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Discussions

# *Interactive comment on* "Vertical hydraulic conductivity of a clayey-silt aquitard: accelerated fluid flow in a centrifuge permeameter compared with in situ conditions" *by* W. A. Timms et al.

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The authors would like to thank the two anonymous referees for their thoughtfulness in considering the findings of this paper. We appreciate the time that the referees have made available for these reviews. Our initial response to the comments of Referees #1 and #2 are provided here for further consideration.

AR1 is Anonymous Referee #1

AR1: This paper needs major revisions concerning the discussion of results. The Kv values presented cause me to conclude that flow in vertical fractures is common in



many of the samples because the values reported are higher than what is expected from unfractured, intact silty clay samples with more than 10-15 percent clay size particles, particularly clay that is smectite rich. So there needs to be discussion of the evidence for and against the presence of vertical fractures. This needs to include a discussion of the geologic origins and post depositional influences on the deposits focused on the evidence for the presence or absence of fractures. This would require a geologic literature review-best to discuss with a geologist. Aquitard science is mostly about the presence or absence of fracture effects because this is generally what governs aquitard integrity. I suspect that the centrifuge method errors on the high side. The issue of error or bias needs more consideration. In general Kv values for smectite rich silty clay sample at insitu stress conditions should be less than 10e-8 cm/sec.

Author's response: We agree with the authors that fractures often dominate flow through aquitards, however, we would like to present further evidence, in addition to the in situ K measurements, that fractures do not affect these results. We would be pleased to provide more information on the alluvial sedimentary geology in this area (Kelly et al. 2014) and fracture flow that occurs near the surface in these sediments (eg Acworth and Timms, 2009; Greve et al. 2012). There is evidence that the Kv values reported in this paper are not affected by fracture flow as this reviewer suggests for two reasons which we seek to explain in a more detailed response in a revised manuscript.

Firstly, any fracture or preferential flow effect is amplified and readily identified in the geotechnical centrifuge methodology. Flow volumes 10 to 80 times greater occur at 10g to 80g applied in this study, meaning that core seal or fracture failures are readily identified from anomalous flow rates and effluent volumes. For example, Bouzalakos et al. (2013) report on rock core tests in this geotechnical centrifuge where unreliable values of 3x10e-8 and 10e-5 m/s were observed in core that otherwise had K values of 10e-10 to <10e-12 m/s.

Secondly, these experiments were conducted with cores that were saturated, with swelling clay effectively sealing any defects. The cores were obtained from depths below the water table at each site, and preparation of the cores for testing ensured saturated conditions (as described in Section 5.3). Although further research is in progress, we propose to add comments to Section 6.6 (limits and uncertainties of centrifuge permeameter testing), on consolidation status of these aquitards and possible bias of these CP tests. In Section 6.7, we would propose also identifying possible reasons for relatively high in situ and core scale permeability for these aquitards. Relatively high permeability in these semi-consolidated alluvial deposits may be attributed to several factors other than fracturing, and is the focus of ongoing research.

AR1: This paper represents a lot of good work and I hope that the authors will hang in there and elevate the discussion of the results and re submit. Comparison to slug tests done in piezometers is not very useful because these tests mainly show Kh and Kh is typically much larger than Kv due to micro bedding effects. That is why papers that address Kv are so important. Good Kv values are hard to come by. Kh is easy and that is why we have so much Kh in the literature.

Author's response: Yes these comments are reasonable. Therefore we have not attempted to compare Kv values with slug test values that measure Kh values. The in situ Kv values were derived from harmonic analysis of pore pressure propagation between shallow and deep piezometers in the aquitard sequence.

AR2 is Anonymous Referee #2

AR2: A weak point of this study is the use of deionized water for the 1g tests of some cores.

Given the high clay content I suspect this makes the resulting data invalid. The authors themselves also point to this, which begs the question why these tests were not made with a solution that represents the in situ solution, and why these data are included in the paper.

Author's response: The 1g data is a useful comparison constraining the lower limit of



Kv measurements, but is not essential to this geotechnical centrifuge method and we would agree to omit the data from this paper.

AR2: You employ many references to later sections in the text. This indicates the text is poorly organized and disturbs the flow of the paper. You probably need to rethink the set-up of the paper and the order of the segments. Using sections 2 through 5 to describe Materials and Methods also constitutes a clue that the organization of the paper is not optimal.

Author's response: If the paper organisation is more optimal, Section 2 could be moved from the main paper to supplementary material, retaining only key information that is essential for the main paper. We also agree that Section 3 (centrifuge calculations) could be combined with Section 5 (experimental methods). However, combining Sections 2 through 5 in one long section we consider would be counterproductive to the clarity of the paper. We also recommend retaining Section 4 (site investigation methods) separately from Section 5 (experimental methods).

AR2: There are several references to Australian standards/regulations that seem to have little relevance for an international readership. Why not instead give an account of the methodology you adopted. A paper should be written in such a way that a competent researcher can repeat the experiment (even though that won't happen).

Author's response: Three American (ASTM, API) and two Australian standards (AS) were referred to. We agree to add further information on how standard methods have been applied in this study, however, the reference to standards should be retained for professional reasons.

AR2: The paper is too wordy at the moment. It can be easily shortened (and made easier to read) by removing the information that is not relevant to the study (the power of the centrifuge's motor, all kinds background and history of the design, elaborate de- tails of alternative methods to measure low conductivities). Include the details of the instruments we need to follow your calculations, give the limitations of alternative measurement methods to show how you improve of them, and give references that allow us to look up the details of these methods if we need them.

Author's response: We would agree to relocate most of Sections 2.2 to 2.5 to supplementary information, retaining Section 2.1 and key details of the subsequent sections in the main paper.

AR2: Sections 5.2 and 5.3 have some peculiar grammar in them that makes them hard to understand. Information is given that does not really seem to pertain to the paper, which is very confusing in a Methods section. Use SI notation throughout (the bar is not an suitable unit for pressure), and go over the number of significant digits – sometimes there are extremely few for an easily measured quantity, like the height of a tube.

Author's response: We will ensure that an independent technical editor assists the authors to revise the grammar in Section 5.2 and 5.3. SI units will be corrected, and we thank AR2 for identifying this oversight in our paper (Page 23, Line 6).

AR2: HESS is a hydrology journal. You do not need to explain elementary materials such as Darcy's Law in detail.

Author's response: We consider that Section 3.1 is an essential discussion on intrinsic permeability for geotechnical centrifuge applications because some geotechnical centrifuge studies scale permeability, not the gradient that drives flow. Darcy's Law in Equation 7 is given as a foundation for Equation 8 which expresses Darcy's Law in terms of angular acceleration in a centrifuge.

AR2: In Table 3 I cannot match up the void ratio and the particle density with the bulk density (neither dry nor wet, in the latter case accounting for the degree of saturation). I checked this for the first core only (BF C2.8). Please check your calculations.

Author's response: Thankyou for noting this apparent discrepancy. These calculations will be checked and corrected.

AR2: Why do we need Fig. 7 in a paper on a centrifuge?



Author's response: Figure 7 is important to help verify the reliability of point scale measurements of Kv for this site by indicating that the sediments are laterally homogeneous. Both fracturing and heterogeneity need to be considered in whether or not small scale measurements of permeability on core are worthwhile. The study title and paper structure (eg. Section 4 site investigations) were intended to indicate that the paper extends to site application of a new experimental laboratory method.

AR2: Why do the pressure diagrams in Fig. 8 not have scales on two of the horizontal axes, and how are pressure diagrams reflecting 'conceptual relationships'? The message that this figure and the text discussing it try to convey did not become clear to me.

Author's response: The figures show the relationship between the direction of centrifugal inertial head and pore pressure to help explain the concept of flow outwards from the centre of rotation. Otherwise, the variation of fluid pressure along the axis of rotation may be incorrectly interpreted as causing flow towards the centre of rotation. A similar unscaled figure was also presented by Nimmo and Mello (1991).

As it is beyond the scope of this paper to present calculations and numerical modelling to quantify these relationships, Figure 8a can be omitted from this paper if necessary. Figure 8b is however essential to quantify the magnitude and direction of forces driving flow in the centrifuge and is a foundation to Figure 9.

References not previously cited

Greve, A.K., Andersen, M.S., Acworth, R.I.: Monitoring the transition from preferential to matrix flow in cracking clay soil through changes in electrical anisotropy. Geoderma 179–180, 46–52, 2012.

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Aust. J. Earth Sciences, 61, 501-511, 2014.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 3155, 2014.