論文の内容の要旨

Thesis summary

博 士 論 文

Undrained behavior of sand with non-plastic silt and its application to ground deformation analysis

(非塑性シルトを含む砂の非排水せん断実験と地盤変形予測への応用)

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本文

In the past three years, severe damages in urban areas caused by liquefaction of sand containing non-plastic fines have raised the interest in this topic. However, liquefaction of silty sand is not a recent issue. Seed et al. (1984) found that the amount of fines increased liquefaction resistance when studying SPT measurements in sandy soil containing fines from 5 to 30%, Robertson and Campanella (1985) made the same observation on CPT data from sites with sand with fines content from 10 to 25%. In laboratory, many researchers have tried to investigate the effect of fines content on the liquefaction resistance of sands following several approaches, by setting constant parameters as void ratio, e (e.g., Huang et al. 2004; Polito and Martin 2001; Thevanayagam 2000), sand skeleton void ratio, e_s, which assumes that the volume occupied by silt particles is part of the volume of voids (e.g., Kuerbis 1989; Polito and Martin 2001) or relative density, D_r, (e.g., Carraro et al. 2003; Polito and Martin 2001; Shen et al. 1977). A summary of the results obtained by these researchers shows that when relative density is kept constant, cyclic resistance ratio, CRR, increases with fines content; when void ratio is the parameter of comparison, CRR decreases with fines content and when sand skeleton void ratio is kept constant, CRR either increases or remains constant with the addition of fines. Thus, it is clear that the use of density parameters can be misleading due to the impossibility of keeping all parameters constant for comparison. In this regard, a series of hollow torsional shear tests were conducted on sand retrieved from Tokyo Bay after the liquefaction events of 2011. The fines contained in this sand were found to be non-plastic.

The first stage of the experimental program consisted on evaluate the effect of fines on the liquefaction resistance by keeping the compaction energy constant during testing. This was achieved by using air pluviation for sample preparation and keeping the height of fall constant for every test. This intended to simulate natural deposition and the method yielded uniform samples.

Fines content was varied from 0 to 80% and two different heights of fall were used: 5 and 50 cm. Consolidation tests as well as monotonic and cyclic undrained loading were carried out on the specimens. Based on the cyclic tests, it was observed that, keeping the compaction energy constant, cyclic resistance ratio (CRR_{20}) initially decreased with fines content, from 0 to 20%; then, it increased from 30 to 40% and finally, from 60 to 80% reported an increment again. Results of CRR_{20} compared with fines content for the two different heights of fall are shown in Figure 1.

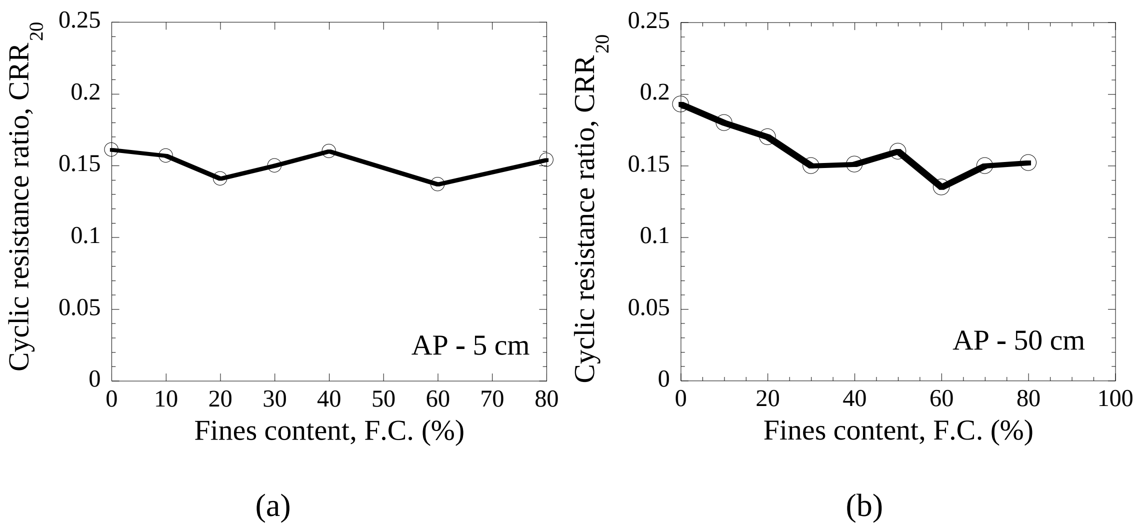

Figure 1. Cyclic resistance ratio variation with fines for a) AP-5 cm and b) AP-50 cm

These results identified three different groups of behavior:

1. From 0 to 20% fines content, the sand matrix controls the response and the addition of fines reduced the sand-to-sand contacts reducing also the liquefaction resistance.
2. From 30 to 40% fines content, both sand and fines are contributing to the force chain, having an increase in resistance when more fines are added.
3. From 60 to 80% fines content, the fine matrix controls the response and sand grains do not make contact with each other anymore, thus having an overall reduction in resistance. However, as less sand is present, the contacts fine-to-fine increase having also a raise in the liquefaction resistance.

These results can be explained considering a binary packing. As depicted in Figure 2, the existence of two different sizes of particles affects the values of maximum and minimum void ratios It is observed that both curves have a V-shape and a minimum value, denominated threshold fines content, F_{thr} (Thevanayagam et al. 2002) where fines fill all the voids within the sand matrix and start contributing to the resistance. Below the F_{thr}, fines do not contribute to the force chain and reduce the resistance. There is a third point, called limiting fines content, where sand grains are surrounded by fines and there are no contacts sand-to-sand. After this point, fines controlled the matrix and the response.

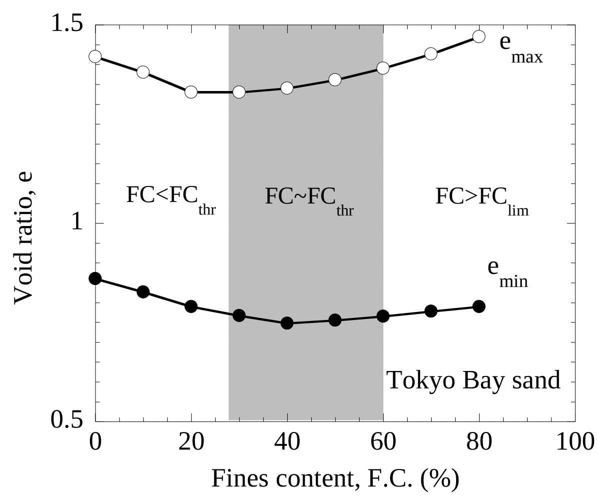

Figure 2. Binary packing

This is very useful to understand the previous results and the expected behavior in natural deposits for different fines contents; however during evaluation of liquefaction resistance the most common simplified procedures use field parameters as the SPT N-value. To be able to compare laboratory results at the same SPT N-value, an equivalent parameter should be kept constant during testing. Based on the correlation proposed by Stroud and Butler (1975) between SPT N-value and the coefficient of volume compressibility, a new set of experiments was conducted by preparing samples at the same coefficient of volume compressibility m_v=1.20x10^{-4} (1/kPa) measured after consolidation.

The variation of liquefaction resistance at the same mv value is shown in Figure 3. In the variation with fines content, it can be noted that liquefaction resistance decreases from 0 to 20%, slightly increase from 30 to 40%, exhibit a large reduction for 60%, but raises again for 80%. These results agree with the previous obtained at the same compaction energy. This indicates that at the same SPT N-value, clean sand always has the greatest resistance and in overall the addition of fines increases the liquefaction potential.

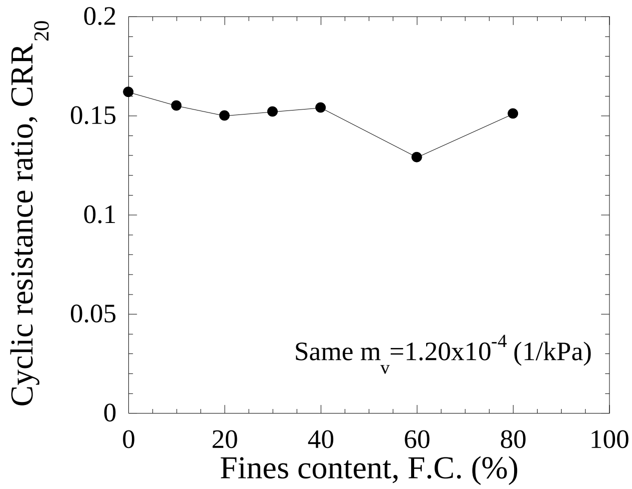

Figure 3. Cyclic resistance ratio variation with fines at the same m_v

Moreover, volumetric strain was measured after liquefaction and it was observed that FC=0% had the smallest volumetric deformation while FC=60% had the largest. The other fines contents had intermediate values.

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