
POST-LIQUEFACTION VOLUME CHANGE IN MICA-CEOUS SANDY SOILS OF OLD GEDIZ RIVER DELTA

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abstract

Post-liquefaction settlement characteristics of micaceous sands are not well investigated topic. Currently available charts relating post-liquefaction volumetric strain to relative density were developed for clean sand. Estimation of post-liquefaction settlement of micaceous sands, therefore, may stay on the unsafe side, since there is evidence indicating that mica grains could increase volume change tendency. Influence of mica content on post-liquefaction volumetric strain of sand-mica mixtures is studied in this article. Soil samples were prepared at various relative densities. Influence of fine content that could be present in the field was also investigated on tamped natural field samples recovered from boreholes drilled in a highly populated alluvial site known as the Old Gediz River Delta of Izmir. It was found that increasing mica content at a certain relative density resulted in higher volumetric strains as compared with the data on clean sands. It is deduced that influence of mica grains on sand behavior depends on initial void ratio of sand. Effects of mica grains decrease with increasing of relative density. Simple empirical relationships were derived relating mica content and relative density to volumetric strain. It was also noticed that fine content accelerated and increased post-liquefaction volumetric strains.

keywords

sand, mica, non-plastic fines, post-liquefaction volume change

1 INTRODUCTION

One of the consequences of seismic action on saturated sand deposits is post liquefaction settlement. The excess pore water pressure generated during earthquake loading dissipates as the ground motion ceases generating volumetric deformations of which magnitude depends on the severity of the loading, initial void ratio, grain size distribution, grain shape, depth, effective stress state, degree of saturation and fine content [1~6].

It was shown in previous studies that platy mica grains present in sandy soils affect mixture's packing and engineering characteristics [7~9]. Harris et al. (1984) [7] and Lee et al. (2007) [8] have revealed that platy mica grains would decrease shear strength and increase compressibility potential of sands. Harris et al. (1984) [7] showed that mica grains became more influential as their ratio in the mixture exceeded 10% by weight.

Lee et al. (2007) [8] studied influence of mica grain size on sand-mica mixture behavior in triaxial, direct shear and oedometer tests. They found that mica grains would increase global void ratio of the mixture when median mica grain size was equal to or larger than that of the sand. This was attributed to the bridging mechanism generated by the mica grains. This so called bridging effect was more pronounced with growing mica size resulting in a marked reduction in the stability and strength of the mixture. Knowledge on the dynamic behavior of silty sands involving platy grains such as mica flakes is limited. It can be said that it has not been systematically researched in the literature yet. Limited studies showed that mica grains could cause a considerable change in dynamic parameters of the sand such as shear modulus, damping ratio and shear wave velocity [8, 9].

Lee and Albesia (1974) [3] pioneered studies on post liquefaction volume change. In the last few decades, however, extensive experimental research was made regarding post-liquefaction volumetric strains of satu-

rated sands. It was stated that post-liquefaction volume change would attain a maximum value as the cyclic axial strain level exceeds 7~8% in cyclic triaxial tests [1, 3, 10~13]

It has long been known that fine grains were quite effective on liquefaction resistance of coarser soils [2, 4, 14]. The manner how plastic or non-plastic fines affect dynamic shear strength, however, has not been well understood yet. Although plastic fines contribute to the liquefaction resistance, there are cases where dynamic shear strength decreases at certain fine contents [4]. This is especially valid for low plasticity silts as they may separate sand grains enabling them to slide and roll over from each other more easily inside the mixture.

Findings on dynamic behavior of sandy and silty soils that contain platy grains (flake or plate shaped such as mica grain) are limited [8, 9]. In this study, effects of platy and non-plastic fine materials on post-liquefaction volume change of sandy soils are examined by means of a cyclic triaxial compression testing program.

Soil samples utilized throughout the study were obtained from a site well known with deep and saturated liquefiable soil deposits [2, 5]. The study area is located in northern Izmir Bay area on a Quaternary age old river delta (The Old Gediz River Delta). The Gediz River carried its sediments through valleys, which contain abundant amount of mica-schist rocks [15]. Disturbed sand samples from various depths were recovered down to 25 m below surface and transferred to the soil dynamics laboratory where artificial test specimens were prepared. Comprehensive liquefaction tests were made in cyclic triaxial testing device where post-liquefaction volumetric strains were measured at large axial strain levels (i.e. axial strains exceeding 8%) Influence of mica content on post-liquefaction volumetric strains was studied on test samples at different initial void ratios. The testing program also provided information regarding effect of non-plastic fines on post-liquefaction compressional behavior of sands with mica grains.

2 MATERIALS AND EXPERIMENTAL METHODS

Disturbed micaceous silty sand samples were recovered in eight engineering boreholes that were drilled down to ~25 m depth. Locations of the boreholes can be grouped into three sites as shown in Fig. 1. During drillings, Standard Penetration Test (SPT) was performed at 1.5 m depth intervals and test samples were obtained by means of SPT spoon.

Laboratory studies commenced with the physical separation of mica and sand grains in the field samples. Flotation technique as described by Geredeli et al. (1995) [16] was used for this purpose. Accordingly separated mica and sand portions can be seen in Fig. 2 where natural



Figure 1. Study area in the Old Gediz River Delta and locations of boreholes (modified from <http://maps.google.com>).

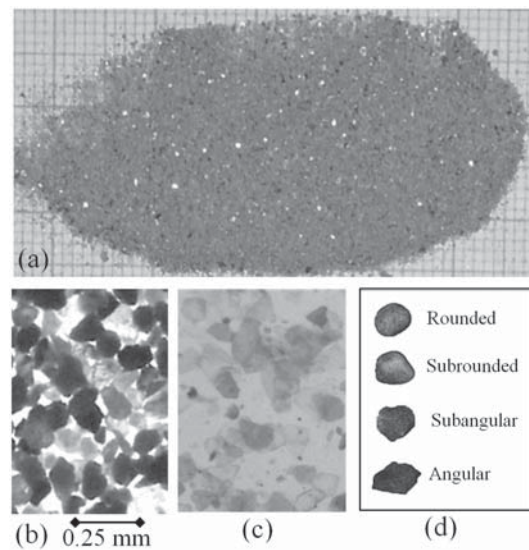


Figure 2. Images of test materials, (a) micaceous natural sand, (b) separated sand, (c) separated mica, (d) angularity chart.

micaceous sand is also given. One may notice in Fig. 2 that sand grains can be characterized as sub-angular.

X-Ray diffraction spectrometer (XRD) counts of artificial sand-mica mixtures were obtained in order to establish a correlation between XRD counts and mica portions. A sample XRD count plot is given in Fig. 3 where peaks

corresponding to mica grains at $2\theta=8.82^\circ$ are marked (2θ : angle of diffracted X-rays). The variation of XRD counts with respect to mica content is shown in Fig. 3. The procedure explained by Aydal (1990) [17] was utilized in order to establish the correlation. A simple linear regression that fit to the data yields Eq. 1:

$$M = (10.5 \times 10^{-3})X_{RD} - 3.7 \quad (1)$$

where M and X_{RD} stand for the mica content and XRD counts, respectively. Coefficient of correlation is equal to $(R^2) = 0.96$.

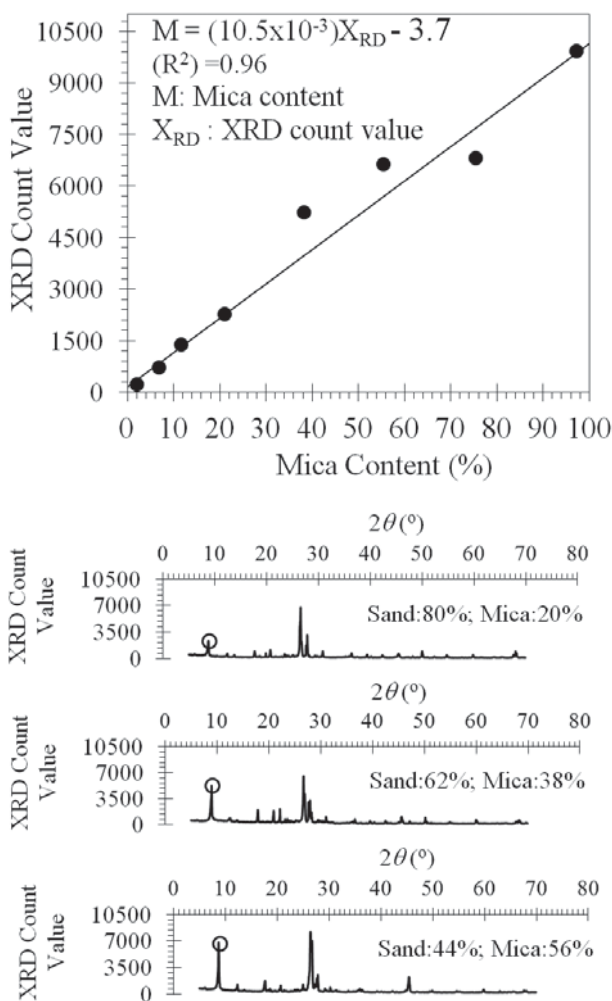


Figure 3. The relation between mica content by weight and XRD count values of test samples.

XRD values of field samples were also determined in order to obtain mica content variation with depth using Eq.1 (Fig. 4). As one can notice in Fig. 4, there is a slight increase in mica content with depth in Site-2 and Site-3 whereas variation is more remarkable to the depth of 12.4 m below ground surface in Site-1.

Fundamental characteristics of test soils were determined by means of standard index and classification tests. The maximum and minimum void ratios of artificially prepared sand-mica mixtures were found following the procedures of ASTM [18]. It can be

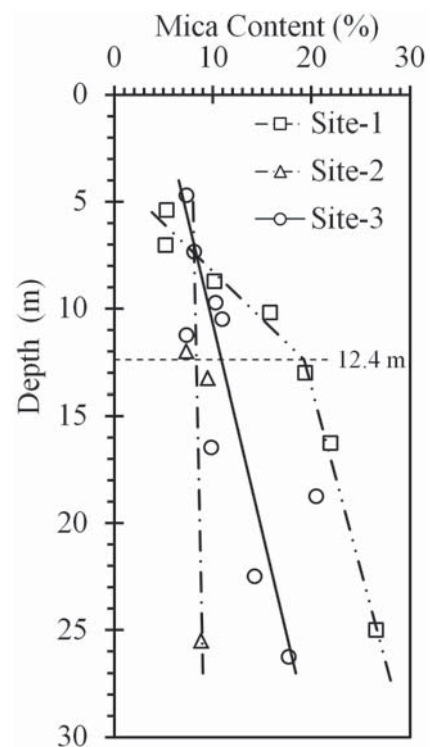


Figure 4. Variation of mica content of field samples with depth in Old Gediz River Delta.

followed in Fig. 5 and Table 1 that physically separated sand and mica samples are poorly graded. The natural field samples exhibit a rather wide variation range. Fig. 5 also contains liquefiable sands reported in the literature [19~23]. One should note that test materials of this study fall in the general range for liquefiable sands.

Great care was spend in order to obtain pure sand and mica samples by means of the floatation technique.

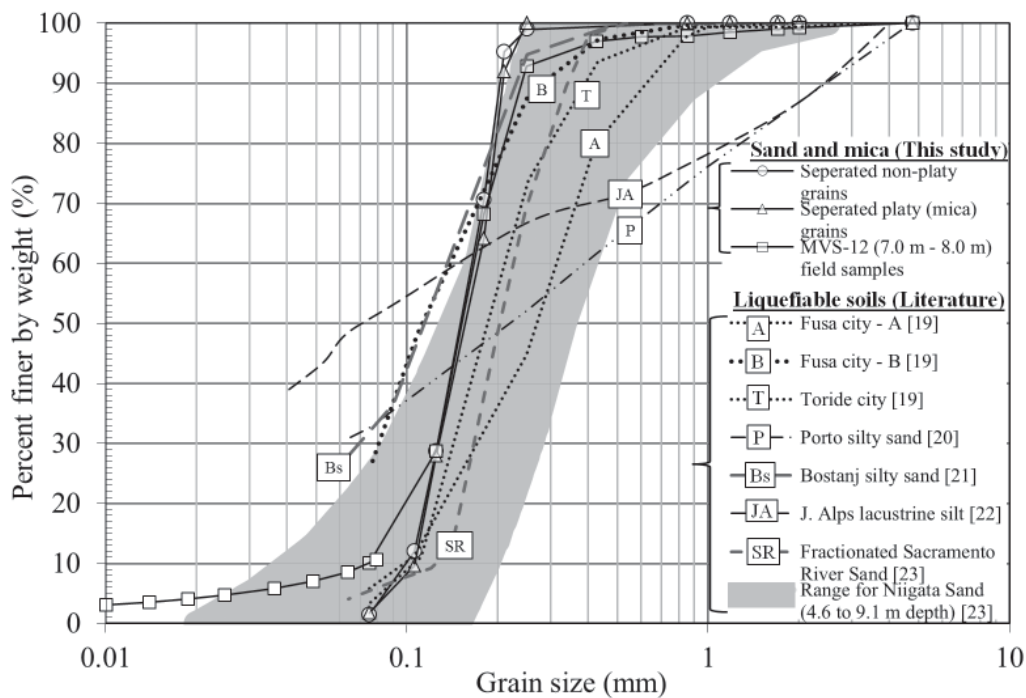


Figure 5. Grain size distribution for liquefiable soils including the test materials of this study.

However, a small amount of mica was left over in sand on the order of 1.5%. Mica grains in proportions of 5, 10 and 20% by weight were mixed with sand. These artificially prepared test mixtures were subject to undrained cyclic triaxial tests at varying relative densities (i.e. ~32%, ~47%, ~64 and ~79%). Similar

tests were also made on natural micaceous sand samples recovered 7.0~8.0 m below ground surface involving 10% non-plastic fine and 7.5% mica. Relative densities of the natural micaceous sand samples happened to be ~32%, ~52% and ~69% on the average.

Table 1. Physical characteristics and index properties of the test materials.

| | Separated Sand (Non-platy grains) | Separated Platy Grains (Mica grains) | MVS-12 Borehole Sample (7.0 ^m -8.0 ^m) | Fine fraction of MVS- 12 Borehole Sample |
|---|--------------------------------------|---|---|---|
| Specific gravity, G | 2.67 | 2.80 | 2.67 | 2.69 |
| Coefficient of uniformity, c_u | 1.67 | 1.64 | 2.30 | 39.70 |
| Coefficient of curvature, c_c | 0.98 | 0.89 | 1.33 | 2.70 |
| Mean diameter, D_{50} (mm) | 0.15 | 0.16 | 0.15 | 0.03 |
| Maximum dry unit weight, γ_{dmax} (gr/cm ³) | 1.54 | 1.23 | 1.75 | 1.17 |
| Minimum dry unit weight, γ_{dmin} (gr/cm ³) | 1.23 | 0.45 | 1.17 | 0.77 |
| Minimum void ratio, e_{min} | 0.74 | 1.28 | 0.53 | 1.28 |
| Maximum void ratio, e_{max} | 1.16 | 5.19 | 1.29 | 2.46 |
| Fines Content, FC (%) | < 2.0 | < 2.0 | 10.6 | 100.0 |
| Plasticity Index, I_p | - | - | Non-Plastic | Non-Plastic |

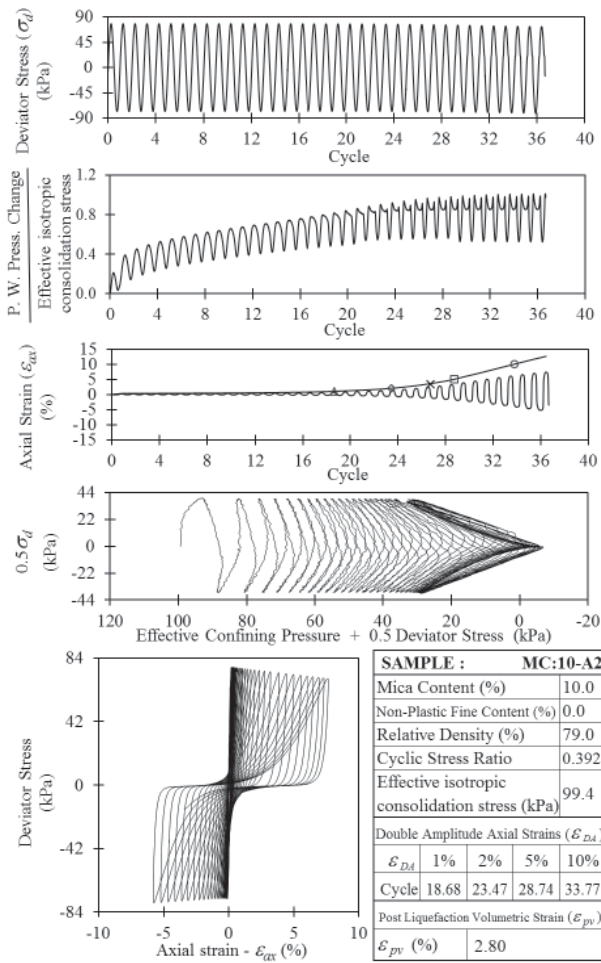


Figure 6. A typical liquefaction test for micaceous sand.

All of the 70 mm x 140 mm test samples were prepared in six layers using moist tamping method. In order to overcome saturation problem, carbon dioxide was circulated through the samples. Skempton's B value [24] was 0.975 or higher in the test. The loading frequency was 0.1 Hertz in cyclic undrained triaxial tests. The load was applied in terms of a sine wave. Samples were isotropically consolidated under 100 kPa prior to cyclic loading. Triaxial tests were terminated as the axial strain exceeded 8% and full liquefaction took place (Fig. 6). Following termination of the test, drainage was allowed and post-liquefaction volumetric strains (ε_{pv}) were measured. Axial strains (ε_{ax}) were transformed to shear strains (γ) by means of Eq. 2.

$$\gamma = (1 + \nu) \epsilon_{ax} \quad (2)$$

where Poisson's ratio (ν) is equal to 0.5 for undrained condition.

3 TEST RESULTS AND DISCUSSIONS

Post-liquefaction volumetric strains are plotted with respect to relative density in Fig. 7. The clean sand curve developed by Ishihara and Yoshimine (1992) [1] constitutes a lower bound for the results of this study. Multiple linear correlation study yields the following relationship among relative density (D_r), mica content (M), and post-liquefaction volumetric strain (ε_{pv}):

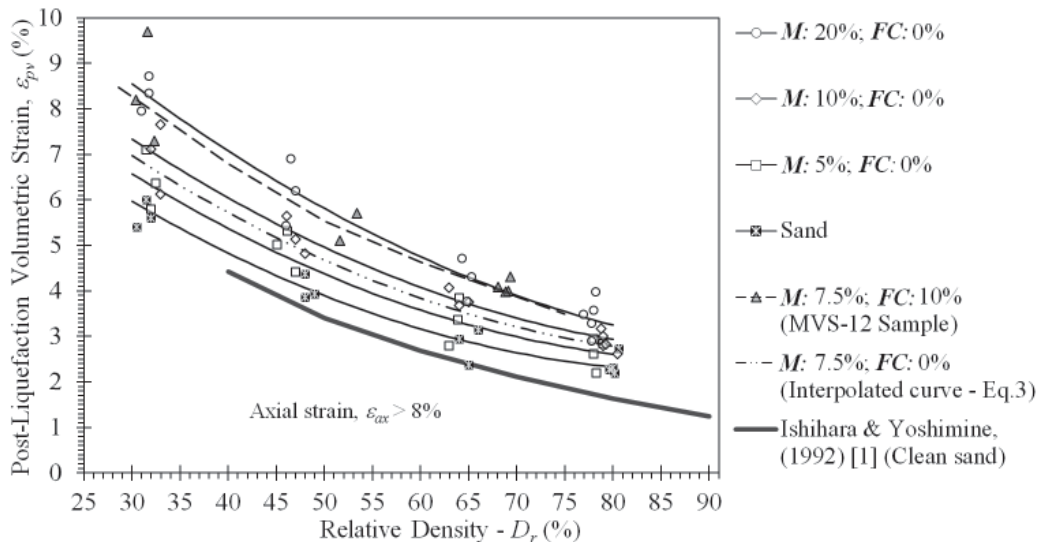


Figure 7. Post-liquefaction volumetric strain (ε_{pv}) of sand-mica mixtures and MVS-12 field sample which contains 7.5% mica and 10% non-plastic silt.

$$\varepsilon_{pv} = 10.28 - 0.1835D_r + 0.2387M + 0.00103D_r^2 - 0.0018D_r \times M - 0.0021M^2 \quad (3)$$

where D_r , M , ε_{pv} are expressed in percentage. Adjusted coefficient of correlation (R^2_{adj}) is found as 0.95.

Comparison of the volumetric strains of MVS-12 samples involving 7.5% mica and 10% non-plastic silt with the interpolated data using Eq. 3 corresponding to sand containing 7.5% mica with no fines shows that presence of non-plastic silts considerably increases post-liquefaction strains. One may note that the data obtained in this study are within the bounds of the literature. Influence of mica grains on volumetric strains is on the same order with that of the silt.

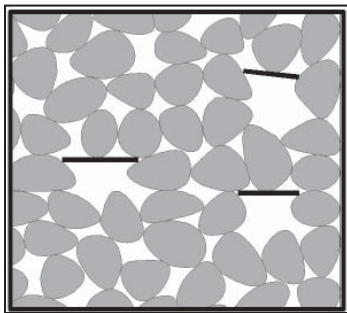


Figure 8. Bridging effect of the mica grains.

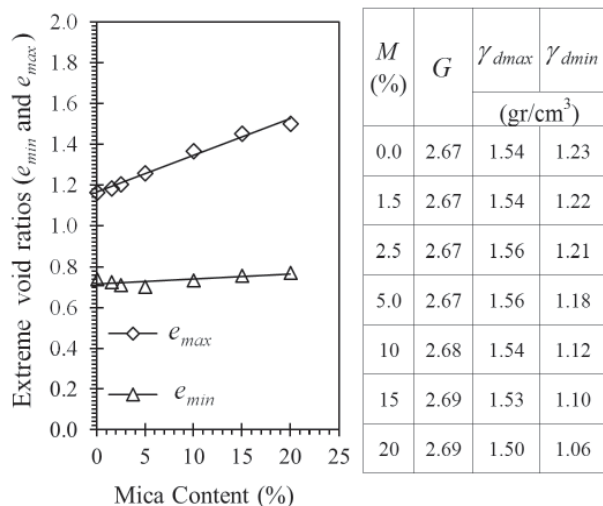


Figure 9. Maximum and minimum void ratios are plotted versus mica content with corresponding dry unit weights.

The fact that mica grains increase post-liquefaction volumetric strain at a certain relative density may be attributed to the bridging effect [8, 25] as shown in Fig. 8. It may be said that platy mica grains force the global void ratio to increase considerably by generating larger size voids inside the sand-mica mixture. This effect is more visible for loose samples. Larger number of bridges appears to collapse as compaction energy increases to form denser samples. This behavior may also be followed in Fig. 9.

Post-liquefaction volumetric strain of the Old Gediz River Delta sand sample containing non-plastic fine material is higher than that of the clean sand sample at same relative density containing same amount of mica. When post-liquefaction volumetric strain curve of clean sand for 7.5% mica content is compared with that of field samples containing 7.5% mica and 10% non-plastic fine material (Fig. 7), it can be seen that non-plastic fine material causes an increase in post-liquefaction volumetric strain. For instance, volumetric strains corresponding to relative density, $D_r = 40\%$ are determined as 5.7% and 6.8% for clean sand with 7.5% mica content (i.e., not including fine fraction) and MVS-12 field sample, respectively.

Fine material causes an increase in post-liquefaction volumetric strain potential and a decrease in stability of the sand. When grain size distributions of fine and coarse fractions are close to each other, fine grains may locate between contact points of coarse grains. Such fine grains at the contact points of coarse grains cause a decrease in the number of contact points. Therefore, stability of the materials decreases and compression potential of the materials increases. Consequently, fines may cause a decrease in stability and cause an increase in compressibility potential of coarse soils [26, 27]. Chien et al. (2000) [11] explored effects of fine content on post liquefaction settlement in an experimental study. In the study, it is reported that post liquefaction settlement increases with fine content for certain relative densities. This effect was also observed for the MVS-12 (7.0–8.0 m) sample containing 10% non-plastic fine materials.

Increasing trend due to mica content in extreme void ratio is more visible for e_{max} (Fig. 9). Same trend is also observed on variation of volumetric strain with respect to relative density (Fig. 7). These findings show that, mica grains become more effective on sand characteristics when the sample is loose. An increase in relative density reduces influence of mica grains on sand behavior. This indicates that bridging effect of mica grains is shaded with an increase in relative density of sand samples. In other words, in loose samples, more bridges are formed among sand grains by mica flakes.

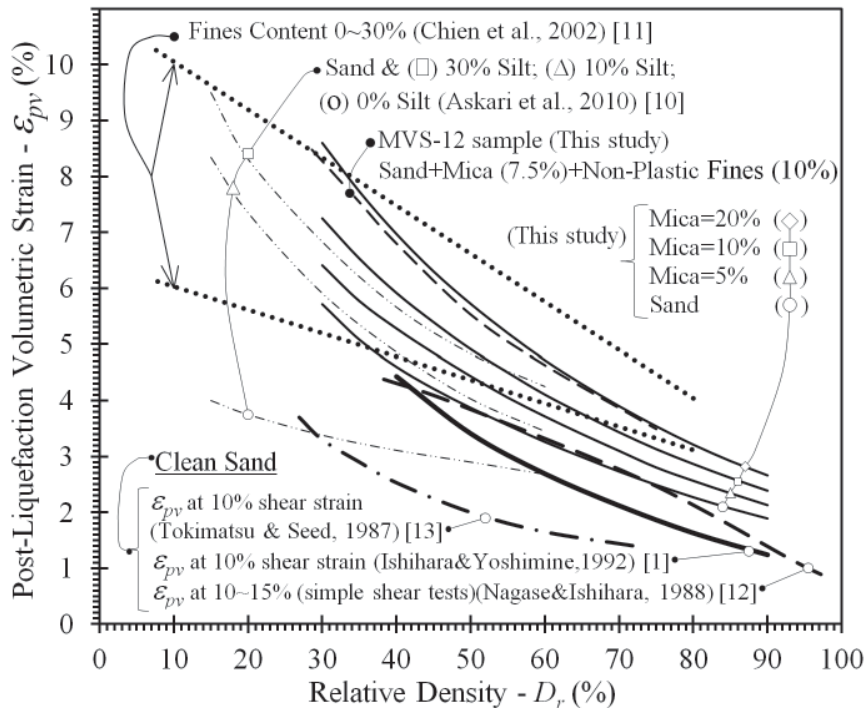


Figure 10. Comparison of test results with literature.

Non-plastic fines have a similar impact on volumetric strain as shown Fig. 7. Test results are plotted in Fig. 10 with the data available in the literature. One may note in Fig. 10 that post-liquefaction volumetric strain curve belonging to the clean sand sample of this study is in agreement with majority of data acquired from the literature. The curves pertaining to sands involving mica flakes demonstrate higher volumetric strains.

4 CONCLUSIONS

Platy mica grains and non-plastic fine materials cause a considerable increase in post-liquefaction volumetric strain of sandy soils. Test results of this study indicate that mica grains and fine materials have more effect on sand behavior for loose uniform fine sand. Mica influence on volumetric strain may be attributed to the formation of bridges among sand grains resulting in large size voids beneath platy mica grains. The effect of mica grains on sand behavior is less pronounced as relative density increases. It is thought that higher tamping effort applied to soil samples to increase the relative density results in smaller amount of mica bridges.

The relationship (Eq. 3) between relative density, mica content and post-liquefaction volumetric strain may be helpful in estimating such post-liquefaction settlement.

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