AN EXPERIMENTAL STUDY ON EFFECT OF PLASTIC FINES CONTENT ON LIQUEFACTION PROPERTIES OF SAND

S.Eswara Rao¹, Vilbin Varghese², S.Patel³

ABSTRACT

Soil liquefaction is one of the most common geohazards that is often the root cause of damage and disruption to the civil infrastructure systems. It has been reported in the literature that the effect of low fraction of plastic fines within sand matrix on liquefaction resistance is not clearly understood. In this paper an attempt has been made and a series of stress controlled cyclic triaxial test were carried to investigate the effect of low plastic fines on pore pressure generation in sand and liquefaction resistance of sand as well. In this study, clean sand was mixed with 10%, 20%, 30%, and 40% plastic fines. The main parameter varied in this study was amount of fines where the observed parameter was pore water pressure generation. The results showed that liquefaction resistance tended to decrease initially for 10% fines and thereafter this trend is reversed i.e. liquefaction resistance increases with increasing of fines. The factor of safety against liquefaction was also calculated in this study.

Keywords: Liquefaction, Plastic fines, Pore pressure, cyclic shear stress ratio (CSR).

1. INTRODUCTION

Soil liquefaction is one of the most interesting phenomena in geotechnical engineering that has been under research for decades. Its consequences may be catastrophic whether it is caused by seismic or static loading. Liquefaction is mainly occurs due to an increase in excess pore water pressure and a corresponding decrease in effective stress in a saturated soil deposit. Study on liquefaction of sands started greatly after the Niigata Earthquake of 1964 and the Alaska Earthquake of 1964 which caused dramatic damages due to liquefaction. Most of the earlier research was focused on clean sands with an idea that the presence of fines in a sand deposit resists the development of pore water pressure. However, Kishida et al. reported liquefaction of soils with up to 70% fines and 10% clay fraction during Mino-Owar, Tohankai and Fukui earthquakes. Tohno and Yasuda et al. reported that soils with fines up to 90% and clay content of 18% exhibited liquefaction during the Tokachi–Oki earthquake of 1968. More recently, researchers have focused on the effect of fines content on liquefaction potential with the realization that most soil deposits contain some plastic or non-plastic fines. This study focuses on using

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stress-controlled, cyclic triaxial testing to evaluate the effect of plastic fines (clays) on the excess pore pressure response and factory of safety against liquefaction for concern soil.

2. RESULTS AND DISCUSSIONS
The results obtained from this study noted that for sand +10% plastic fines the amount pore pressure generated is more compared to all, for remaining combinations the amount of generated excess pore water is low. And it also noted that for 20% plastic fines the decrement of pore water pressure is less and not that much significant whereas for 30% and 40% plastic fines the decrement is more and noticeable. The final trend of pore pressure with plastic fines was shown in figure 1 as well as final trend of cyclic resistance with plastic fines was shown in figure 2.

![Fig.1 Variation of pore pressure with plastic content (%)](image1)

![Fig. 2 Variation of cyclic resistance with plastic fines content (%)](image2)

3. SUMMARY AND CONCLUSIONS
1. The amount of generated excess pore water pressure is found to be more for 10 % plastic fines only.

2. With increasing of fines more than 10%, the generated pore water pressure is observed to be low and the decrement was about 15% for 20% fines and about 40% for 40% fines compared to 10% fines.

3. The reason for above behavior is mainly due to that 10% plastic reduces the dilatant tendency of the sand–clay mixture, and consequently reduces its resistance to cyclic loading. And one more thing that the clay particles typically have lower friction angles than the sand, the presence of these particles may make it easier for the sand grains to slide past each other, thus requiring less work to liquefy the soil.

4. REFERENCES

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ABSTRACT: Soil liquefaction is one of the most common geohazards that is often the root cause of damage and disruption to the civil infrastructure systems. It has been reported in the literature that the effect of low fraction of plastic fines within sand matrix on liquefaction resistance is not clearly understood. In this paper an attempt has been made and a series of stress controlled cyclic triaxial test were carried to investigate the effect of low plastic fines on pore pressure generation in sand and liquefaction resistance of sand as well. In this study, clean sand was mixed with 10%, 20%, 30%, and 40% plastic fines. The main parameter varied in this study was amount of fines where the observed parameter was pore water pressure generation. The results showed that liquefaction resistance tended to decrease initially for 10% fines and thereafter this trend is reversed i.e. liquefaction resistance increases with increasing of fines. The factor of safety against liquefaction was also calculated in this study.

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1. INTRODUCTION

Soil liquefaction is one of the most interesting phenomena in geotechnical engineering that has been under research for decades. Its consequences may be catastrophic whether it is caused by seismic or static loading. Liquefaction is mainly occurs due to an increase in excess pore water pressure and a corresponding decrease in effective stress in a saturated soil deposit. Study on liquefaction of sands started greatly after the Niigata Earthquake of 1964 and the Alaska Earthquake of 1964 which caused dramatic damages due to liquefaction. Most of the earlier research was focused on clean sands with an idea that the presence of fines in a sand deposit resists the development of pore water pressure. However, Kishida et al. reported liquefaction of soils with up to 70% fines and 10% clay fraction during Mino-Owar, Tohankai and Fukui earthquakes. Tohno and Yasuda et al. reported that soils with fines up to 90% and clay content of 18% exhibited liquefaction during the Tokachi–Oki earthquake of 1968. Soils with up to 48% fines and 18% clay content were found to have liquefied during the Hokkaido Nansai–Oki earthquake of 1993. Seed et al. have recommended that for sands containing less than 5% fines, the effect of fines may be neglected for sands containing more than 5% fines, the liquefaction potential decreases. More recently, researchers have focused on the effect of fines content on liquefaction potential with the realization that most soil deposits contain some plastic or non-plastic fines. This study focuses on using stress-controlled, cyclic triaxial testing to evaluate the effect of plastic fines (clays) on the excess pore pressure response and factor of safety against liquefaction for concern soil.

Generally two methods are employed to examine the excess pore pressure response of soils as reported in the literature. Lee and Albaisa (1974) suggested examining the pore pressure response against the cycle ratio (i.e. the ratio of cycles of
loading to the cycles of loading required for initial liquefaction). The curves obtained by plotting excess pore pressure ratio against cycle ratio fell within a relatively narrow band for a wide range of relative densities and consolidation pressures. The excess pore water pressures may also be analyzed in terms of the strains required to generate them as suggested by Dobry et al. (1982). Significant research have been carried out in the past by various researchers on the pore water pressure generation of clean sands as well as sands with some amount of fines, but the manner in which the presence of fines in a sand affects the pore pressure response and in turn the cyclic resistance behaviour is a matter of discussion until now.

2. REVIEW OF PAST LABORATORY WORKS

The effects of fine contents and plasticity on liquefaction or shear strength of sandy soils have been investigated extensively (Ishihara et al. 1980; Garga and McKay 1984; Horsi et al. 1984; Tronsco and Verdugo 1985; Erten and Maher 1995; Puri et al. 1996; koester1994; Thevanayagam 1998; Tianqiang and Prakash 1999; Guo and Prakash 1999; Polito 1999; Bouferra and Shahrour 2004; Sadek and Saleh 2007; Chang and Hong 2008; Tsai et al. 2010). Koester (1994) presented data from stress-controlled triaxial testing on reconstituted samples of sand/silt/clay mixtures. Specimens were tested at a constant overall void ratio representing 50% relative density for the clean sand and the plasticity index (PI) of the fines ranged from 4 to 40. The results from this study indicated that the cyclic strength generally decreases with increasing fines content up to 20% fines, after which the cyclic strength increases. Similar results were found for different sands and fines with different PI.

El Hosri et al. [9] present data regarding the rate of excess pore pressure development from testing of undisturbed samples of silts and clayey silts with PI less than 15. Considering the development of excess pore pressure as a function of the cycle ratio (N/NL where N = cycle number and NL = number of cycles to liquefaction) during stress controlled testing, they found that the silts initially displayed a higher rate of pore pressure generation than sands, but that this rate decreased significantly after a pore pressure ratio of about 0.8. For these silts, which had 60–100% fines, the cyclic strength increased with increasing PI.

Tianqiang and Prakash (1999) synthesized data from various studies on the liquefaction potential of undisturbed and reconstituted silts and silty clays. They concluded that PI is an important parameter affecting the liquefaction resistance of soils, with the cyclic strength decreasing with increasing PI at low level of plasticity (PI = 0–5), but increasing with increasing PI at larger levels of plasticity (PI ≥ about 10).

Bouferra and Shahrour (2004) also showed that from a cyclic triaxial test using sand containing up to 15% clay, the liquefaction resistance decreased as the clay content increased. They insisted that small amounts of clay contents within sand matrix decreased the dilation of an entire specimen. However, in most cases the plasticity of the entire specimen did not vary significantly because a small amount of plastic fine was included. The effect of the plasticity of the fines on liquefaction behavior has not been clearly understood, and more research about the types of fines and their plasticity is necessary (Sadek and Saleh 2007).

3. EXPERIMENTAL PROGRAM

3.1 Materials Used

The base sand used in this study was locally available construction sand in surat region. It has a maximum grain size of 2 mm, and a minimum grain size of 0.150 mm. The specific gravity of sand material used in this study was 2.65. The plastic fines used in this study were derived from the fine-grained portion of Black Cotton Soils available in SVNIT campus. It has a maximum
grain size of 0.425 mm, a minimum grain size of less than 0.002 mm. The specific gravity of clay fraction is 2.70 and classifies as highly plastic clay (CH) with a liquid limit of 60.26 %, a plastic limit of 27.19%, and a plasticity index of 33.07. The grain size distribution curve is as shown in figure 1. Sand–silt mixtures were prepared by adding non-plastic silt in various percentages (by weight of total soil) to the clean sand i.e. like 60% sand +40% plastic fines, 70% sand +30% plastic fines, 80% sand +20% plastic fines and 90% sand +10% plastic fines. The index properties are given in table 1 for both sand and plastic fines.

Table 1 Properties of Sand and Plastic fines

<table>
<thead>
<tr>
<th>Index properties</th>
<th>Sand</th>
<th>Plastic fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Grain Size D_{50} (mm)</td>
<td>0.8936</td>
<td>0.15</td>
</tr>
<tr>
<td>Uniformity Coefficient (C_u)</td>
<td>4.37</td>
<td>2.91</td>
</tr>
<tr>
<td>Minimum Index Density (kN/m^3)</td>
<td>14.98</td>
<td>12.14</td>
</tr>
<tr>
<td>Maximum Density (kN/m^3)</td>
<td>17.30</td>
<td>17.14</td>
</tr>
<tr>
<td>Minimum Void Ratio (e_min)</td>
<td>0.531</td>
<td>0.57</td>
</tr>
<tr>
<td>Maximum Void Ratio (e_max)</td>
<td>0.769</td>
<td>1.22</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.65</td>
<td>2.70</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>-</td>
<td>60.26</td>
</tr>
<tr>
<td>Plastic Limit</td>
<td>-</td>
<td>27.19</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>-</td>
<td>33.07</td>
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<tr>
<td>Free Swell Index</td>
<td>0</td>
<td>66.67</td>
</tr>
<tr>
<td>USCS Classification</td>
<td>SP</td>
<td>CH</td>
</tr>
</tbody>
</table>

3.2 Sample Preparation:

Soil specimens used in this study were of 50 mm in diameter and 100 mm in height. The specimens were formed by using dry deposition method. The oven dried soil (quantity by weight) was filled into the rubber membrane lined split mould, which was fixed to the pedestal of the base plate, by means of a funnel having a nozzle of 12 mm diameter with a long spout. Each specimen was prepared in three layers. Depending upon the desired relative density corresponding to any approach, each layer was subjected to pre-assessed number of tamping blows in a symmetrical pattern from outside the specimen mould. Every care was taken to maintain a uniform density over the entire height of the specimen. The specimen was formed carefully with maximum achievable accuracy.

Fig. 1 Particle size distribution curve

3.3 Saturation and Consolidation

Once the preparation of the specimen was complete and the specimen was formed, initial saturation of the specimen was done by passing carbon dioxide followed by deaired water through the specimen. After a desired volume of water was collected, the specimen was saturated with sufficient back pressure till it was ensured that the Skempton’s B parameter was greater than 95%. The specimens were then isotropically consolidated to an effective confining stress of 100 kPa. The duration for the process of consolidation was varied from about 4 minutes (for clean sands) to about 30 minutes (for sand+ 40% fines).

3.4 Cyclic Triaxial Testing Equipment:

The pore pressure response of sand–silt mixture specimens was studied by performing undrained cyclic triaxial tests on isotropically consolidated specimens. Testing was carried out using state of
the art cyclic triaxial testing apparatus. The equipment consists of a triaxial chamber, an LVDT to measure the vertical displacement, a submersible load cell of 5 kN capacity, and three transducers to measure the volume change, chamber pressure, and pore water pressure. The loading system consists of a load frame and hydraulic actuator capable of performing both static and dynamic (strain-controlled as well as stress-controlled) tests with a frequency range of 0.01–10 Hz, employing built-in sine, triangular and square wave forms. The equipment is computerized and servo-controlled.

4. RESULTS AND DISCUSSIONS

4.1 Typical result

The results of a typical cyclic triaxial test, performed on a specimen with 10% plastic fines content to a constant gross void ratio (e) of 0.65 and loaded at a cyclic stress ratio of 0.25 are presented below. Here the number of cycles is fixed to 100 and a constant Deviator stress is applied to the specimen to generate the excess pore water pressure. In this study the behaviour between deviator stress versus cycles of loading, axial strain versus cycles of loading and excess pore water pressure versus cycles of loading were taken for analysis.

In figure 3-5, the typical test results of sand +10% plastic fines were shown. The constant deviator stress was applied to the specimen to generate the excess pore water pressure and that is shown in fig 3. The corresponding axial strain induced in the specimen was presented in fig.4 against cycles of loading. It is noted that the specimen was achieved 80% excess pore water pressure at the 100th cycle of uniform loading. The pore water pressures generated in the specimen as a result of the induced axial strains was presented in Fig.5. It may be seen in these figures that the deviator stress remained unaltered till the end of the test. The axial strain development on the specimen remained very less at initial cycles of loading but it drastically increased towards the end. This drastic increase in axial strain is seen to start corresponding to around 60-70% excess pore water pressure generation due to a drastic reduction in stiffness of the specimen as a result of increased excess pore water pressure. Similar observation was made in all the tests corresponding to any approach and fines content.

4.2 Effect of Plastic Fines content on Liquefaction Resistance:

A series of cyclic triaxial tests were performed in order to determine the effects which increased plastic fines content upon the liquefaction resistance of soils. The specimens were prepared at
a constant void ratio and relative density and tests were done on sand and sand plastic fines mixtures. Loading conditions were CSR = 0.25 and Deviator stress = 50 kPa, frequency = 0.5 Hz and $\sigma_3c = 100$ kPa. The pore pressure generation for all sand and sand plastic fine mixtures were shown in figure 6.

The pore pressure generation for all sand and sand plastic fine mixtures were shown in figure 6.

4.3 Final Trend of Cyclic Resistance with Addition of Plastic Fines

From previous studies it is noted that the addition of plastic or clayey fines is widely thought to increase the liquefaction resistance of sand. While the addition of even small amounts of fines is believed to increases the liquefaction resistance of sand, the addition of sufficient clayey fines is even thought to make a soil non-liquefiable.

But the results obtained from this study noted that for sand +10% plastic fines the amount pore pressure generated is more compared to all, for remaining combinations the amount of generated excess pore water is low.
And it also noted that for 20% plastic fines the decrement of pore water pressure is less and not that much significant whereas for 30% and 40% plastic fines the decrement is more and noticeable. The final trend of pore pressure with plastic fines was shown in figure 7 as well as final trend of cyclic resistance with plastic fines was shown in figure 8.

The basic reason for the above behaviour is mainly due to any one of the following reasons, increase in the fines content up to 10-15% reduces the dilatant tendency of the sand–clay mixture, and consequently reduces its resistance to cyclic loading. This result was confirmed with cyclic tests, which clearly show that the increase in the fines content in the range 0–15% leads to a significant reduction of the soil resistance to liquefaction.

The decrease in cyclic resistance that occurs when small amounts of clay are added to sand may have an explanation on a mechanical basis also. When small amounts of clay are added to the sand the clay particles may either adhere to the surface of the sand particles or be located between the normal sand grain to sand grain points of contact. Because the clay particles typically have lower friction angles than the sand, the presence of these particles may make it easier for the sand grains to slide past each other, thus requiring less work to liquefy the soil.

4.4 FACTOR OF SAFETY CALCULATION

The CSR applied to all cases is of 0.25 and the cyclic resistance ratio (CRR) is defined as cyclic stress ratio required to causing excess pore water pressure of 50 kPa in 100 numbers of cycles.

Factor of safety for sand = \( \frac{\text{CRR}}{\text{CSR}} = \frac{0.169}{0.25} = 0.676 \)

Factor of safety for sand+ 10% plastic fines = \( \frac{0.131}{0.25} = 0.524 \)

Factor of safety for sand+ 20% plastic fines = \( \frac{0.1535}{0.25} = 0.614 \)

Factor of safety for sand+ 30% plastic fines = \( \frac{0.255}{0.25} = 1.02 \)

Factor of safety for sand+ 40% plastic fines = \( \frac{0.266}{0.25} = 1.064 \)

From the above calculations it was observed that factor of safety was more than one in case of sand+ 30% plastic fines and sand+40% plastic fines.
5. SUMMARY AND CONCLUSIONS

The effect of plastic fines content was analysed by conducting a series of cyclic triaxial tests on soil with various combinations of plastic fines. The results were summarized as given below.

1. The amount of generated excess pore water pressure is found to be more for 10% plastic fines only.

2. With increasing of fines more than 10%, the generated pore water pressure is observed to be low and the decrement was about 15% for 20% fines and about 40% for 40% fines compared to 10% fines.

3. The reason for above behaviour is mainly due to that 10% plastic reduces the dilatant tendency of the sand–clay mixture, and consequently reduces its resistance to cyclic loading. And one more thing that the clay particles typically have lower friction angles than the sand, the presence of these particles may make it easier for the sand grains to slide past each other, thus requiring less work to liquefy the soil.

4. The factor of safety against liquefaction was found to be more than one in case of sand + 30% plastic fines and sand + 40% plastic fines.

6. REFERENCES


