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DISCUSSION

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Discussion "Determination of the Hydraulic Conductivity Function of a Highly Compressible Material Based on Tests with Saturated Samples" By Parent, S-E., Cabral, A., Dell'Avanzi, E., and Zornberg, J. G.

REFERENCE: Geotechnical Testing Journal, Vol. 27, No. 6, Nov. 2004, pp. 614–618

The discussers have read this paper with considerable interest and, like the authors and many others, they have also observed that compressibility can significantly influence the unsaturated properties of soft materials. Obtaining valuable experimental results on these types of materials is quite a challenge, and the authors should be commended for their effort to measure the (WRC) of deinking residues. The results and analysis presented in their paper have nevertheless raised some questions.

1. The simultaneous volume change and water loss induced by increased suction are expressed by the volumetric shrinkage curve (VSC) $e(\psi)$ [Fig. 5*b*] and (WRC) $\theta(\psi)$ [Fig. 5*a*], respectively. The WRC can also be represented by the $w(\psi)$ or $S_r(\psi)$ functions, where w represents the gravimetric water content and S_r is the degree of saturation (e.g., Mbonimpa et al. 2005). In these representations, w, θ, S_r, and e are interrelated as shown by the following equation:

$$\theta = \frac{e}{1+e}S_r = \frac{G_s}{1+e}w \quad \text{(D-1)}$$

where G_s [-] is the specific gravity of the solid particles.

Typical test results obtained on compressible, initially saturated fine-grained soils show that the onset of desaturation, associated with the air entry value ψ_{aev} (or AEV), is typically fairly close (although not exactly equal) to the suction corresponding to the shrinkage limit ψ_s. For suction higher than ψ_s, the void ratio remains quasi constant at e_c. Typical results and their ensuing analysis tend to show that the volume change during the desaturation phase is usually small (e.g., Subba Rao and Satyadas 1985; Biarez et al. 1987; Fleureau et al. 1993; Huang et al. 1998; Fredlund 1999). However, according to the authors' results [presented in Fig. 5*b*], the value of ψ_s is 400 kPa, (for e_c=1.3) for the tested deinking residues while the observed ψ_{aev} (Fig. 3) are much lower (below 25 kPa). Also, the void ratio that corresponds to ψ_{aev} is high (between 2.42 and 3.24) compared to e_c (=1.3). This difference with previously published results may indicate that the assumption of negligible volume change during the desaturation phase is not applicable for these materials. If this is the case, Eq 2 cannot be used as it is based on the assumption mentioned above (ψ_{aev} close to ψ_s). A clarification of this point would be welcome.
2. The ψ_{aev} corresponds "to the suction value where significant loss of water was observed, i.e., in the region of the inflection point determined using the procedure proposed by Fredlund and Xing (1994)." However, the authors do not mention on which curve $[w(\psi), \theta(\psi), S_r(\psi)]$ the evaluation was applied. A significant water loss can occur as a result of a significant volume change, particularly in the "normal" shrinkage phase where the sample remains fully saturated (e.g., Chertkov 2003; Tripathy et al. 2004). In fact, for compressible materials, the onset of a significant water loss may not correspond to the start of a significant desaturation associated with ψ_{aev}. Hence, the inflection point on the curves $S_r(\psi)$ and $\theta(\psi)$ can be quite different (see Eq D-1). The actual AEV should be determined from the $S_r(\psi)$ curve, as was done by Huang et al. (1998). The results shown by the authors in Figs. 3 and 4 should thus be reassessed.
3. In the Conceptual Model section, the authors mention that they have used " Eq 2 and the *e*-function [to determine] the air entry value for Test *i*, ψ_{aev_i}." However, the void ratio e_{aev_i} used in Eq 2 cannot be obtained from the VSC $e(\psi)$. It is not clear how this analysis was performed.
4. Curve 3 in Fig. 4 is presented as the envelope [defined by Eq 4*b*] of the saturated hydraulic conductivity at different

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AEV values, based on tests performed at different initial void ratios. The authors then mention, that for Test *i* starting at an initial void ratio e_{0_i} (corresponding to ψ_{aev_i}), the unsaturated hydraulic conductivity k_{unsat_i} at a suction value ψ_{aev_ii} ($>\psi_{aev\_i}$) corresponds to the saturated hydraulic conductivity at ψ_{aev_ii} corresponding to Test *ii* performed at an initial void ratio e_{0_ii} (see Fig. 4). However, this approach can only be valid if all the WRC curves "superimpose into a single virgin desaturation branch" [e.g., Fig. 5*a*], and if all the VSC curves superimpose into a single virgin compression branch. Such conditions do not appear to be satisfied here (based on the results shown in the paper; see Figs. 2 and 5). It should be noted here that $\theta(\psi)$ data obtained by Huang et al. (1998) from flexible and rigid wall permeability tests on the same materials at different initial void ratios do not appear to satisfy these conditions either. Additional information from the authors would be appreciated.

5. Some of the permeability test data obtained by Huang et al. (1998) on the same materials at different initial void ratios have been used by the authors to validate the proposed approach. It appears, however, that the procedure was not consistently applied in all cases. Different hydraulic conductivity functions should be obtained for different initial void ratios when suction is below the AEV (see Fig. 4), but instead the authors have used "All-data best-fit" (see Fig. 6). This raises concerns about the observed discrepancies which could be attributed to the measurements or to the validity of the proposed approach. Again, comments from the authors would be welcome.
6. The range of suction values for which the proposed approach remains valid has not been defined by the authors. The phenomena of interest can take place for suctions between 0 kPa (full saturation) and 10^6 kPa (fully dry; e.g., Fredlund and Xing 1994). The maximum suction considered in the presented approach corresponds to $\psi_{aev}(e_{\min})$ obtained from a test starting with the lowest possible initial void ratio $e_{\min}$. For compressible materials without mechanical densification, the minimum void ratio $e_{\min}$ is attained at the shrinkage limit (i.e., $e_{\min}=e_c=1.3$, see Fig. 5). From Eqs. 1 and 2, it can be expected that a test performed at e_0 ($=e_c$) of about 1.3 would lead to $\psi_{aev}\cong 62.7$ kPa and $k_{sat\text{-}aev}\cong 8.6\times 10^{-11}$ m/s. For tests performed at $e_0>e_c$, the unsaturated hydraulic conductivity k_{unsat} at $\psi=62.7$ kPa would thus be 8.6×10^{-11} m/s. However, it is unclear what value of k would be obtained for $\psi>62.7$ kPa. The approach proposed in the paper is ill-defined for $\psi>\psi_{aev}(e_{\min})$. The unsaturated k range covered by the approach thus appears fairly limited. The authors should clarify their views in this regard.

References

Biarez, J., Fleureau, J.-M., Zerhouni, M.-I., and Soepandji, B. S., 1987, "Variations de volumes des sols argileux lors de cycles de drainage-humidification," *Revue Française de Géotechnique*, Vol. 41, pp. 63–71.

Chertkov, V. Y., 2003, "Modeling the Shrinkage Curve of Soil Clay Pastes," *Geoderma*, Vol. 112, pp. 71–95.

Fredlund, D. G. and Xing, A., 1994, "Equations for the Soil-Water Characteristic Curve," *Can. Geotech. J.*, Vol. 31, No. 4, pp. 521–532.

Fredlund, M. D., 1999, "Soilvision 2.0, A Knowledge-based Database System for Unsaturated-saturated Soil Properties," Version 2.0n, Soilvision Systems Ltd.

Fleureau, J.-M., Kheirbek-Saoud, S., Soemitro, R., and Taibi, S., 1993, "Behavior of Clayey Soils on Drying-wetting Paths," *Can. Geotech. J.*, Vol. 30, pp. 287–296.

Huang, S., Barbour, S. L., and Fredlund, D. G., 1998, "Development and Verification of a Coefficient of Permeability Function for a Deformable Unsaturated Soil," *Can. Geotech. J.*, Vol. 35, No. 3, pp. 411–425.

Mbonimpa, M., Aubertin, M., Bussière B., and Maqsoud, A., 2005, "A New Equation for the Suction Induced Shrinkage of Soils," *6th Joint IAH-CNC and CGS Groundwater Specialty Conference, 58th Canadian Geotechnical Conference*, Saskatoon, Saskatchewan, Canada, September 18–21. Proceedings on CD-ROM.

Subba Rao, K. S. and Satyadas, G. L., 1985, "Measurement of Volumetric and Linear Shrinkage on Back Cotton Soil," *Geotech. Test. J.*, Vol. 8, pp. 66–70.

Tripathy, S., Subba Rao, K. S., and Fredlund, D. G., 2002, "Water Content-void Ratio Swell-shrink Paths of Compacted Expansive Soils," *Can. Geotech. J.*, Vol. 39, pp. 938–959.

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Response to Discussion of 'Determination of the Hydraulic Conductivity Function of a Highly Compressible Material Based on Tests with Saturated Samples' by Parent, S.-É., Cabral, A., Dell'Avanzi, E., and Zornberg, J.G.

REFERENCE: Geotechnical Testing Journal, Vol. 27, No. 6, Nov. 2004, pp. 614–618

1. **Equation 2 can not be used as it is based on the assumption that $\psi_{aev} \approx \psi_s$, which is not the case of DBP.**
   Compaction of a material increases its air-entry value (AEV). Huang et al. (1998) reported a linear relationship between the logarithm of AEV and the void ratio at the AEV. For a given material, the void ratio at the AEV depends on the initial void ratio. It is irrelevant here whether the void ratio stops to decrease or not for suction values higher than the AEV; the same relationship between void ratio at AEV and AEV is valid.
2. **The actual AEV should be determined from the S(ψ) curve.**
   The curve θ(ψ) was used to determine the AEV. However, although there is no standard method to obtain the AEV from a water retention test, using $S(\psi)$ would indeed be more precise, as volumetric water content may decrease even though the material remains saturated. As a consequence, the discussers are right: the relationship between AEV and void ratio, and as a consequence the slope of the k_{sat} versus AEV curve, would be affected. Parameters of the relation between AEV and void ratio at the AEV obtained using θ(ψ) and $S(\psi)$ curves are presented in Table 1.

TABLE 1—*Parameters for the relationship between AEV and void ratio.*

	Obained Using θ(ψ)	Obtained Using $S(\psi)$
ψ'_{aev} (kPa)	27.0	27.0
e'_{aev}	2.42	2.49
ε	−0.327	−0.243

The authors thank the discussers for bringing out this precision. Indeed, the difference in the value of ε is not negligible and will engender a steeper slope on the k_{sat} versus AEV curve.

3. **Void ratio e_{aev_i} in Eq 2 cannot be obtained from a void ratio function e(ψ).**
   Equation 2 has two unknown variables: e_{aev} and ψ_{aev}. And so does Eq. 3 where the unknown variables are e_i and ψ. If one must determine e_i and ψ at the AEV, than $e_i = e_{aev}$ and $\psi = \psi_{aev}$. A system of two unknowns and two equations is obtained. The determination of the AEV of a test from its initial void ratio can also be performed graphically by determining the intercept between the *e* versus ψ and the e at AEV (e_{aev}) versus ψ at AEV (ψ_{aev}) curves, as shown in Fig. 1. The points in the latter curve are determined using Eq. 2 in the paper.
4. **The approach can only be valid if all the WRC superimpose into a single virgin desaturation branch; such conditions do not appear to be satisfied here.**

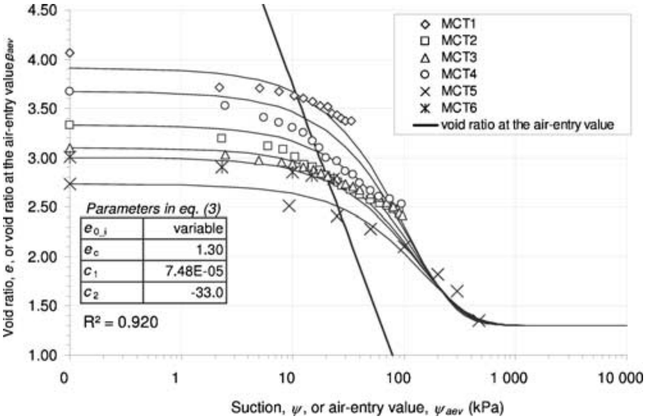

FIG. 1—*Void ratio function and e_{aev}-ψ_{aev} relation of deinking byproducts.*

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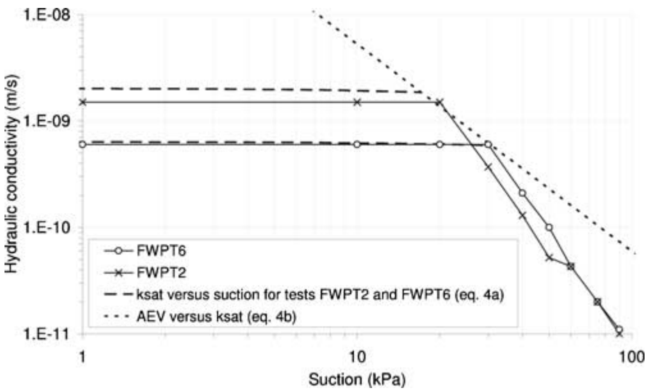

FIG. 2—*Hydraulic conductivity as a function of suction* (*data from Huang et al. 1998*).

Although there is no apparent superimposition of the data points presented in Fig. 5 of the paper (same as Fig. 1 above), regression analysis made using the same set of data points led to the solid lines in this same figure, which do converge to a single value of e_c for all curves ($R^2=0.92$).

5. **Validation should be performed using corresponding data rather than an all-data best fit.**

   The issue is of concern and we appreciate that this was pointed out by the discussers. Indeed, the validation of a k-function estimation of a sample with an initial void ratio of e_{0_i} should be performed by comparing it with a sample with a similar initial void ratio.

   A new validation was performed based on this principle. The output is presented in Fig. 2. In the present case, the new curves are not that different from those presented in the initial paper. As a consequence, the interpretation of the results remains valid.

6. **The range of suction values of which the proposed approach remains valid has not been defined by the authors.**

   The approach is indeed limited in terms of lowest saturated k value that can be determined by the procedure. This lowest value is associated with e_c. Lower k values must be extrapolated using Eq. 4b.