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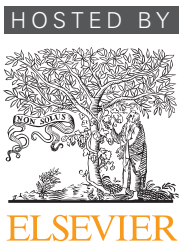

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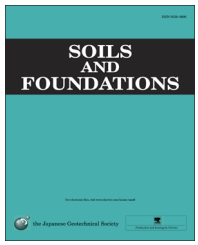

Closure

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We thank the Discussers for their contribution to this fascinating topic. We too were a little surprised by the low values that we measured for the coefficient of inter-particle friction of quartz particles, but we believe that the data are reliable because we had previously carried out control tests on chrome steel balls of known frictional properties. In comparing our data with the literature we believe that it is important to emphasise that there are very limited data available for the type of test that we have undertaken, shearing one sand particle against another. As we have discussed in the paper, almost all the references in the literature use other techniques such as shearing an assembly of grains against a prepared surface (e.g. Rowe, 1962), shearing a single particle against a surface (e.g. Proctor & Barton, 1974), a flat against a flat (e.g. Horn & Deere, 1962) or a prepared sphere against a prepared flat (e.g. Cole et al., 2010). We do not know what effect these other preparation and testing techniques would have on the data, but we believe that testing natural particles is a more sound approach, even if it is technically much more difficult.

Apart from differences of technique discrepancies might, as the Discussers highlight, arise from differences of roughness. The influence of roughness was highlighted by Cavarretta et al. (2010) in their tests on glass ballotini, but although there seemed to be an effect their data were highly scattered, emphasising that there is much more work to do in this area. Our particles are from a natural soil, Leighton Buzzard sand, that has been quarried. While it is possible that there may have been some particle breakage during the quarrying processes, the roughnesses we have measured were quite consistent at around 0.38μm and this should represent the true surface roughness of this natural sand. It was a pity that the Discussers had no such measurements for their own sands. The sand would have been washed during the quarrying processes, and we washed individual particles with distilled water before sample preparation. The tested surfaces were then degreased with butanone to avoid any possible contamination with finger grease or glue, although we were also careful not to touch the particles. It is most unlikely therefore that any clay contamination could affect the data.

Another possible influence is surface humidity. Our own tests showed little difference between dry and saturated conditions, although the ambient humidity in our laboratory was high. Cavarretta et al. (2010) reached a similar conclusion. Others have measured lower values for dry quartz surfaces, for example Horn and Deere (1962) measured only 7.4°, emphasising that this too is an area where more work is needed.

Where we differ from the Discussers is in the importance of these discrepancies. As was shown conclusively by Skinner (1969) the role of inter-particle friction in determining the global angle of shearing resistance is not a direct one, because as explained by Thornton (2000) and Mitchell and Soga (2005) it is strong force chains that carry the deviatoric load, not specifically friction at the particle contacts. The inter-particle friction only has a secondary role in supporting the strong force chains, higher friction creating more stable chains.

Reference

Mitchell, J.K., Soga, K., 2005. Fundamentals of Soil Behaviour 3rd ed. Wiley.

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