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Response to "Discussion on "Evaluation of the swelling characteristics of bentonite-sand mixtures""☆

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The swelling of bentonite-sand mixtures is mainly induced by the montmorillonite absorbing water. We assumed in the original paper (Sun et al., 2015) that non-montmorillonite clay in the bentonite did not absorb any water. The important base of evaluating the swelling characteristics of bentonite-sand mixtures was that the maximum amount of water absorbed by montmorillonite per unit volume was constant under a certain stress after swelling reached a stable state, and it was independent of the initial dry density and initial content of water or sand (Sun et al., 2009).

In the original paper (Sun et al., 2015), the authors actually assumed that all the pores and available water were associated with the montmorillonite fraction and used a state parameter "montmorillonite void ratio e_m" proposed by Sun et al. (2009). However, it was not the only premise or state parameter. The critical sand content α_s was also introduced as a limit. For bentonite-sand mixtures with less sand than the critical sand content, the sand skeleton will not form and the unique linear $\log e_m - \log \sigma_v$ relationship is valid under any vertical stress, but when the sand content is more than the critical sand content, a sand skeleton will form at a certain vertical stress.

As mentioned in Sun et al., 2015 and the Discussion (Schanz et al., 2016), some swelling results from different types of bentonite-sand mixtures with less sand than the critical sand content satisfy the unique linear $\log e_m - \log \sigma_v$ relationship. However, when the sand content exceeds the critical sand content, very low bentonite contents can lead to mixture inhomogeneity, or an uneven bentonite distribution within the mixture, and the swelling of mixtures expressed in terms of the montmorillonite void ratio deviates from the unique linear $\log e_m - \log \sigma_v$ relationship above a 'starting deviation stress' σ_s which depends on the sand content. According to a predictive method suggested and verified in Sun et al., 2015, the swelling due to saturation of bentonite-sand mixtures where the sand content is down to 10% can be predicted. Mollins et al. (1996) conducted one-dimensional swelling tests on pure bentonite and mixtures with 80, 90 and 95% sand contents by weight. Here the authors supplement the prediction of experimental data by Mollins et al. (1996). Fig. 1(a) normalizes the swelling test data with montmorillonite void ratio, Fig. 1(b) shows the prediction of 'starting deviation stress' for Wyoming bentonite-sand mixtures with different sand contents, and Fig. 1(c) is the prediction of e_m - σ_v relationship for mixtures with more sand than the critical sand content. The relevant parameters used for the swelling prediction are listed in Table 1.

Schanz et al. (2005) proposed the plausible mechanism for pore water redistribution where most of the water located in the macro-pores initially would be redistributed to the micro-pores gradually due to the suction gradient with elapse time, while the suction would increase from an initially quasi-equilibrium state to a higher total suction. This condition occurs when water inflow into soils is relatively fast. In Schanz et al. (2005), the swelling development process is concerned. Moreover, the discussers suggested that the swelling characteristics of bentonite-sand mixtures depend upon the applied compaction energy, the induced swelling pressure (bentonite content) and applied stress in the Discussion (Schanz et al., 2016).

It is true that many factors can influence the swelling of mixtures simultaneously, apart from several factors mentioned above, as well the type of bentonite, the bentonite content in the mixture, the deformation of voids among sand particles due to stress, and whether the macro-pores are invaded completely or partly by swollen bentonite, and so on. However, in the predictive method (Sun et al., 2015), the authors avoid considering the apparently complicated swelling processes during water uptake, but just consider the changes between two states, one is the initial unsaturated state, and another is the final saturated state.

☆ Schanz, T., Rawat A., Baille W. Discussion of "Evaluation of the swelling characteristics of bentonite-sand mixtures". Engineering Geology, 209, 209-210.

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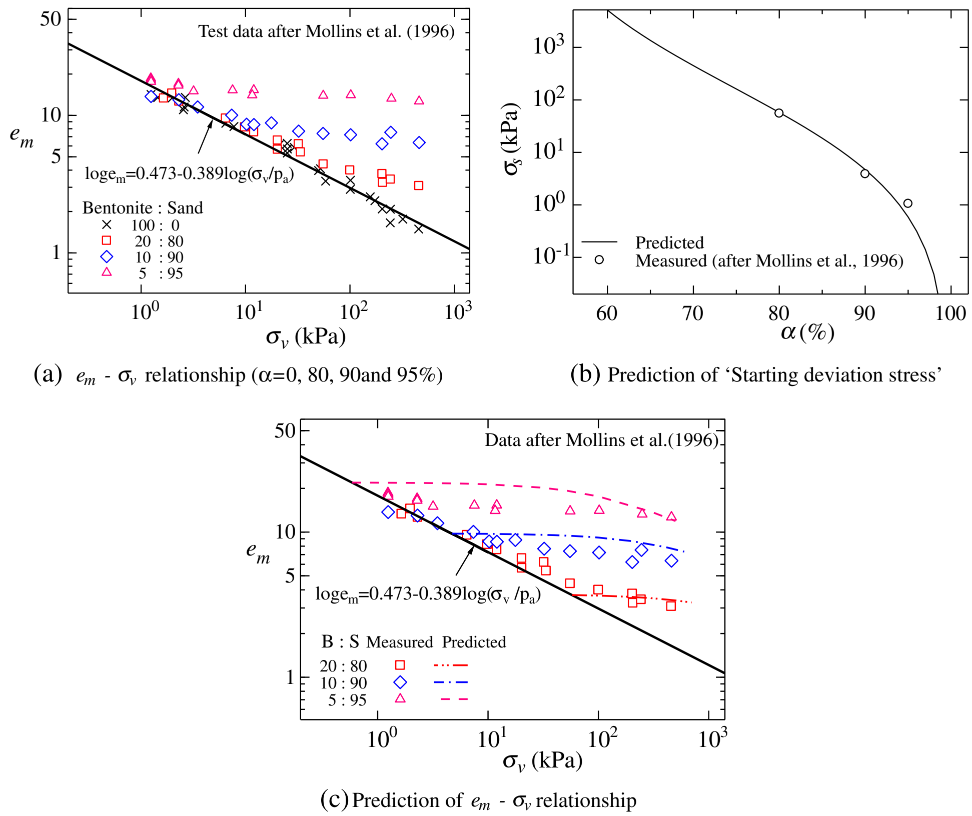

Fig. 1. Swelling prediction for Wyoming bentonite-sand mixtures.

Table 1
Relevant parameters for swelling prediction of Wyoming bentonite-sand mixtures.

Type of mixture	ρ_m (g/cm^3)	ρ_{nm}	ρ_{sand}	β (%)	e_{smax}	a	b	α_s (%)	φ
Wyoming bentonite-sand mixtures	2.76[a]	2.67[a]	2.67[a]	85[b]	0.978[b]	0.473	0.389	49.3	−13.11

Note: ρ_m, ρ_{nm} and ρ_{sand}: the density of montmorillonite, non-montmorillonite clay minerals and sand respectively; β: the content of montmorillonite in bentonite; e_{smax}: the maximum void ratio of sand; a, b: the material parameters in the linear relationship $\log e_m = a - b\log(\sigma_v/p_a)$, where p_a is atmospheric pressure in kPa; α_s: the critical sand content; φ: the parameter linked to stress distribution coefficient, as shown in Eq. (13) in Sun et al., 2015.

[a] Mollins et al. (1996).

[b] Mollins (1996).

To better understand, the authors manage to describe the predictive method briefly. When the sand content is less than the critical sand content, sand particles are dispersed within the bentonite. The linear log e_m – log σ_v relationship, which represents the final saturated state line, is valid under any vertical stress. Once this unique line is determined, the relationship between the final void ratio and the vertical stress (e_f - σ_v) after full wetting for mixtures with a specified sand content can be obtained. According to the e_f - σ_v relationship, the deformation

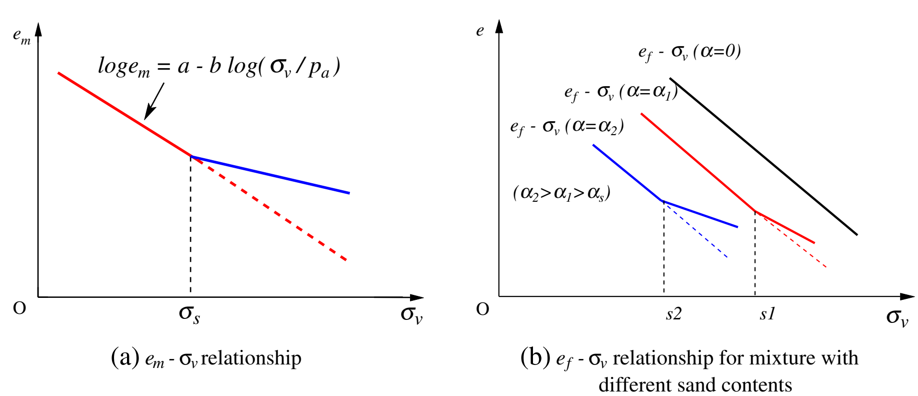

Fig. 2. Swelling prediction for bentonite mixed with more sand than critical sand content.