Effect of saturation degree on the behaviour of clear sand in very dense state

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ABSTRACT: In this paper, a series of tests were carried out to investigate the effect of saturation degree on the liquefaction behaviour of Hostun sand in a very dense state. All the samples were reconstituted by the wet tamping method at a high relative density of 83%. After sample wetting and sample consolidation, the samples having different saturation degrees have been subjected to cyclic loading to study the liquefaction behaviour. The Cyclic Stress Ratio (CSR) of the cyclic loading increased after a given number of cycles until the liquefaction of material. The results show that even though the samples were in a very dense state and not fully saturated, they were liquefied under cyclic loading with increasing CSR. The saturation degree or Skempton's coefficient B affects significantly the liquefaction potential of samples. A decrease of B value from 0.97 to 0.7 results in the increase of CSR needed to liquefy the samples from 0.25 to 0.35. However, the effect of this parameter on the friction angle seems not to be clear.

Key words: Liquefaction, unsaturation, Skempton's coefficient B, dense, Hostun sand.

I. INTRODUCTION

In the last few years, many researchers have paid attention on the liquefaction phenomenon of unsaturated sands subjected to cyclic loading and there is an agreement that soils with a saturation degree lower than 100% can be liquefied. However, there are still some issues needing to be clarified such as: (i) the behaviour of dense unsaturated soil under cyclic loading; (ii) the effect of the saturation degree on the cyclic behaviour of different soil types. Through the value of Skempton's coefficient B, Arab et al. (2016) studied the effect of saturation degree on the behaviour of RF Hostun sand in dense state. They showed that the characteristics including initial stiffness, shear strength, cyclic shear strength, and the sample deformation during cyclic loading have been affected by the saturation degree. Vernay et al. (2019) studied the effect of parameters like suction, pore fluid compressibility and saturation degree on the liquefaction potential of Fontainebleau sand subjected to cyclic loading. In this study, the saturation degree was varied through three zones and the results show that the soil can liquefy and the B value affects significantly the behaviour of soil. The effect of saturation degree in three zones was also studied by Tsukamoto (2018). The cyclic triaxial test on undisturbed specimens was carried out by Mase et al. (2019). In this study, the parameters like the excess pore pressure ratio, hysteresis loop, and effective stress path were surveyed.

II. SKEMPTON'S PARAMETER B

To link the variations in pore pressures associated with variations in total stresses in soils, Skempton (Skempton 1954) used two parameters called Skempton coefficients, A and B. The equation below shows the relationship between them (Equation 1):

$$\Delta u_w = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)] \qquad \text{(Eq. 1)}$$

where A and B are the Skempton coefficients and $\Delta\sigma_1$ and $\Delta\sigma_3$ are the changes of the major and minor total principal stresses. Δu_w is the pore water pressure increment due to the $\Delta\sigma_3$ and $\Delta\sigma_1$

One of the common uses of these coefficients is to assess the saturation of triaxial samples in isotropic pressure condition. With this condition, the second term of the equation 1: $(A(\Delta\sigma_1 - \Delta\sigma_3))$ equals to zero and the equation 1 becomes simple in practical measurement as equation 2:

$$B = \frac{\Delta u_w}{\Delta\sigma_3} \qquad \text{(Eq. 2)}$$

$\Delta\sigma_3$ and ΔU_w are respectively the increase of the imposed isotropic confining stress and the resulting measured increment of pore water pressure.

III. MATERIAL AND APARATUS

The material is fine quartz sand (RF Hostun) which has been used by many researchers in literature (Tran et al 2021; Arab et al. 2016). The sand parameters are: specific gravity 2.65g/cm^3, maximum grain size 0.6mm, minimum grain size 0.12mm. Other parameters are shown in table 1 with D_{10}, D_{50}, D_{60} are the particle size distributions of RF Hostun sand, e_{max} and e_{min} are the maximum and minimum value of void ratio. The grain size distribution and the photos of the sand are shown in figure 1 and figure 2.

TABLE 1. The parameters of RF Hostun sand.

D_{50} (μm)	D_{10} (μm)	D_{60} (μm)	e_{max}	e_{min}
300	200	400	1.041	0.648

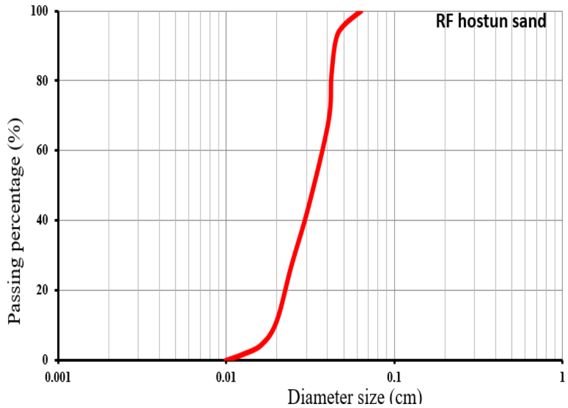

FIGURE 1. Grain size distribution of RF Hostun sand

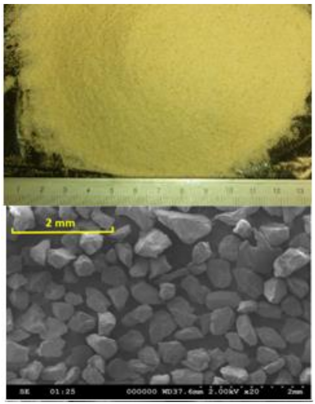

FIGURE 2. RF Hostun sand

The Dynamic (Cyclic) Triaxial Testing System 5Hz/5kN used in this study has been provided by VJ tech with a dynamic controller to generate and control dynamic parameters, i.e. force, displacement and pore water pressure.

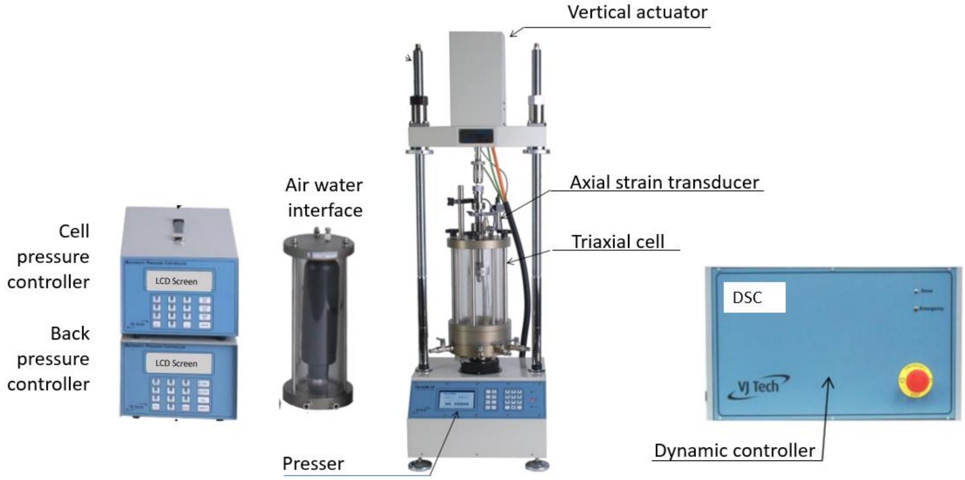

FIGURE 3. Triaxial dynamic testing apparatus

IV. TEST PROCEDURE

A. Sample preparation

The samples were prepared by the wet tamping method which is widely used in liquefaction laboratory testing. After compacting, the sample size is 70 mm in diameter and 140 mm high and initial void ratio of 0.73 corresponding to the relative density of 83% calculated as following equation (Equation 3):

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \qquad \text{(Eq. 3)}$$

B. Sample saturation, B check and consolidation

The samples have been circulated by de-aired water, however, there are still air bubbles inside the samples. From our experience, the saturation degree achieved by this method is about 70-80%. To dissolve the remaining air bubble inside the samples after that pore water pressure and back pressure were increased in a process called Ramp (figure 4). With unsaturated samples, they were circulated by de-aired water in vacuum condition. After sample saturation, the B value was measured to evaluate the sample saturation degree and then an effective stress of 100 kPa was applied to consolidate the samples.

B. Cyclic loading with increasing Cyclic Stress Ratio (CSR)

The load has saw teeth form with frequency of 0,1 Hz. The CSR is chosen initially of 0.15 corresponding to the deviator stress of 30 kPa. The relationship between CSR and deviator stress is shown in equation (4)

$$CSR = \frac{q_{max}^{c}}{2.\sigma'_{3c}} \qquad \text{equation 4}$$

q_{max}^{c} is the amplitude of deviator dynamic stress. σ'_{3c} is the effective consolidation stress.

Due to the difficulty in liquefying the unsaturated samples in very dense state, the value of CSR was increased after each 100 cycles (Figure 5). In the case there was a clear sign of liquefaction, the CSR is kept unchanged, so the number of cycles of the final load case may be greater than 100.

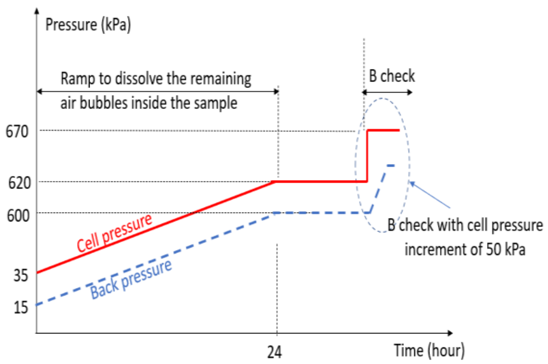

FIGURE 4. Ramp process to saturate completely the sample

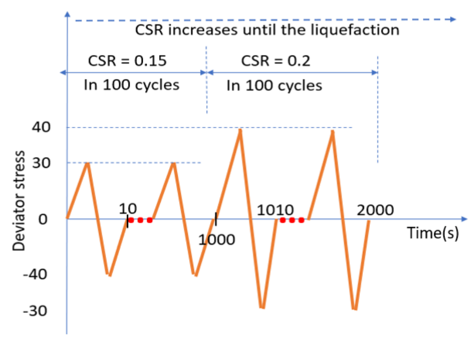

FIGURE 5. Cyclic loading

V. RESULTS AND CONCLUSION

Figure 6 shows two tests with saturation degree of 0.97 for fully saturated test (Figure 6a) and B of 0.6 for unsaturated test (Figure 6b). The results show that the initial saturation degree affects significantly the behaviour of the sample. The decrease in B value from 0.97 to 0.6 results in the increase of CSR from 0.25 to 0.35 and as well the rise of number of cycle at liquefaction from 222 cycles to 432 cycles. The pore water pressure increment at liquefaction shows the two-peak mechanism for both saturated and unsaturated tests. It means that in one cycle, the sample changed two times from dilatancy phase to contractancy phase. This is a characteristic of cyclic mobility, the liquefaction of sand in dense state.

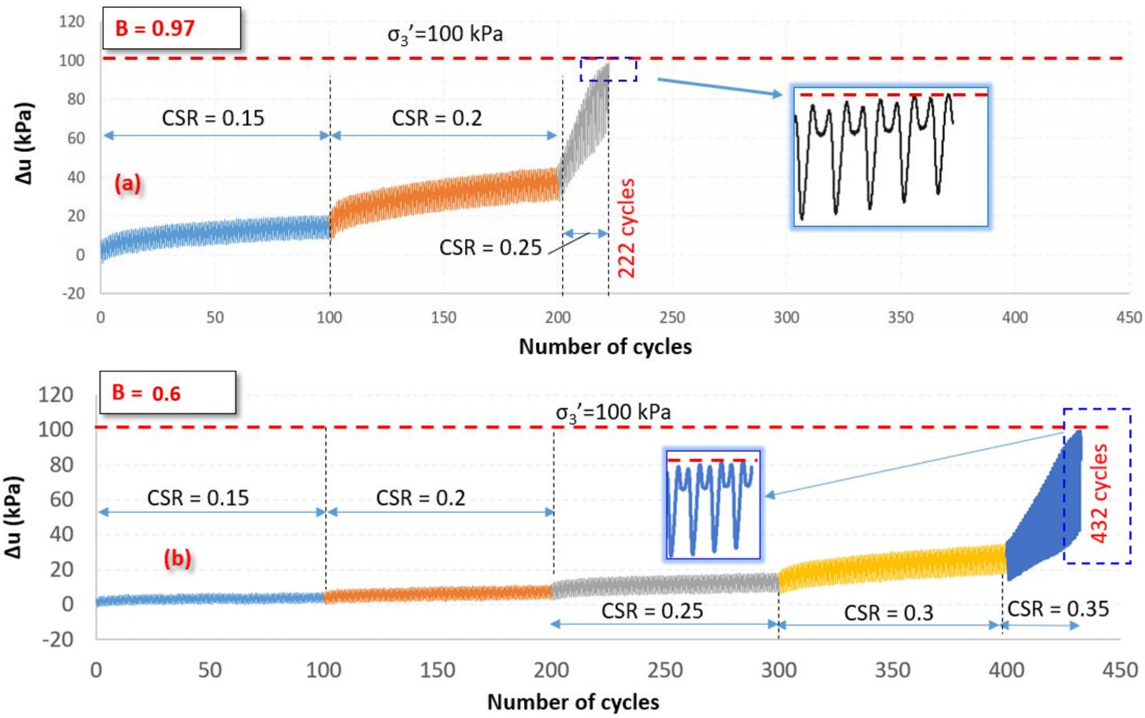

FIGURE 6. **Pore water pressure increment for saturated sample (a) and unsaturated sample (b)**

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