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Effects of particle breakage and stress reversal on the behaviour of sand around displacement piles

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Manuscript title: Discussion: Effects of particle breakage and stress reversal on the behaviour of sand around displacement piles

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Sand gradation and derived properties are modified by pile installation. The authors deserve praise for providing an extensive and unprecedented set of triaxial data to clarify this fundamental issue. One conclusion of practical significance refers to the position of critical state lines in the compression plane. The authors state that "*New critical state lines apply to the fractured sand that fall substantially below those manifested by fresh samples when sheared at lower effective stress levels*"

We would like to offer here a complementary view, based on recently published results from a DEM model of Fontainebleau sand (Ciantia *et al.* 2018). Muir Wood & Maeda (2008) introduced the idea of a unique critical state plane (CSP), to which all critical state lines of a given sand at different stages of grading evolution would belong. A CSP equation may be written as

$$e_{cs} = \alpha + \beta I_G + \delta \left(\frac{p'_{cs}}{p_{atm}} \right)^{0.7} \qquad (1)$$

Where e_{cs} and p'_{cs} are the values of void ratio and mean effective stress at critical state, and I_G is the grading state index (Muir Wood, 2007), quantifying the evolution of grading when critical state is attained. The parameters α, β and δ are to be determined by experiment.

Ciantia *et al.* (2018) performed an extensive set of numerical high-pressure triaxial tests in which grading evolution was continuously tracked. From that work it followed that the CSP of Fontaineblau sand was given by

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$$e_{cs} = 2.553 - 2.441 I_G - 0.002325 \left(\frac{p'_{cs}}{p_{atm}} \right)^{0.7} \quad (2)$$

It was shown in Ciantia *et al.* (2018) that this equation described well the critical states experimentally presented by Luong & Touati in 1983. However, Luong & Touati only sheared normally consolidated specimens and not pre-consolidated and/or pre-sheared specimens, as the authors have done. It was then with some trepidation that we set out to check if this new set of experimental results would fit the prediction of the numerical model. The results are summarized in Figure 11 and the supporting data are provided in tabulated form as supplementary material to this discussion. The experiments fit well the numerically predicted CSP, with a normalised standard error of 0.1%.

It is perhaps surprising that results derived from such an idealized model as that presented in Ciantia *et al*. (2018) compare so well with physical experiments. Amongst its many simplifications two stand out: non-spherical particle shape effects are mimicked by the expedient approach of blocking element rotations; also some particle volume is loss at every single crushing event. It would appear that it is advantageous to adopt a flexible modelling approach that focuses specifically on the important aspects of granular interaction.

Ciantia *et al.* (2018) calibrated their DEM model using results from two triaxial tests at low pressure and a single high pressure oedometer on Fontainebleau sand. That was supplemented with generic single particle crushing information from other quartz sands. We think that the technical skill, human effort and level of investment required to obtain a CSP using DEM simulation is far smaller than that applied by the authors in the laboratory.

We wonder if they concur with us in believing that the two techniques may share the burden of future efforts in this important research topic.

Authors' reply

The authors would like to express their appreciation to the discussers for their interest in our work and for extending their DEM modelling to reproduce the CSP that we examined in our physical experiments. We are aware of the discussers' CSP plane proposals and are highly encouraged that the reported DEM simulation outcomes fall so close to the experimental findings. The discussers also refer to particle crushing and changes of soil grading during shearing at high pressures, which raises the question as to whether their simulation was also able to recover the measured changes in soil grading accurately? In addition, were they able to match the experimentally observed dilation rates? The discussers also raise the interesting question of how the non-spherical particle shapes may have led to disparities between their results and the tests. It is interesting that they report that the restrictions they placed on grain rotation in their DEM analysis appear to have made at least partial allowance for the impact of the non-spherical grain shapes developed through particle breakage by Fontainebleau sand.

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Figure caption

Figure 11. Comparison of numerically predicted and experimentally obtained critical state data for Fontainebleau sand.

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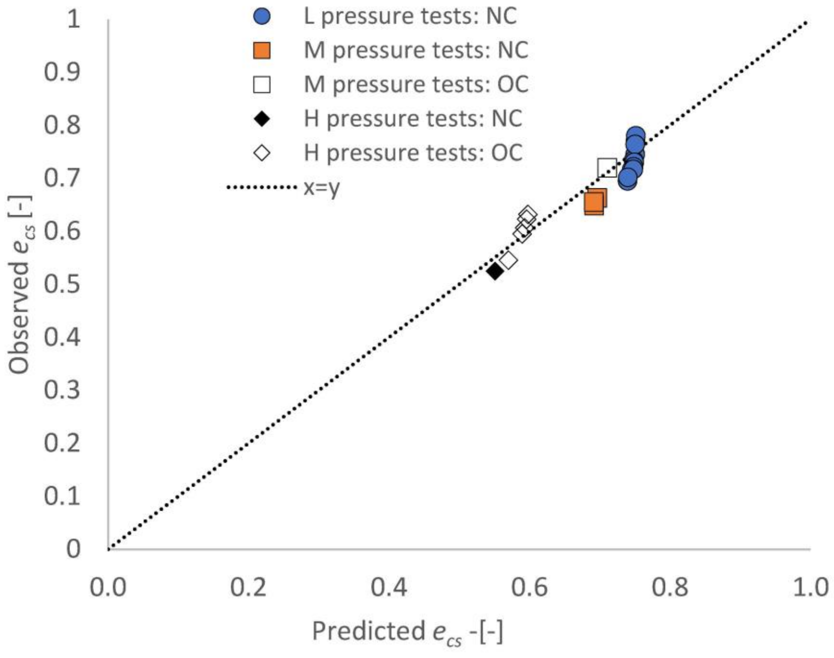

Figure 11