Diffuse failure in granular media: influence of the loading path.

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Summary The mechanical behaviour of a granular assembly depends on local parameters such as the shape and roughness of grains and on non-local parameters such as the global density and anisotropy. As this medium is pressure-sensitive, non-associated and path-dependent, its behaviour depends on the effective mean stress and loading paths. An experimental investigation has highlighted potential instabilities revealed by the second order work criterion at low deformation (ε_1 around 0.1 %) without any kinematic localisation.

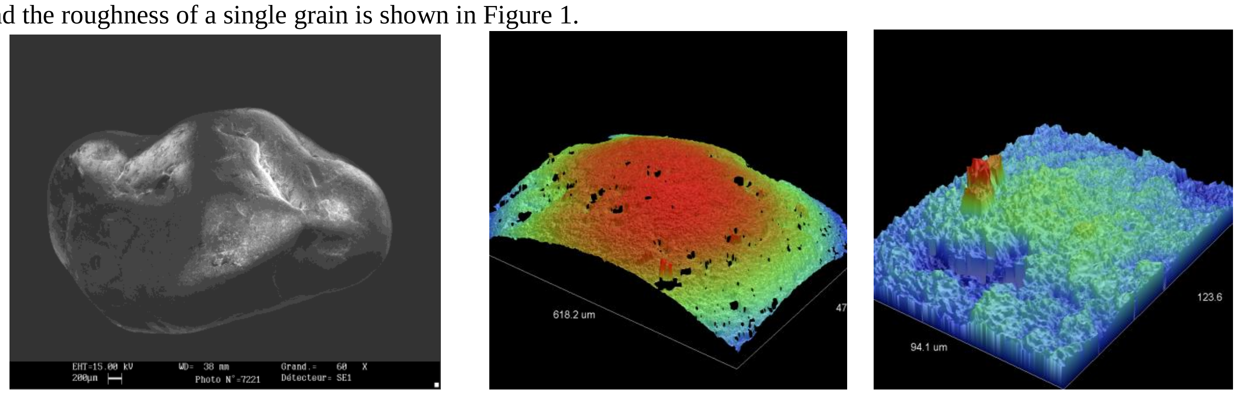
INTRODUCTION

One of the most investigated instability in granular media concerns the creation and propagation of single or multiple shear bands. Another thoroughly studied instability occurring under isochoric (*i.e.* undrained) conditions, without kinematic localisation, is the so called "static liquefaction". However, the onset of collapse during strain dilatancy-imposed tests occurs before the one observed during isochoric tests, which is revealed by the second-order work criterion applied to non-associated materials.

LOADING PROGRAMS

Experimental setup and tested material

All the triaxial tests are performed using the Hostun S28 which is a poorly graded subangular medium sand ($C_U=2$). The moist tamping method is utilized for sample preparation to obtain loose samples. Enlarged lubricated platens are used in order to reduce the friction with the soil. Saturation is achieved by first flushing carbon dioxide and then de-aired water and was assumed to be sufficient when the Skempton's *B* parameter is greater than 98% ([1]). The shape and the roughness of a single grain is shown in Figure 1.



a) b) c)

Figure 1. A single grain of Hostun sand at different scales using a confocal interferometer: a) an entire grain, b) a magnified portion of the same grain, c) magnification of the same grain at x50.

Strain proportional tests

Although *in situ* conditions can be different, a constant strain ratio is chosen during the whole test to study the influence of drainage conditions on the instability of loose Hostun sand specimens. Drainage conditions considered are not only fully drained or fully undrained as is commonly done during most laboratory tests but also included partially drained tests. Similar tests have been performed by Lancelot et *al.* ([2]) and Sivathayalan and Logeswaran ([3]). The loading program is written in the following form, using the common sign convention used in geomechanics where axial compression and volume outflow are considered as positive:

$$\begin{cases} d\varepsilon_1 > 0 \\ d\varepsilon_2 = d\varepsilon_3 \\ d\varepsilon_1 + 2R\,d\varepsilon_3 = 0 \end{cases} \qquad (1)$$

Experimental data for loose samples loaded under four proportional strain paths performed under an effective mean pressure p'_0=100 kPa are plotted in Figure 2. Different values of the parameter R corresponds to expansive ($R=0.68$), undrained or isochoric ($R=1$) and contractive ($R=1.36$ *and* 2) volumetric strains. Figure 1c shows a linear variation of volumetric strain versus axial strain, which corresponds to the desired linear proportional path (see Eq. (1)). The

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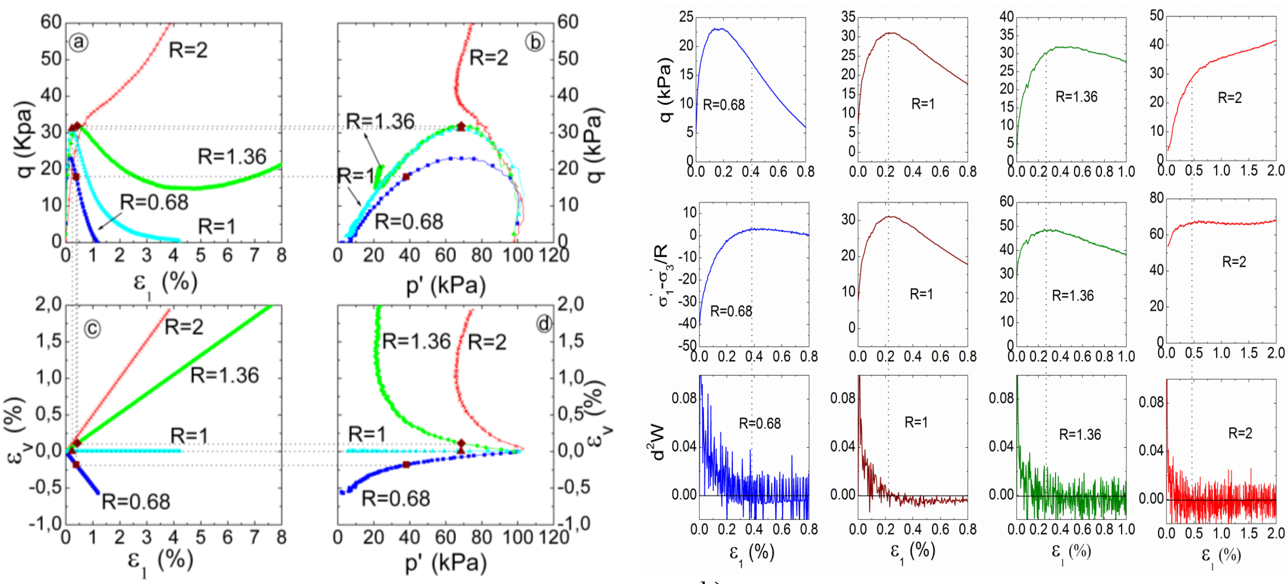
deviatoric stress q could present a peak or not depending on the value of the parameter R as shown in Figure 2a,b. The observed peaks are followed by a total loss of strength (vanishing of the deviatoric stress) for values of R less than or equal to 1 or a partial loss of strength for $R=1.36$. It should be emphasised that for $R=2$, no peak is observed and high strength mobilization can be reached. It is also observed in Figure 2a that the peak values of the deviatoric stress q decreases with volumetric expansion *i.e.* for decreasing values of R. The minimum q value reached during an expansive proportional strain path ($R=0.68$) is smaller than the one reached during a conventional undrained test ($R=1$) which classically defines the onset of collapse ([4]).



a) b)

Figure 2. Experimental results of proportional tests on loose Hostun sand. One initial effective mean stresses is presented (p'_0 =100 kPa) for four different values of R (*0.68*, *1*, *1.36* and *2*).

DISCUSSION / CONCLUSIONS

The second order work is written for axisymmetric samples $d^2W = d\sigma'_1 d\varepsilon_1 + 2d\sigma'_3 d\varepsilon_3$ and can be rewritten as $d^2W = \left(d\sigma'_1 - \frac{d\sigma'_3}{R}\right) d\varepsilon_1 + (d\varepsilon_1 + 2Rd\varepsilon_3)\frac{d\sigma'_3}{R}$ for proportional paths. It reduces to $d^2W = \left(d\sigma'_1 - \frac{d\sigma'_3}{R}\right) d\varepsilon_1$ as $d\varepsilon_1 + 2Rd\varepsilon_3 = 0$ is imposed during the test (Eq. 1).

It is shown that the second order work vanishes after the peak of the deviatoric stress for the expansive test ($R=0.68$), at the peak for the isochoric test ($R=1$) or after the peak for the contractive test ($R=1.36$ and 2). This demonstrates that the peak of the deviatoric stress (q) is not the relevant parameter to detect the onset of collapse whereas the peak of the generalized stress $\left(d\sigma'_1 - \frac{d\sigma'_3}{R}\right)$ is (Figure 2b). The axial strain corresponding to this peak is about 0.1%, which is much less than the observed axial strain (around 4%) when shear bands are seen for such loose samples. More important, whereas no deviatoric peak is observed for $R=2$ and thus no instability is expected using the classical interpretation, we show that not only a peak of the generalized stress is observed indicating the onset of instability but it occurs at a low axial strain (around 0.5%). This analysis also demonstrates that the second order work criterion is the relevant criterion for the detection of instabilities in granular materials.

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