Some aspects of the cyclic behavior of quasi-saturated sand

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RÉSUMÉ. *L'article présente des résultats expérimentaux sur le comportement hydro-mécanique d'un sable lâche, soumis à des sollicitations cycliques. Le matériau est le sable d'Hostun RF largement utilisé comme matériau de référence par la communauté scientifique en France depuis une trentaine d'année. L'état de saturation du sable est évalué à l'aide du paramètre B de Skempton. Les résultats montrent qu'avec un B de l'ordre de 0.85 initialement correspondant à un état non saturé, le matériau peut atteindre un état de liquéfaction pour un niveau de contrainte déviatoire cyclique* $q_c/2\sigma'_3 = 0.25$.

ABSTRACT. *The paper presents experimental results on the hydro-mechanical behavior of loose sand submitted to cyclic loading. The material is Hostun RF sand widely used as a reference material by the scientific community in France for thirty years. The saturation state of the sand is evaluated using the Skempton parameter B. The results show that with an initially B value of the order of 0.85, corresponding to an unsaturated state, the material can reach a liquefaction state for a cyclic deviatory stress level* $q_c/2\sigma'_3 = 0.25$.

KEY WORDS: *Hostun RF sand; unsaturation; cyclic loading; liquefaction; Skempton parameter B.*

1. Introduction

Soil liquefaction is a phenomenon in which granular soils under cyclic load lose much of their resistance or strength and behave like a liquid. The reason is that loose sands tend to be compacted when subjected to dynamic loading that results in an increase of the pore water pressure and a decrease of the effective stress within the soils. When soils liquefy, the deformation develops rapidly and causes the collapse of infrastructure on a large scale. The term spontaneous liquefaction was first coined by Terzaghi and Peck in 1948 ([ISH 93]). Since then, many studies have focused on the liquefaction of saturated soils and the behavior of saturated soils has been clearly understood ([CAS 69]; [SEE 82]; …). Recent studies have shown that liquefaction can be observed not only on saturated soil but also on unsaturated sandy soils ([YOS 89]; [VER 17]); however, their behavior has been little studied and poorly understood.

2. Material

The material is fine quartz sand (Hostun RF) from Sika Co., Hostun, France. The properties are listed in table 1.

Grain specific weight (kN/m^3)	Maximum grain size (μm)	Minimum grain size (μm)	D_{50} (μm)	D_{10} (μm)	D_{60} (μm)	Friction angle (°)
26.2	600	120	300	200	400	40

Table 1. *Properties of Hostun RF sand.* ([FLA 90] ; [BIA 89])

3. The test apparatus

The apparatus of the test is based on the apparatus used for dynamic triaxial tests. The Dynamic (Cyclic) Triaxial Testing System 5Hz/5kN includes a dynamic controller to generate and control dynamic parameters as force, displacement, pore water pressure. Cell pressure and back pressure are controlled by Pneumatic Automatic Pressure Controll (APC) and Hydraulic APC correlatively. The pressure produced by Pneumatic APC impacts on the cell through a device called Air-Water Interface. This device’s duty is to make the pressure more responsive and mellifluous. Specimens used for this apparatus have dimensions of 70mm in diameter and 140mm in height. Back pressure can be applied on both top and bottom of the sample while pore water pressure is measured only on the bottom of the sample. The displacement can be controlled by both dynamic controller and the axial displacement transducer.

4. Soil water retention curve (SWRC)

In unsaturated medium, the pressure in the water phase (u_w) is less than the pressure in air phase (u_a). The variation in the suction $s=u_a-u_w$ of the material versus its moisture content can be obtained using several devices ([BIA 89]): Tensiometers and tensiometric plates for suction lower than 30 kPa, and Filter papers and Richard’s pressure membrane cells for pressures between 50 and 1000 kPa. The paths followed by the samples are drying-wetting paths: On wetting paths, the samples, initially dry, are prepared in the measurement cell by letting the particles fall from a height of approximately 50 cm; the water content measurement is made once the equilibrium of the sample is reached under the applied suction. On drying paths, the same protocol was used with initially saturated samples. The results are shown in figure 1. The pF, defined as pF=log s (s: suction in cm), is plotted versus water content for both imposed drying and wetting paths. It must be noted that the hysteresis between the wetting and the drying paths is very limited. The curves are in general agreement with other results obtained on similar materials.

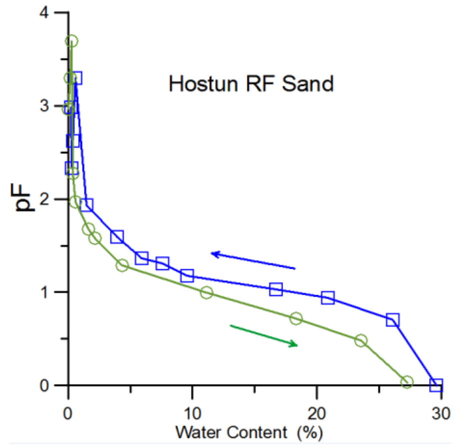


Figure 1. *pF versus water content on drying, wetting paths for Hostun sand* **[BIA 89]**.

5. Cyclic loading

5.1. Sample preparation

The initial condition of the sample including the water content and void ratio was achieved in the following way. 824.9g of dry sand was mixed with 65.99ml of water corresponding to a water content of 8%. The mixture was compacted to reach a relative density Dr of 40%.

5.2. Sample saturation and consolidation.

Firstly, the cell pressure of 35 kPa was applied and then the back pressure of 15 kPa was applied on the base of the sample. The sample is considered to be filled by the water when the water without air bubbles comes out through the pipe on the top of the sample. To dissolve the remaining air in the sample, the cell pressure and back pressure were increased slowly to the target value. In this process, the effective stress was always 20 kPa. This process is named Ramp. Skempton coefficient B is measured base on the following formula:

$$B = \frac{\Delta u_w}{\Delta \sigma_3} \quad [1]$$

$\Delta\sigma_3$ and Δu_w are the imposed increment of confining stress and the resulting measured increment of pore water pressure correlatively. If Skempton coefficient B is higher than 0.96, the sample can be considered to be saturated ([CHA 78]). If Skempton coefficient B is smaller than 0.96, the pore water pressure and back pressure can be increased to the next level. During the two Ramp processes, there was always a slight difference between pore water pressure and back pressure. It is because the sample was not completely saturated. The maximum measured Skempton coefficient B is 0.85. To make the sample consolidate after saturation step, the cell pressure was increased from 820 to 900 while back pressure valves were closed. The back pressure valves were opened when pore water pressure was stable. s

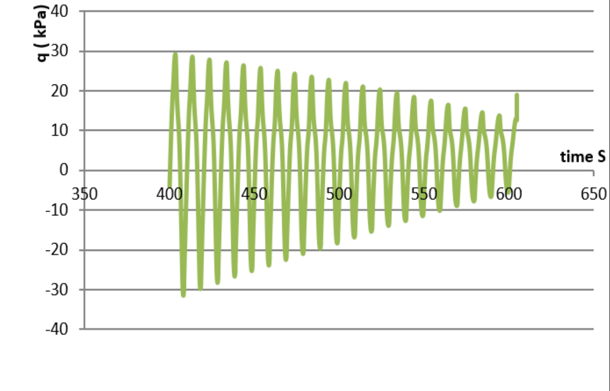
5.3. Cyclic loading

The load frequency was 0.1 Hz and 100 cycles were applied. The amplitude of the deviator stress was chosen based on the ratio $\frac{q^c_{\max}}{2\sigma'_3} = 0.25$, corresponding to $q^c_{\max} = 50$ kPa.

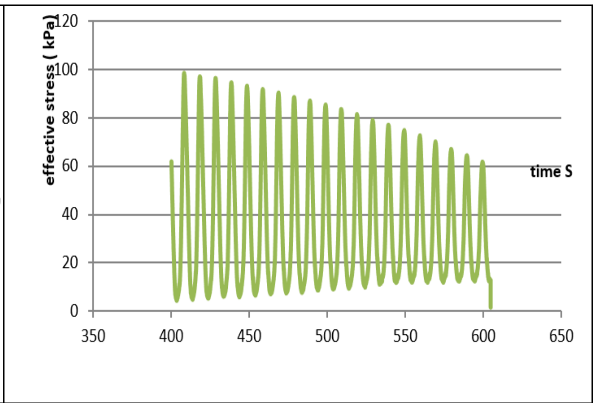
Figure 2 shows the results of the last 20 cycles of cyclic loading. Figures (2a) and (2b) respectively show the variations of the deviatoric stress and pore water pressure versus time. Note that the deviatoric stress continuously decreases with time (fig 2a) as the pore water pressure increases to a value of 900 kPa in the last cycle (fig 2b), corresponding to the value of applied total confining stress. This means the remove of the effective confining stress as shown in Figure (2c). If one analyzes these last 20 cycles mean effective stress p' according to the deviatoric stress [p '; q] (figure 2d), the cycles reach finally the failure criterion or critical state line (CSL) of the sand, corresponding to the line M of slope = 1.64.

6. Conclusion

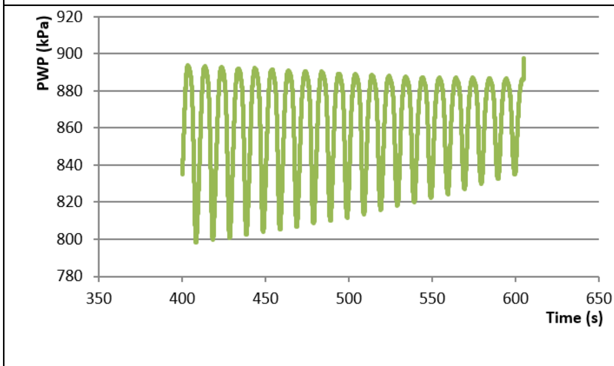
Although B measure shows that the sample is not well saturated (B=0.85), but the cyclic loading with $\frac{q_{\max}^{c}}{2\sigma_3^{'}} = 0.25$ reached the liquefaction state.



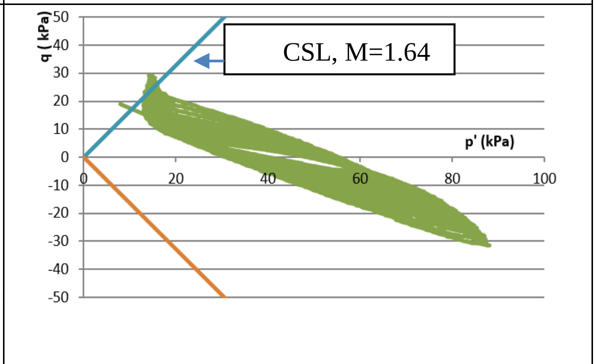
(a) Deviator stress - time



(b) Effective stress – time



(c) Pore water pressure - time



(d) Deviator stress – effective mean stress with failure criterion line

Figure 2. *The last 20 cycles of dynamic loading.*

7. References

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