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Discussion

Discussion of “Improved cone penetration test predictions of the state parameter of loose mine tailings”

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Quantitative evaluation of the CPT in sands depends on calibration chamber data, but these data are rare with engineering usually interpolating existing information to the soil being considered. The new small chamber, “MiniCal”, (Ayala et al. 2020) is thus a most interesting innovation, offering almost the ease of triaxial testing compared to 2 ton samples needed in conventional chamber studies. However, contrary to the conclusion of the paper, Fig. 14 can be viewed as the *MiniCal* producing different calibrations to standard chambers and this needs further consideration.

The dominant properties differentiating drained CPT response from one soil to another are χ and λ (with λ strongly influencing the soil’s plastic hardening as well as quantifying “compressibility”). Figure 1 compares these properties for the two soils tested in the *MiniCal* with other studies and shows that the soils tested in the *MiniCal* are within the range of experience for large chambers. The same conclusion also follows if the other soil properties (M, N, and H) are considered. Thus, the “simulation trends” shown in Fig. 14 are what should be expected based on mechanical properties.

The history of CPT scaling to spherical cavity expansion summarized in Table 1 of the paper stops short of field-scale validation. Both Rose Creek (Shuttle and Cunning 2007) and Neves Corvo (Shuttle and Jefferies 2016) involved direct measurement of in situ void ratios for comparison to inferred state from CPT, but neither site involved piston sampling (or better) with uncertainty in the measured void ratios. But, in the case of the Cadia liquefaction slump, very high-quality piston samples gave close correspondence between “*CPT data + CPTwidget*” and subsequently discovered “*recovered void ratio + laboratory CSL*”: Figs. E4–5 of (Morgenstern et al. 2019). In the case of Tar Island (Shuttle et al. 2021), there was a close match between the measured and computed displacement during the liquefaction slump—a displacement that is sensitive to assessed state (which was based on *CPTwidget*). More generally, there is a limited range of states at both Cadia and Tar Island that allow stable construction of what was built with the subsequent evolution of liquefaction-driven slumps—the in situ state parameter is quite constrained for these two case histories. These full-scale validations suggest that the *CPTwidget* produces calibrations within a precision of better than $\Delta\psi < \pm 0.02$, a precision that challenges Fig. 14 of the paper. Further, while the *MiniCal* data are unusually loose compared to existing chamber studies, the *MiniCal* data are comparable to the characteristic in situ states at Cadia ($\psi_k \approx +0.08$) and Tar Island ($\psi_k \approx +0.06$).

So, what might be the cause of the discrepancy between scaled trends and *MiniCal* on Fig. 14? Soil flows around the CPT during a sounding, akin to a fluid where the situation is better described by velocities rather than strains, but such analyses for sands seem beyond current mechanics. Hence, the widespread adoption, following Gibson (1950), of cavity expansion is an analogue for CPT (or pile) penetration. The beauty of the analogue is that stress and strain rates are both coaxial and in fixed direction, while symmetry reduces a 3D problem to a single spatial variable (radius to the moving element)—complex soil behaviour becomes readily computable. Figure 2 illustrates the stresses acting on the tip and shaft of a CPT and their relation to the spherical cavity limit pressure (P_{lim}).

The spherical cavity limit pressure scales with the far-field stress (= mean of the geostatic stresses) and depends on soil properties. But, it is easily appreciated from Fig. 2 that the CPT shaft friction (f_s over the sleeve, but greater areas likely involved) amounts to additional boundary confining stress—and this stress is significant. Figure 3 shows data from two sandfills, one dense and one less so, in terms of the stress ratio f_s/σ'_{V0} (where σ'_{V0} is the pre-existing vertical effective stress); f_s/σ'_{V0} can far-exceed the steel–sand friction ratio because dilation during CPT sounding amplifies the horizontal geostatic stress (measured: Jefferies et al. 1987). Thus, the friction on the CPT probe, possibly extending about a metre above the tip, amounts to a substantial change of confining stress from the spherical cavity idealization; it is this effect that largely causes scaling between the CPT and the spherical cavity analogue (notice the similarity of the trend in Fig. 3 to C_Q). The obvious question then is the following: is shaft friction in *MiniCal* similar to that in large chambers? Further, how do the 10 mm probe results for which f_s was measured compare with Fig. 3 (accepting limitations from boundary correction issues)?

Fig. 1. Comparison of the soil properties from *MiniCal* studies to soils in other studies.

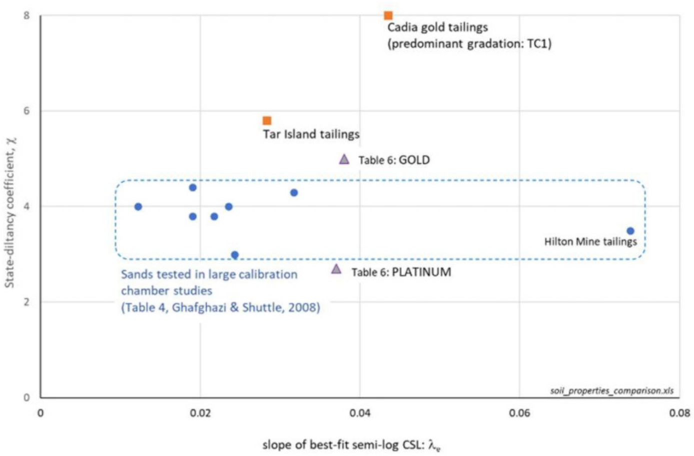

Fig. 2. Comparison of spherical cavity idealization to stresses during CPT sounding.

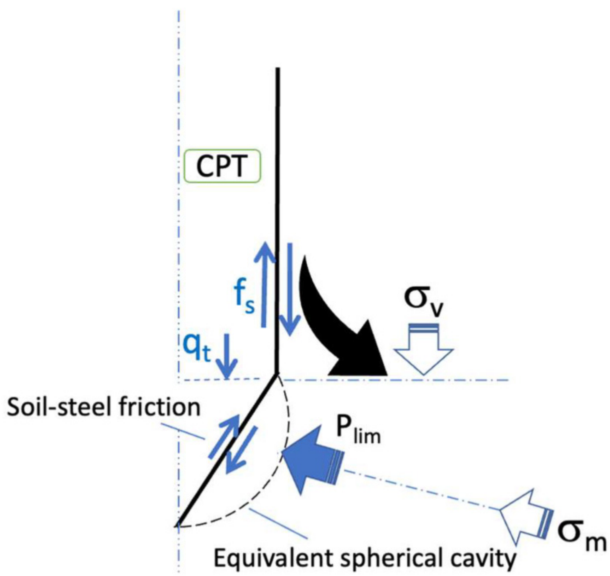

Fig. 3. Mobilized normalized CPT friction during CPT soundings in clean sandfill.

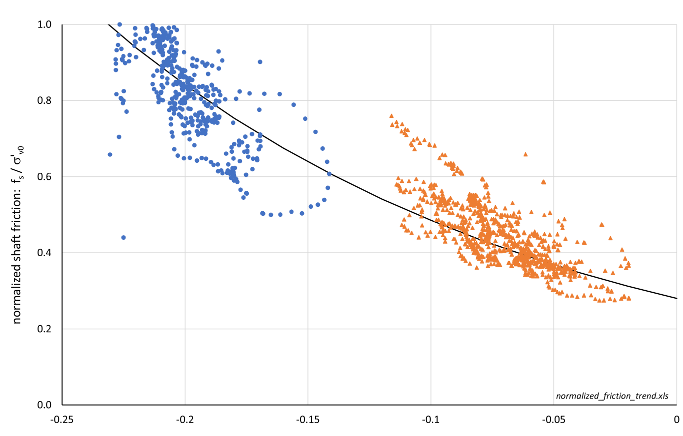

Table 1. NorSand evolution.

Period	Idealization	Used
1990–2000	N controls shape of the yield surface. The soil property $\chi =$ 3.5 is a "universal" constant.	Shuttle and Jefferies (1998)
2000–2011	The property χ now taken as soil-specific and calibrated in triaxial compression. N continues to control shape of the yield surface.	Ghafghazi and Shuttle (2008)
2011 onwards	Yield surface shape is now constant, with N determining the "operating" zero-dilatancy friction coefficient and thus scaling the aspect ratio of the yield surface (see Jefferies and Shuttle 2011). The property χ is soil-specific and calibrated.	Shuttle and Jefferies (2016)

Finally, a comment on Fig 2. NorSand (NS) has evolved since first derived with two particular changes: (i) how Nova's property N is used; (ii) the nature of the property χ. Table 1 summarizes the evolution. These changes to NS have been carried through to *CPTwidget* (see Table 1), but in each case, the cavity expansion solution was matched to the calibration chamber data, which is unchanging and taken as "truth"; this is why scaling is embedded in *CPTwidget* as that ensures each release contains the optimized scaling for the constitutive idealization implemented. But, this then means that C_Q has evolved in parallel with NS and the comparison shown in Fig. 2 of the paper omits differences in constitutive representation between the studies. There are also issues between the various calibration chamber programmes with that on Ottawa sand appearing biased (see Fig. 21 of Shuttle and Jefferies 2016) and which affects the optimization determining C_Q in any particular study—there are inevitable judgements. Going forward, since it now appears that $C_Q(f_s/\sigma'_{V0})$, then that is where attention should go rather than further optimizing $C_Q(\psi)$.

Based on the above, it seems premature to conclude that the revised scaling law for loose soils is "improved"; rather, the correct conclusion is that the scaling found with the *MiniCal* is "different". Further work is needed, and an appropriate investigation would use the 10 mm probe with its measurement of f_s and a slightly larger MiniCal (which will still be much more convenient than a conventional large chamber). And, sands similar to those in large-chamber studies should be tested to establish the equivalence of *MiniCal* procedures with current reference calibrations.

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Data availability

The data (triaxial, calibration chamber, and in situ CPT) referred to in this discussion are public-domain and were posted for downloading as part of the *Soil Liquefaction* book (Jefferies and Been 2006). However, that data now appear less accessible than intended 15 years ago; please contact the discussers directly for data of interest regarding this discussion if unable to find online.

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