

Membrane penetration characteristics of gravelly soil in torsional liquefaction tests

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1. INTRODUCTION

In the past, liquefaction has been considered to only occur in loose, saturated, sandy soils. As a result, essential structures such as nuclear powerplants are built on gravelly soil deposits. Nonetheless, several case studies of large deformation in gravelly soil liquefaction highlight the need to investigate. In this study, several factors such as membrane penetration (MP), membrane force, and undrained cyclic behavior were examined in the large strain region. In element tests, MP delays pore water pressure generation which causes an overestimation of the liquefaction strength. There are generally two ways to address this. The first is to apply correction (Nicholson et al., 1993; Tokimatsu & Nakamura, 1987) and the second is to eliminate it in the test (Miura & Kawamura, 1996). As far as the authors know, there have been no study on the use of the MP-reducing layer on the hollow cylinder torsional shear apparatus.

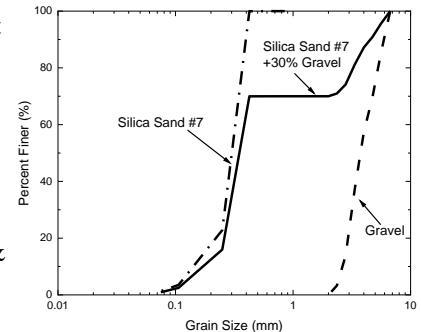


Fig. 1. Grain size distributions

2. EQUIPMENT, MATERIALS AND PROCEDURE

A large strain controlled hollow cylinder torsional shear apparatus with outer diameter of 200mm, inner diameter of 120mm, and height of 300mm was used in this study (Kiyota et al., 2008). 30% gravel content (GC) mixture of silica sand #7 and gravel was prepared (shown in Fig. 1). The specific gravity is 2.68. Maximum and minimum densities are 1.772 g/cm³ and 1.513 g/cm³, respectively. The specimen was prepared by dry tamping in 10 layers. A relative density (Dr) of 50% was maintained for the tests. Two test conditions were compared in this study to compare the effect of a peripheral sand layer to the undrained cyclic behavior of gravelly soil. A triple pane mold was used to separate the core material from the peripheral sand layer (Fig. 2).



Fig. 2 Specimen preparation

3. RESULTS

3.1 Membrane force

Membrane force correction must be considered for torsional shear tests. To calculate the actual stress applied on the soil, the shear stress measured by the load cell must be corrected for the apparent shear stress induced by the membrane. This correction is significantly more important at larger shear strains as point out by previous studies (Chiaro et al., 2015; Umar et al., 2021). Water specimen test was conducted to verify the correction for this test (Fig. 3). The results show that the previous correction is applicable to this study.

3.2 Undrained cyclic behavior

Fig. 4 shows the effective stress paths and torsional shear stress-shear strain relationships. There is a significant difference in the number of cycles (Nc) to reach liquefaction (i.e. $\gamma_{DA}=7.5\%$). For the case with no sand layer, the specimen liquefied in 29 cycles. In contrast, the specimen with sand layer liquefied in only 4.5 cycles. This large disparity in liquefaction resistance may be caused by MP. To confirm the effectivity of the sand layer in eliminating MP in undrained torsional shear tests, existing MP correction method was applied to the no sand layer case. Past studies have proposed D_{50} as a parameter for MP but D_{20} was found to be a better indicator of MP in non-uniform soils (Nicholson et al., 1993). The variables needed for the correction are rebound factor (C), normalized membrane penetration (S), compliance ratio (Crm) and cyclic ratio (Cn). The number of cycles without membrane penetration (No) is obtained by diving Nc by Cn (Table 1 & Table 2). After applying corrections (Tokimatsu & Nakamura, 1987), the MP elimination and MP correction showed good agreement in the case where D_{20} was used (Fig. 5). Additional tests were conducted for the specimen with sand layer to complete the liquefaction curve. This was then compared to the results of plain silica sand #7 (Figs. 4 e & 4f). The results show that number of cycles to cause liquefaction were similar for the silica sand #7 and 30% GC specimen (Fig. 6).

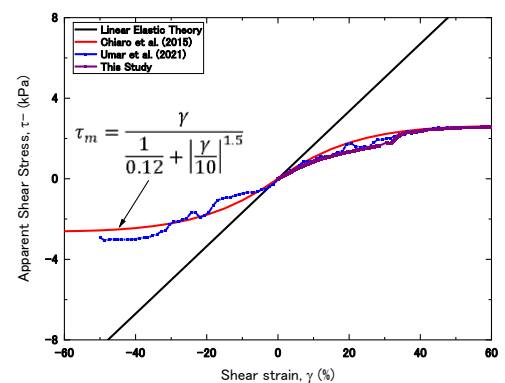


Fig. 3 Membrane force correction

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However, looking at the stress-strain relationship shows that the gravelly soil had a slower strain development. This means that at larger strain levels, gravelly soils would be stronger than sands. In lower strain levels, they would behave like each other.

Table 1. Correction Coefficients (Tokimatsu & Nakamura, 1987)

	D ₅₀	C	S	C _{rm}	C _n	N _c	No	No'
$\gamma_{DA}=7.5\%$	0.36	0.003	0.002	0.309	1.673	29	17	4.5

Table 2. Correction Coefficients (Nicholson et al., 1993)

	D ₂₀	C	S	C _{rm}	C _n	N _c	No	No'
$\gamma_{DA}=7.5\%$	0.263	0.003	0.004	0.673	3.181	29	9	4.5

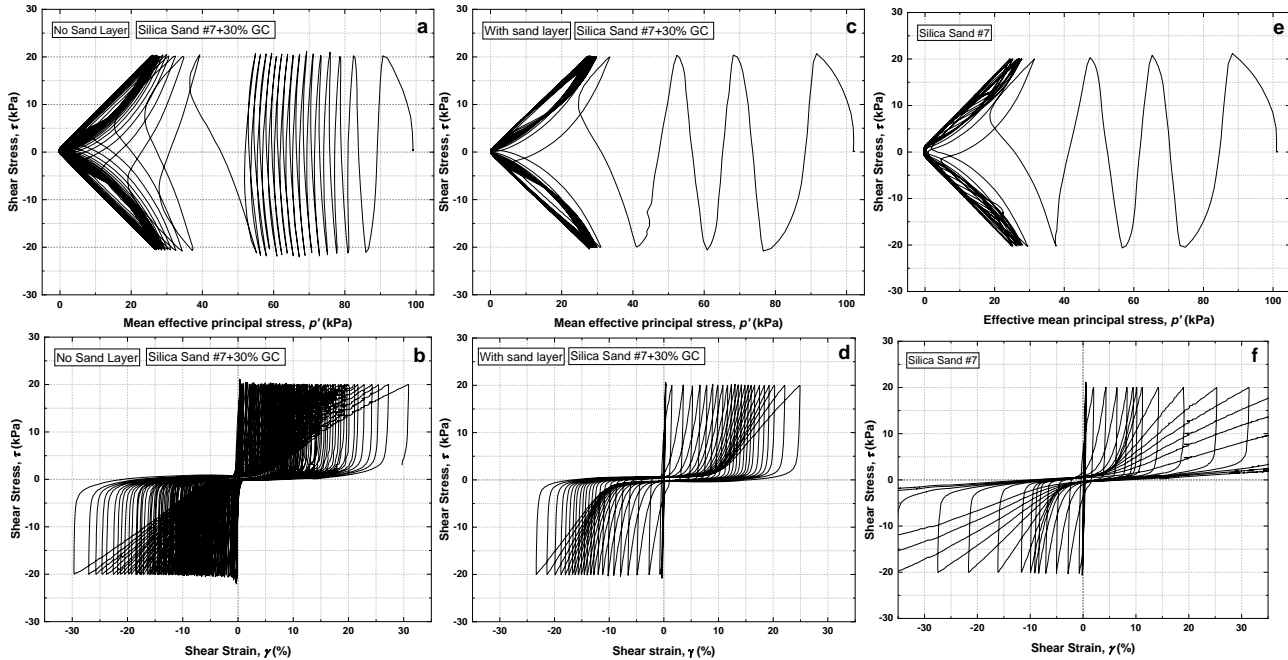


Fig. 4 Test results no sand layer (a & b), with sand layer (c & d), and silica sand #7 (e & f)

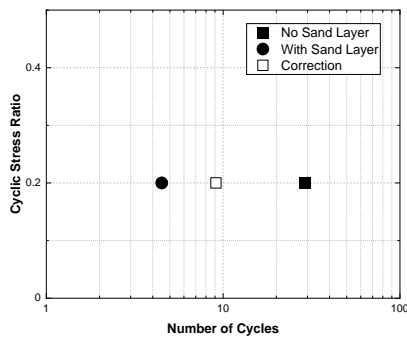


Fig. 5 CSR comparison MP cases

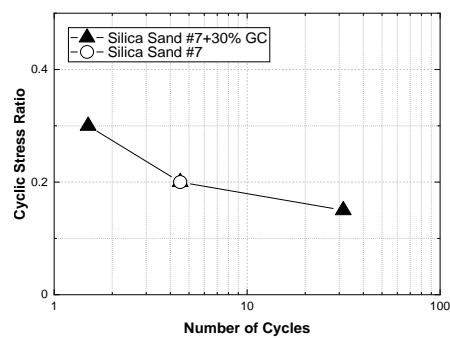


Fig. 6 CSR vs. N_c

5. CONCLUSIONS

Several aspects of gravelly soil element testing were investigated in this study. Membrane force correction was verified and applied for this study. The effect of MP to the undrained cyclic behavior of gravelly sands in torsional shear tests was found to be large if left uncorrected or eliminated. This study makes use of a sand layer to eliminate the MP in torsional shear tests. Although previous studies have suggested D₅₀ has a good correlation with MP for uniform soils, the use of D₂₀ correction in non-uniform soils resulted in reasonable estimation compared to that of the sand layer method. Gravelly soil and silica sand had similar liquefaction resistance in the lower strain level. However, after initial liquefaction the gravel exhibited a slower strain development. To understand the reasons behind this phenomenon, additional tests will be carried out in the future.

ACKNOWLEDGEMENT

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