EFFECTS OF SAMPLING DISTURBANCE ON DYNAMIC PROPERTIES OF SATURATED SANDS

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ABSTRACT

Disturbance effects on dynamic properties of saturated sand were evaluated in the laboratory by means of cyclic undrained triaxial tests. For this purpose, undisturbed samples were subjected to deformation and liquefaction tests, the sand that constituted the undisturbed samples was kept and oven dried to reconstitute samples. From the shear modulus ratio-strain dependency curves it is shown that there is no significant effect between undisturbed and reconstituted samples for consolidation stresses of 150 and 300 kPa, anyhow as this parameter was reduced the effect turned evident. Damping ratio was also object of analysis, and very slight effects were noticeable for a consolidation stress of 75 kPa. Bender element tests were performed, and P-wave velocity for each sample remained fairly constant in spite of changes in consolidation stress and disturbance condition, and for S-wave velocity the bender element tests confirmed the results from deformation tests, the difference between both disturbance conditions represented a minor divergence. Liquefaction tests were also carried out, when comparing the shear modulus against the liquefaction potential value a very scattered plot was obtained, reflecting that a large difference in liquefaction potential is present due to the significant change in soil fabric or internal structure, even among undisturbed samples. A relationship representing disturbance effects is presented in terms of a maximum shear modulus ratio and liquefaction potential ratio.

Keywords: Liquefaction, sampling disturbance, sand, undrained triaxial tests.

1. INTRODUCTION

During the first week in September of 2008, Tokyo Soil Research Co., Ltd. developed a full soil investigation in Ooarai site located in Ibaraki's east coast, and samples were retrieved using the in-situ freezing method. At present, the in-situ freezing method is considered the most reliable technique to provide undisturbed samples. In spite of all the benefits that this technique offers, its application requires a strong economic investment and besides it's very time consuming. Samples from that project have been preserved under proper refrigeration up to now, and they were available to be used for the purpose of this study. This method is employed when such a soil investigation is reasonably affordable. Small to medium size projects have to deal with traditional soil investigations that imply the acquisition of samples in a disturbed condition, therefore lowering the quality of results to be used to predict possible hazards or to recreate past events. Under or overestimation of results plays an important role since this implies a higher cost or higher risk. Given that the cheapest mean to obtain samples is remolding them from a totally disturbed and loose condition, against the fact that the in-situ freezing method is now considered the most reliable technique to obtain undisturbed samples, these two conditions are to be compared, to quantify the effects of disturbance on deformation characteristics and for cyclic mobility properties, and specifically to determine the impact on the liquefaction potential. In this sense, samples for both states were prepared to carry out this study.

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2. DISTURBANCE EFFECTS ON SHEAR MODULUS-STRAIN RELATIONSHIP

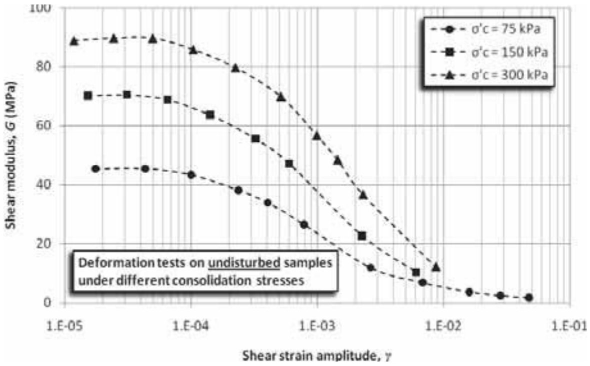

Figure 1. Effect of consolidation stress on the shear modulus-strain dependency relationship

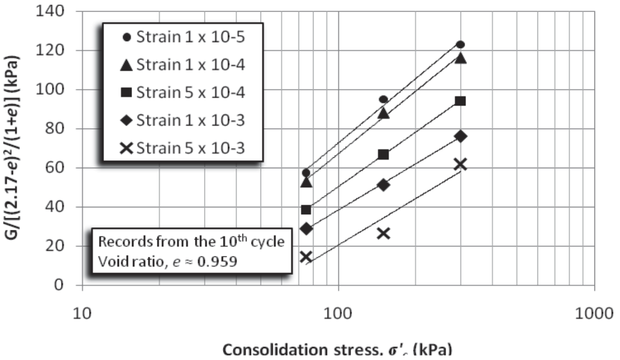

Figure 2. Modulus reduction grouped by strains for undisturbed samples

Three were the consolidation stresses under analysis, namely σ'c = 75, 150 and 300 kPa, and for each of them an undisturbed and a reconstituted sample were assigned. Before analyzing both conditions together, a comparison of the effect of confining stress for each state is to be made. Fig. 1 gathers the shear modulus-strain dependency curves for the undisturbed samples and for the 10th cycle. As expected based on the theoretical background, the shear modulus exhibits a significant growth as the consolidation stress increases; for this case the maximum shear modulus for σ'c = 150 kPa represents 1.55 times that presented for σ'c = 75 kPa. G_o for σ'c = 300 kPa is 1.97 and 1.27 times that reported for σ'c = 75 and 150 kPa, respectively. It can be also quantified that the modulus falls down to 50% of its initial value for a level strain of 1×10^{-3}, 1.1×10^{-3} and 1.6×10^{-3} for a consolidation stress of σ'c = 75, 150 and 300 kPa, respectively; and it falls down to 20% at around 4×10^{-3}, 4.5×10^{-3} and 6.5×10^{-3} for the same set of consolidation stresses. As the cyclic loading steps progress and the strain grows the shear modulus comes reduced, such behavior can be better seen through Fig. 2 where the shear modulus presenting the same strain has been grouped in single tendencies. This graph is intended to establish the relationship between the shear modulus for a given consolidation stress and void ratio function. The expression to correlate Ooarai sand with the consolidation stress has been determined as expressed by Eq. 1. The expression is calculated for a strain amplitude of 10^{-5} and therefore a level indicating the maximum shear modulus. Anyhow, other strains might be set to determine the shear modulus for that given level of strain. In fact the previous proposed relationship differs from that proposed by Hardin and Richardt only by 2.9% indicating that Ooarai sand deformation characteristics have a fair agreement with the original expression. The same procedure as used for the undisturbed samples was used and a relationship between the consolidation stress and maximum shear modulus was determined as presented by Eq. 2.

$$G_o = 7200\frac{(2.17-e)^2}{1+e}\sigma_c'^{\,0..5} \qquad (1) \qquad\qquad G_o = 10600\frac{(2.17-e)^2}{1+e}\sigma_c'^{\,0..4} \qquad (2)$$

Fig. 3 shows both modulus ratio-strain dependency curves for undisturbed and reconstituted sample under σ'c = 75 kPa, and so does Fig. 4 and 5 for σ'c = 150 and 300 kPa, respectively. From Fig. 3 it is visible that disturbance causes a narrow gap between both conditions, indicating a substantial difference in shear modulus. To obtain a correction function, the hyperbolic model was used and a unique relationship for each condition was established to better fit the laboratory results, thereafter determining a correction function in terms of the strain. For σ'c = 300 kPa the difference comes to be less significant and it can be concluded that no major disturbance effect is found for such a consolidation stress. Anyhow, and in spite of the slight difference a correction function has been also established for this case. In consideration of this behavior where the effects of disturbance are in relation to an isotropic consolidation stress, shallow depths are prone to present more disturbance effects than deeper layers. For instance, the consolidation stresses of 75 kPa and 150 kPa correspond to a depth of 6.4 m and 15.2 m, respectively. Hence, for a more detailed assessment of the soil profile behavior when reconstituted samples are meant to be used, deformation characteristics may be corrected through a correction function, for this specific case, Ooarai sand, and Fig. 6 might be used.

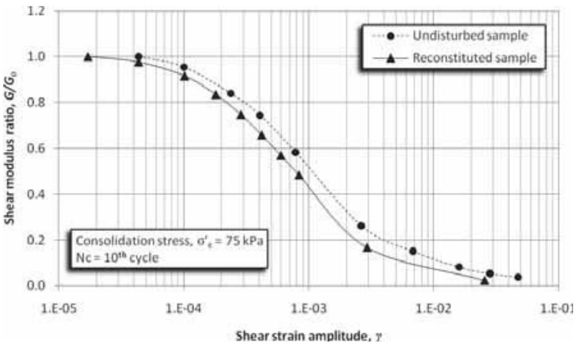

Figure 3. Normalized modulus-strain dependency curve for σ’$_c$ = 75 kPa

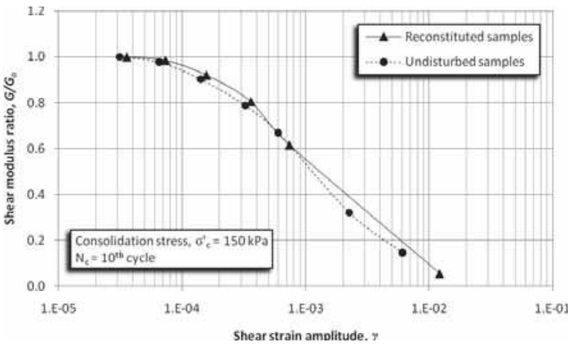

Figure 4. Normalized modulus-strain dependency curve for σ’$_c$ = 150 kPa

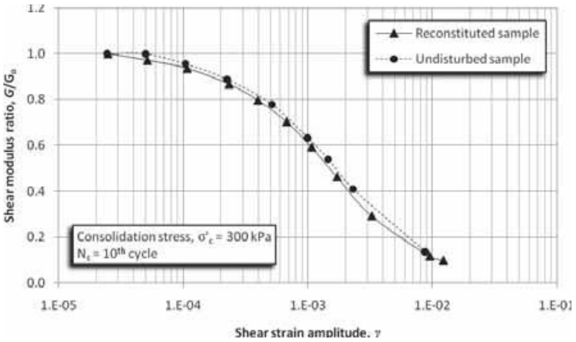

Figure 5. Normalized modulus-strain dependency curve for σ’$_c$ = 300 kPa

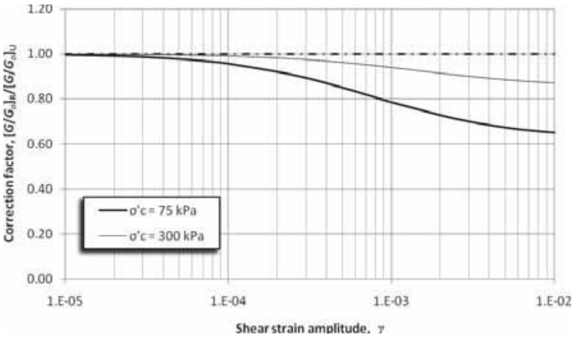

Figure 6. Effects of disturbance on shear modulus-strain relationship

3. DISTURBANCE EFFECTS ON DAMPING RATIO-STRAIN RELATIONSHIP

Shear modulus ratio-strain relationship ($G/G_o - \gamma$) is of primary importance for the analytical study of soil response, when acceleration, velocity and displacement are to be examined. Nevertheless, another property of the same importance is the damping ratio-strain relationship ($D - \gamma$). To check the influence of disturbance on the damping properties Fig. 7 shows the damping ratio-strain dependency curves for both the undisturbed and reconstituted state under a consolidation stress of 75 kPa. Due to the relative small consolidation stress, the initial behavior is very erratic and the final stage represents a large degradation, therefore it is considered for this study that only the points in the range from 1×10^{-4} to 1×10^{-3} are representative for this curve in particular. In such a manner a function for this range has been determined for both conditions and thereafter a correction function as well, which is shown in Fig. 10. This time the hyperbolic model was not employed due to the lack of agreement, the simple use of least squares was used instead. It also has to be said that the variation is small though it was considered that it needs to be corrected. Unlike the previous case, for the consolidation stresses of 150 kPa and 300 kPa no variation in damping ratio is detected between the undisturbed and reconstituted samples. For σ’$_c$ = 150 kPa the agreement is found until a shear strain of around 8×10^{-4}, after this point the large degradation splits the convergence, and it was caused by an abrupt fall in the reconstituted sample due to a big change in the cyclic loading, so similar consequences are reflected for the damping ratio characteristics. For σ’$_c$ = 300 kPa the agreement is notorious for the whole strain range, slightly diverging after a strain of 2×10^{-3} due to the large degradation itself. The same as for the shear-strain relationship, it seems from the results that the disturbance effects on the damping ratio-strain relation get vanished as the consolidation stress grows. It has to be highlighted that this tendency (present in both the shear strain and damping ratio-strain dependency curves), where the disturbance effects grow weaker as the consolidation stress is raised, has a base upon few data, 6 samples, 2 assigned to each of the three selected consolidation stress values, one undisturbed and one reconstituted sample.

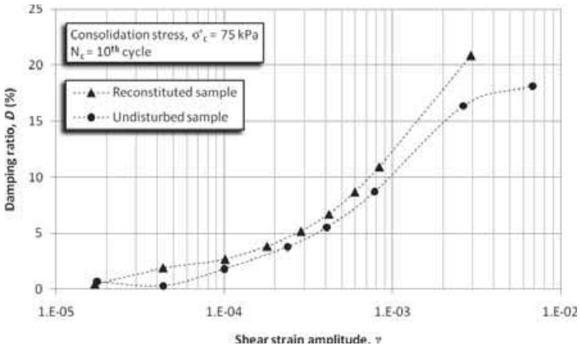

Figure 7. Damping ratio-strain dependency curve for σ'$_c$ = 75 kPa

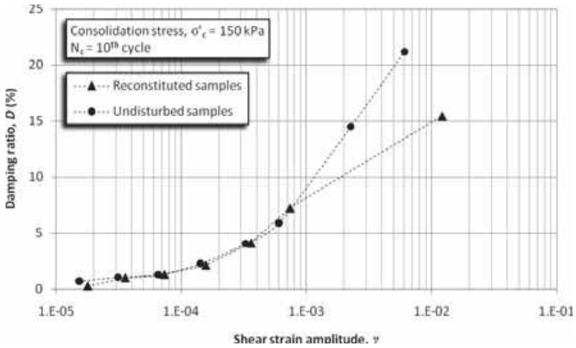

Figure 8. Damping ratio-strain dependency curve for σ'$_c$ = 150 kPa

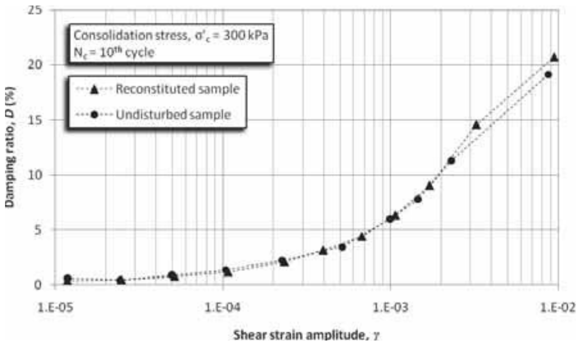

Figure 9. Damping ratio-strain dependency curve for σ'$_c$ = 300 kPa

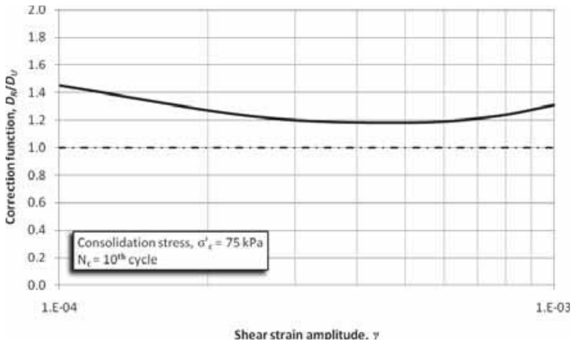

Figure 10. Correction function for damping ratio under σ'$_c$ = 75 kPa

4. DISTURBANCE EFFECTS ON THE SHEAR AND LONGITUDINAL WAVE VELOCITY

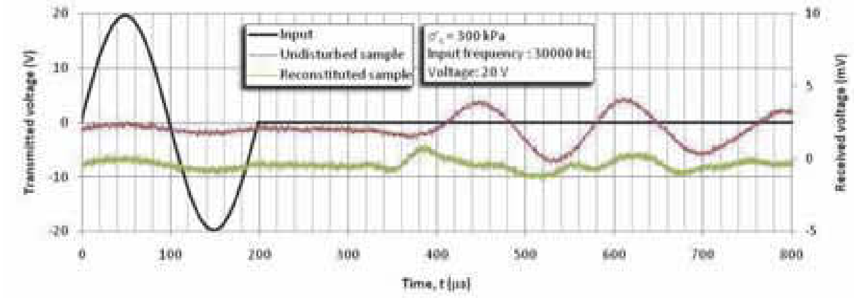

Figure 11. Shear wave velocity comparison against disturbance condition

Fig. 11 shows the S-wave arrival time for an undisturbed and reconstituted sample under a consolidation stress of 300 kPa. Unexpectedly the S-wave arrival time for the reconstituted sample is shorter than that presented by the undisturbed sample, checking the height for each specimen it was found that the velocity for the undisturbed sample was 252 m/s and for the reconstituted sample 257 m/s. It roughly can be said that both conditions report the same shear wave velocity, taking into consideration also that the density after consolidation was higher for the reconstituted sample than for the undisturbed state, 1.378 and 1.350 g/cm^3, respectively. S-wave velocity for σ'_c = 150 kPa represented a small variation, 218 m/s for the undisturbed state and 212 m/s for the reconstituted sample. P-wave velocity was also revised for disturbance effects, for this case the samples subjected to σ'_c = 150 kPa were compared, as well as the consolidation stress effect it was found no significant alteration of the P-wave velocity. The P-wave velocity for each of the 5 samples remains fairly constant in spite of changes in consolidation stress and disturbance condition.

5. EFFECTS OF DISTURBANCE ON CYCLIC MOBILITY CHARACTERISTICS

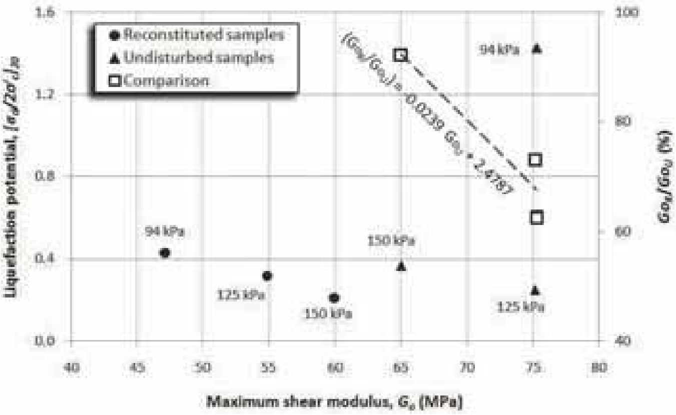

Figure 12. G_o against liquefaction potential

Liquefaction potential was meant to be related with the maximum shear modulus, separately for the undisturbed and reconstituted state, and then comparing both conditions to quantify the disturbance effect. Fig. 12 shows how scattered the actual outputs are; in fact according to this data, liquefaction potential for the reconstituted samples comes reduced as G_o increases. Anyhow, when comparing both conditions for each case, it can be concluded that the large difference in liquefaction potential is due to the significant change in soil fabric or internal structure, brought by disturbance of the original underground condition. Fig. 12 also contains the comparison of results between the undisturbed condition and reconstituted samples. A secondary axis (on the right side) represents the relationship of maximum shear modulus for the reconstituted samples over the maximum shear modulus for undisturbed samples. This tendency seem to be away from previous studies, but also it must be taken into consideration that the number of samples is still considered little for this type of investigation to determine a complete and reliable trend of disturbance effects on liquefaction characteristics. However, a trend curve was established and it is shown in Fig. 12. Shear modulus ratio between undisturbed and reconstituted samples represents direct disturbance effects on the modulus, and it can be symbolized as Go_R/Go_U. Just like for the modulus case, a liquefaction potential ratio between both disturbance conditions would reflect disturbance effects over liquefaction potential. For both, modulus ratio and liquefaction potential ratio, an undisturbed condition comes identified by a relationship equal to 1, so in this sense an ideal undisturbed state would be defined when both ratios are equal to 1. Fig. 13 shows the data obtained evaluated under both ratios, and even though a clear tendency is not possible from the very few points, only three, a correlation representing disturbance effects on liquefaction potential was determined as expressed in Fig. 13.

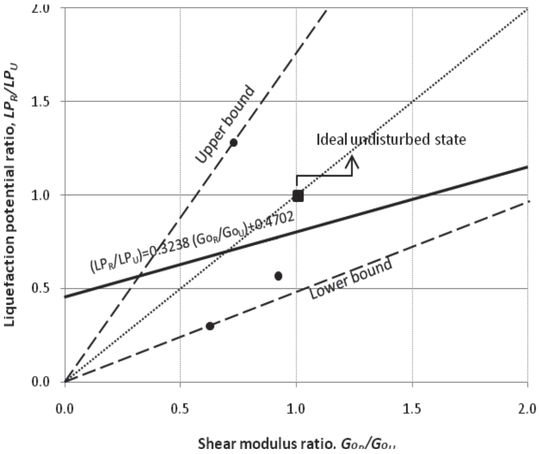

Figure 13. Disturbance effect on the liq. potential

6. CONCLUSIONS

Disturbance effects are reflected during the consolidation process of samples. As the consolidation stress reduces, reconstituted samples not only show a higher amount of settlement in comparison with undisturbed samples, but also an increase in rate at which consolidation occurs. From the shear modulus ratio-strain dependency curves it's shown that there is no significant effect between the undisturbed condition and the reconstituted samples for consolidation stresses of 150 and 300 kPa. Anyhow, as this parameter was reduced the effect turned evident as for the case of a consolidation stress of 75 kPa, for which a correction function was determined. Damping ratio was also object of analysis, and the results showed a similar tendency than that presented by the loss of shear, where very slight effects were noticeable for a consolidation stress of 75 kPa only.

Bender element tests were conducted on samples subjected to deformation tests. P-wave velocity for each of the samples remained fairly constant in spite of changes in consolidation stress and disturbance condition, and for S-wave velocity the bender element tests confirmed the results from deformation tests, the difference between both disturbance conditions represented a minor divergence.

Liquefaction tests were also carried out, when comparing the shear modulus against the liquefaction potential value a very scattered plot was obtained, reflecting a large difference in liquefaction potential due to the change in soil fabric or internal structure, even among undisturbed samples. However, a trend curve was determined for the relationship between the maximum shear modulus of undisturbed samples against the ratio of undisturbed over reconstituted maximum shear modulus, so as to quantify disturbance effect as follows: $(Go_R/Go_U) = -0.0239Go_U + 2.4787$. Maximum shear modulus ratio and liquefaction potential ratio were determined for each pair of samples, undisturbed and reconstituted. Even though a clear tendency was not possible from the very few points, they were only three, a correlation that represents disturbance effects on liquefaction potential was determined as follows: $(Lp_R/ Lp_U) = 0.32(Go_R/Go_U) + 0.47$. The number of samples is considered little for a study of this kind when disturbance effects on liquefaction are under analysis. More pairs of comparison (undisturbed and reconstituted samples) presenting a wider range of initial shear modulus are necessary to establish a clearer trend curve, therefore a more reliable model quantifying the effects of disturbance can be determined.

It's highly recommended to refer to the complete Master Report for a wider and better understanding of this study.

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