

“Stresses Developed around Displacement Piles Penetration in Sand” by Z. X. Yang; R. J. Jardine; B. T. Zhu; and S. Rimoy,

Discussion by J. Butlanska and M. Arroyo¹

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The authors deserve praise by gathering together many different strands of evidence that clarify the mechanics of pile penetration in sand. In their review of numerical approaches to the problem, they correctly indicate, citing work by Arroyo et al (2011), that simulations based on the discrete element method (DEM) have offered quantitative agreement with measurements of tip resistance in calibration chambers. They go on to note that “*DEM analyses of the surrounding stress field remains limited by the number of particles that can be considered*”. The purpose of this discussion is to show that such limitation of DEM models is not as strong an impediment to obtain meaningful stress fields as the authors may have feared.

Butlanska et al [2014] performed DEM analysis of CPT in a virtual calibration chamber. Their analysis was performed at three scales, i.e. macro-, meso- and micro-scale. Some of the results there presented are reanalyzed and extended in what follows.

Macro-scale

Table 1 summarizes one of the simulated test conditions. The virtual calibration chamber (VCC) diameter was 1200mm and height was 700 mm. The cone tip diameter was set to 71.2 mm (twice of standard one). The boundary condition was set to no lateral displacement (BC3). The sample was subjected to anisotropic stress conditions ($\sigma_{vo}=313\text{kPa}$, $\sigma_{ho}=109.9\text{kPa}$) and relative density equal to 96.8%. The discrete material had been calibrated to mimic Ticino sand behavior by matching a single triaxial test (see Arroyo et al. 2011, for details). The ENEL-ISMES database (see Jamiolkowski et al 2003) contains a physical test performed in the same material under similar boundary and initial conditions of stress and density. Figure X compare the experimental result with the raw penetration curve obtained in the simulation and the corresponding adjusted trend.

Penetration curves are macro results of calibration chamber CPT. Those macro results are of direct engineering interest and were typically the only ones available in previous experimental studies. Now, largely thanks to the authors efforts, other experimental results such as stress fields are available.

Meso-scale

In our analysis stresses are typical meso-scale results. Meso-scale results are obtained from micro-scale data (i.e. properties of particles and contacts) using operations such as averaging, grid projection and interpolation.

O’Sullivan et al. (2003) proposed a non-linear interpolation procedure to project discrete element properties on to a regular grid. Butlanska et al (2014) applied this procedure to obtain strain from element displacements. Here we use the same procedure to obtain grid stresses from element stresses. Element stresses are calculated from contact forces following (Ptyondy & Cundall, 2004). The grid used is shown in (Figure 1). The radial grid interval was set to 37 mm and vertical grid interval as 63 mm. Values on this regular grid can be easily displayed as contour plots. Figure 3 shows a plane section of 3D contour plots of radial and circumferential and vertical stresses normalized by the trend cone tip resistance. The contour shapes appear fairly similar to those presented by the authors in Figure 4a.

Figure 4a, analogue to figure 5 of the authors, shows the variation of normalized radial stresses with distance to cone tip at three different normalized radius. The pattern is similar to that observed by the authors, particularly the variation in magnitude of the normalized peak stress with radial distance (see also Butlanska et al , 2014). On the other hand, the high stress region appears shifted upwards in the simulation.

Figure 4b shows the variation of normalized radial stress with normalized distance to cone axis at three normalized distances above cone tip. This is analogue to figure 6a of the authors, although the stresses here are those registered during motion. The pattern of stress decay with radial distance is similar to that observed by the authors. Stress peaks appear away from the shaft, but again only at a certain distance above the tip.

It seems that the general pattern broadly corroborates the authors observations. The main difference (higher stress levels shifted upwards in the simulation) is best explained using microscale data. Figure 5 represents force chains at the instant of stress evaluation, compared with those appearing in a similar test when the radial boundary is stress controlled. It appears that the relatively short distance to the immobile radial boundary favors the apparition of strong horizontal force chains. Because long granular force chains are inherently unstable, (tordesillas et al. 2010) “distance” in this context should be measured in particle diameters. In the simulation that distance is XXXX; in the experiments of the authors is YYYY:

Conclusion

Like all the other methods applied to investigate this important and difficult problem DEM modelling of penetration problems in sand has some limitations. Obtaining relevant stress fields is not the most important one. While the results shown here are preliminary, they broadly corroborate the authors observations.

Table 1. Characteristics and main results

Test ID	σ_v0	σ_h0	DR	BC	dc	Dvcc	Hvcc
	[kPa]	[kPa]	[%]	[-]	[mm]	[mm]	[m]
DenseK0BC3	313	109.9	96.8	3	71.2	1200	700

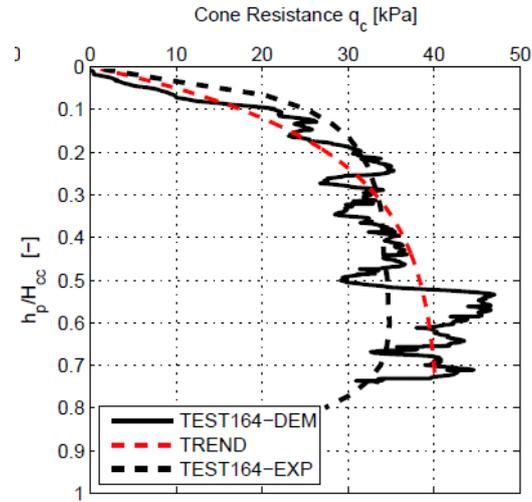


Figure 1

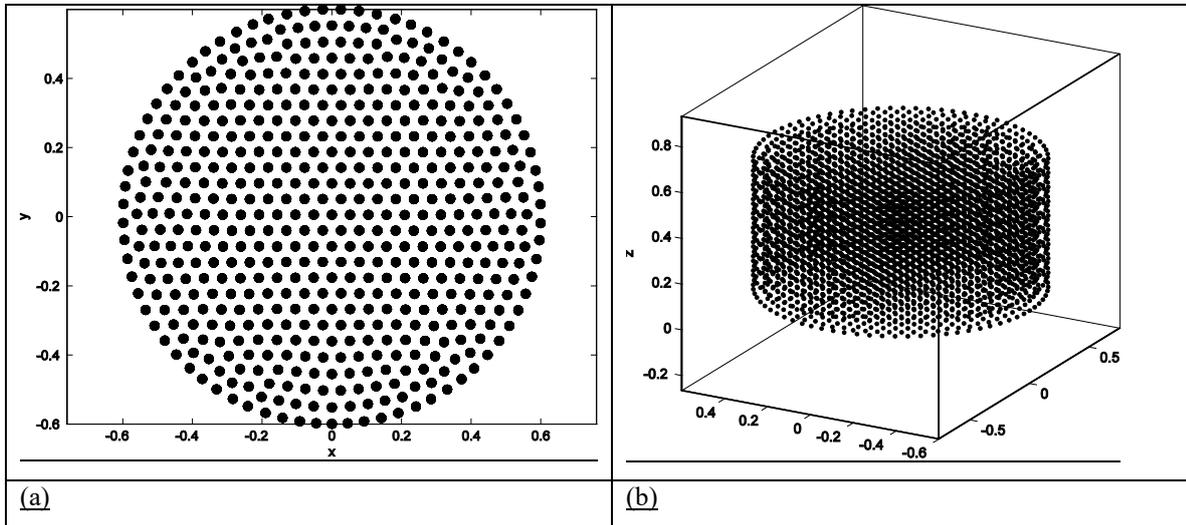
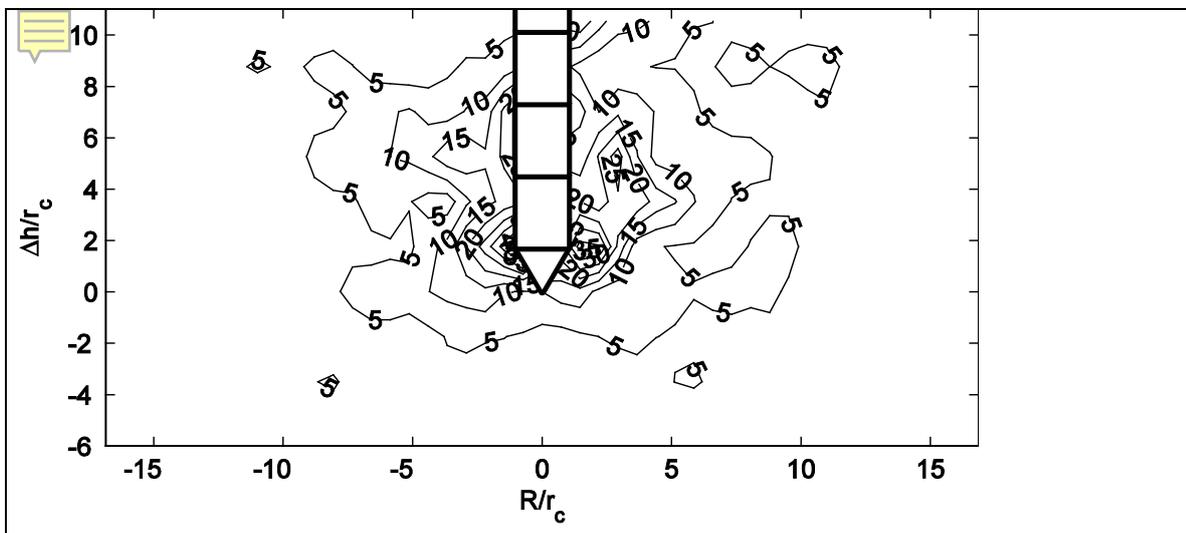


Figure 1 Cylindrical grid used for interpolation of stresses (a) top view, (b) side view



(a) σ_r/q_c

Figure 2. Contour plot of normalized radial stresses (σ_r/q_c) [%] in xz-plane (0-180°).

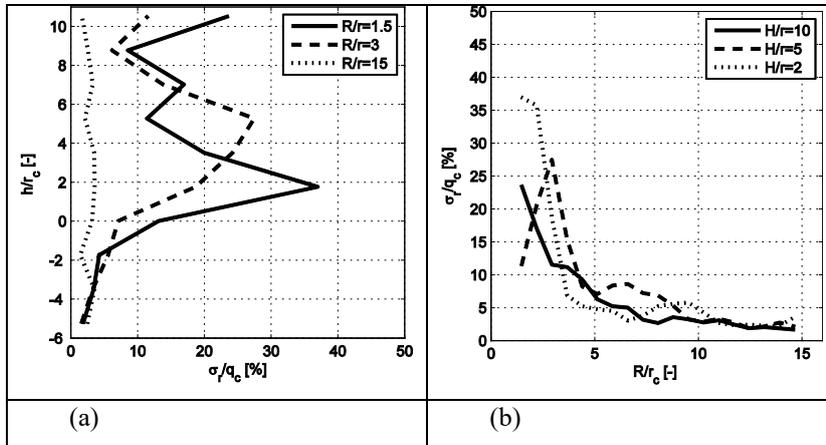
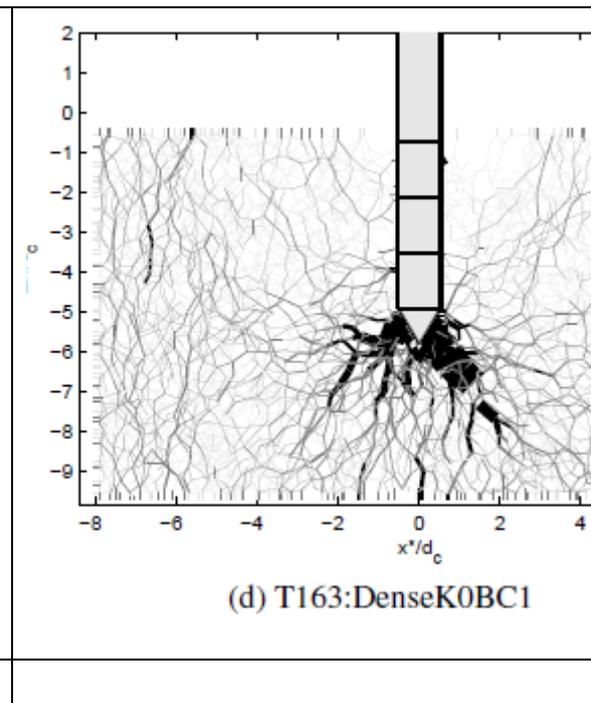
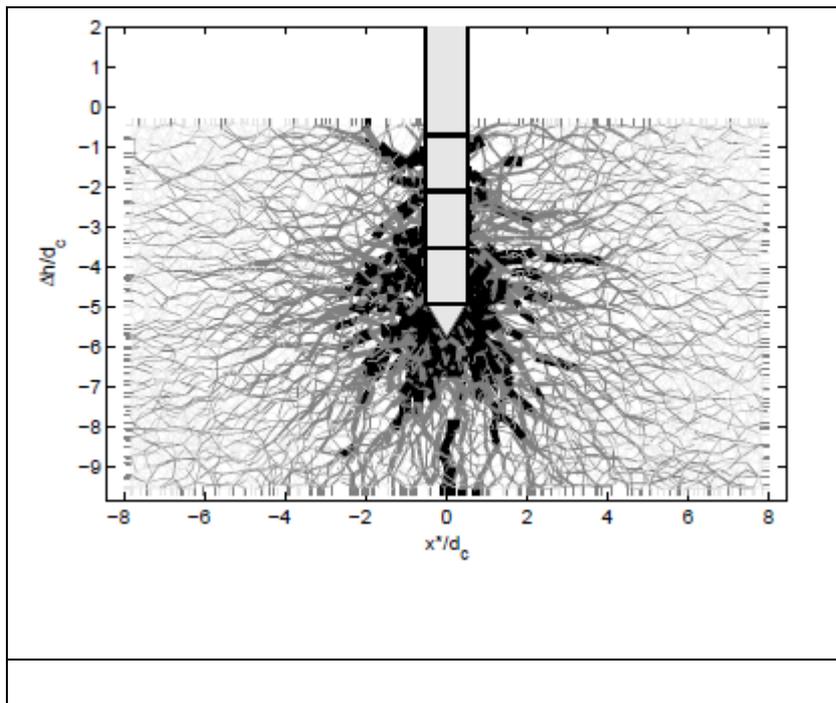


Figure 4 Distribution of normalized radial stresses during penetration (a) plotted against normalized distance to cone tip at three different normalized radius (b) plotted against normalized radius at three different heights above the cone tip



REFERENCES

- Butlanska, J., Arroyo, M., Gens, A., & O'Sullivan, C. (2013). Multi-scale analysis of cone penetration test (CPT) in a virtual calibration chamber. *Canadian Geotechnical Journal*, 51(1), 51-66.