the slipsurface. We will add this clarification in the revised manuscript.

3. It is difficult to evaluate the results because of the design of some Figures and their captions. In this section, Figure 6 needs attention: the columns should be identified as (a), (b) and (c), and so the 'measured' lines in (c) (middle) and (c) (bottom) need to be shown as broken lines (dark blue and black lines of the same thickness are effectively indistinguishable). If there are no measured data at all, do you need this item in the legend? Figure 5 also needs attention: what is each part showing? A cross-section or a plan? If a cross-section, is the x-direction aligned across the slope or parallel to the slope? How do these plans/sections relate to fissures? Any fissures relating to any of these diagrams need to be clearly identified.

We will improve the clarity of Figure 6 as suggested by the reviewer. Figure 5 shows cross-sections. The fissures are on the left side of each of the four graphs. The width of the graphs is half the distance between two fissures (L) and the height is the fissure

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depth (d) as presented in figure 2. We will add this information in the caption.

Technical corrections

page 296, line 26 – Malet et al 2005 is not listed in the reference list OK

page 297, line 9 – rephrase ‘is considered as sliding’ – suggest something like ‘is considered to be unstable’ OK

page 297, line 10 – what is the level of risk that velocities may suddenly increase? We consider this point somewhat outside the scope of our article. We did not model the displacement of the landslides. But different responses have occurred in different landsides in the Trieves. Van Asch et al. (2009) show that the Monestier du Percy and St. Guillaume landslides are typical slow moving deep seated landslides with a deformation zone of approx. 1m thick. The La Mure landslide shows more catastrophic failures at the toe of the landslide (van Genuchten, 1989).

page 297, line 20 – van Asch et al 1996 OK

page 297, line 24 – ‘these dynamics’ not ‘the dynamics’ OK

page 297, line 25 – rewrite: ‘ments. The approach presented is applied ...’ OK

page 297, line 25 – I don’t think ‘pressure propagation in varved clays’ is the appropriate way of describing the work We modeled the water using diffusion equation when the laminae are saturated and the Richards’ equation when unsaturated. Here we mean to say that the pore water pressure in the varved clays changes due to the water height in the fissure system.

page 297, line 27 and elsewhere – ‘a conceptual hydrological model’ not ‘a hydrological conceptual model’ OK

page 298, line 9 – ‘10 000 years ago’ or ’10 000 y ago’, not ‘yr’ OK

page 299, line 1 and elsewhere – check whether the journal requires American ‘meters’

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or English ‘metres’ spellings? OK

page 299, line 8 – ‘indicated that ...’ OK

page 299, lines 20-21 – ‘Vertical flow in the varved clays is considered negligible’ – this statement needs qualifying with respect to the presence of fissures – are you saying that including the fissures the vertical flow is negligible? This is not clear. We mean to say that vertical flow passing the clay laminae of the varved clays is neglected. We do consider vertical flow through the fissures.

page 301, line 12 – ‘Equation (1), subject to boundary conditions (2),’ – add commas OK

page 301, line 16 – ‘Water infiltrates in the horizontal ...’ OK

page 300, line 17 and page 301, line 20 – the symbols probably won’t reproduce in the review text box, but it appears that two different symbols for ‘phi’ (pressure head in the silt layers) have been used, which is confusing – please check and amend as necessary OK

page 302, lines 20-21 – for a water balance of the fissure, surely water entering the varved clays from the fissure should be described as an ‘outflow’ from the fissure rather than an ‘inflow into the clays’? The reviewer has a point, but for reasons of clarity we prefer to write inflow into the varved clays and not outflow of the fissure.

page 305, lines 13-14 – ‘head halfway between the fissures ...’ OK

page 306, line 11 – rewrite: ‘Data are available from four landslides in the Trieves area: La Mure ...’ OK

page 306, line 12 – ‘The data are very scattered ...’ (not ‘is’) OK

page 307, line 20 – Jongmans et al – 2008 or 2009? (no 2008b in the reference list) OK

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page 309, line 7 – cite as ‘BRGM (2011)’ – the web address is in the reference list OK

page 310, line 7 – van Asch et al (1996) OK

page 310, line 9 – ‘Third, the ...’ (delete ‘And’) OK

page 310, line 23 – ‘pressure propagation’ – not adequately demonstrated – see comment 2 under ‘Specific comments’ (above). OK, see reply there

page 311, line 18 – ‘retrogressively, in an upslope direction.’ OK

page 312, line 14 – ‘drains in the downslope ...’ OK

page 312, lines 17-18 – ‘modelled’ (English) or ‘modeled’ (American)? OK

page 313, lines 14-15 – ‘Both the width and the reservoir coefficient of a fissure ...’ OK

page 318, Fig. 1 – either the caption or the legend needs to state that the black dots represent the landslides No, they represent the villages located close to the landslides

page 320, Fig. 3 – identify upper graph as (a) and lower graph as (b) – also the caption is not sufficiently informative to stand alone: dynamic equilibrium of what? OK

page 324, Fig. 7 – what does h = 0 mean in this figure? h = 0 always denotes the level between the colluvium and varved clays as is outlined on p 308, line 20-21, however, we will outline it in figure captions as well

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 295, 2013.