Effect of Non-Plastic Fines on Liquefaction Resistance and Pore Pressure Behavior of Fine Sand

C. Hanumantharao, K L University, India

G. V. Ramana, Indian Institute of Technology Delhi, India

ABSTRACT

The liquefaction behavior of sand-silt mixtures is highly debatable. Various conflicting opinions are prevalent in literature, as no unique test parameter exists that can be used to express the effect of non-plastic fines on liquefaction resistance of sand. Thus, the present study critically reviews and summarizes the effect of non-plastic fines on liquefaction resistance of sand along with the test parameter and the range of fines contents used to arrive at the given conclusion. In addition, several stress controlled cyclic triaxial tests were conducted on fine Yamuna sand with varying percentages of non-plastic silt. In the current study, relative density has been adopted as the standard test parameter, as it can be directly correlated to the standard penetration value in the field. Results shows that if non-plastic fines are added to sand, liquefaction resistance increases below the limiting silt content and then liquefaction resistance decreases as further addition of fines when relative density is constant. As long as the fines are non-plastic, the pore pressure behavior is similar to that of sands and can be represented with the simple models.

Keywords: Cyclic Strength, Cyclic Triaxial Test, Fine Sand, Liquefaction Resistance, Non-Plastic Fines, Pore-Water Pressure

1. INTRODUCTION

Liquefaction has become one of the most interesting, complex and controversial topic of research for geotechnical engineers, especially after the Alaska and Nigata earthquakes in 1964. Most of the earlier studies on liquefaction have focused on clean sands containing little or no fines. However, a number of case histories have revealed that silty sands are also prone to liquefaction (Kuribayashi & Tatsuoka, 1975; Seed et al., 1983; Chang, 1990; Yamamuro & Lade, 1998). Recent laboratory test results have demonstrated that silty sand/sandy silt is more liquefiable than sand (Vaid et al., 1990; Baziar & Dobry, 1995; Lade & Yamamuro, 1997; Zlatovic & Ishihara, 1997; Yamamuro & Lade, 1998; Amini & Qi, 2000; Xenaki & Athanasopoulos, 2003).

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Despite these numerous reported results, the effect of non-plastic fines on liquefaction resistance is not very well understood as the problem lies in the fact that the reported results are conflicting and full of ambiguous. While several researchers (Dezfulian, 1982; Tokimatsu & Yoshimi, 1983; Seed et al., 1983; Kuerbis et al., 1988; Chang, 1990; Pitman et al., 1994; Amini & Qi, 2000) reported that increasing the fines content increases the liquefaction resistance, other researchers also reported that increasing the fines content decreases the liquefaction resistance. Shen et al. (1977) and Lade & Yamamuro, 1997; Yamamuro & Lade, 1997; Zlatovic & Ishihara, 1997).

Effect of non-plastic silt on liquefaction resistance of sand is better understood in terms of sand skeleton/ intergranular void ratio rather than silt content (Shen et al., 1977; Troncoso & Verdugo, 1985; Kuerbis et al., 1988; Vaid, 1994; Polito & Martin, 2001; Xenaki & Athanasopolous, 2003). When clean sand is mixed with non-plastic silt, the maximum and minimum void ratios as well as the range of void ratios change and highly unstable and compressible particle structures may formed in loose deposits (Lade & Yamamuro, 1997; Yamamuro & Lade, 1997). Some of the specimens tested by Shen et al. (1977) had skeleton void ratios lower than the minimum void ratio of the specimen. Shen et al. (1977) also reported that, the trend of cyclic strength with respect to density changed markedly as the silt content exceeded 20%, an observation that is consistent with the postulated change in fabric at this value of fines content.

Different conclusions about the effect of fines on liquefaction resistance are due to different criteria used for comparison and because of variation in the percentage of fines. While some studies conducted only up to the limiting fines content and concluded that liquefaction resistance increases when relative density is kept constant, others concluded liquefaction resistance decreases when void ratio is kept constant. Also several other studies were conducted for all ranges of fines content but the testing parameters were different. In this study, a critical review of experimental investigations carried out in the past on the behavior of sand mixed with non-plastic fines was made by taking into consideration, the range of percentage fines, parameters used, and their effect on liquefaction resistance as shown in the Table 1. A thorough examination of literature and the preliminary studies on the soil used in the current study revealed that the amount of fines is not the parameter that affects the liquefaction resistance; it is the density of packing which plays the major role as long as fines are non-plastic as observed in Figure 1. If fines are plastic, plasticity index is an essential parameter to study the liquefaction resistance. A combination of particle shape, gradation and density of packing will dictate the resistance against liquefaction.

Undrained stress controlled cyclic triaxial tests were conducted on remoulded samples as per ASTM D5311- 92 (ASTM International, 2004) for different sand-silt mixtures to study the effect of non-plastic fines on liquefaction resistance of fine Yamuna sand and the results obtained further verified/strengthened the findings of the existing literature.

The manner in which excess pore pressure is generated can be examined using stress controlled cyclic tests with uniform loading. Lee and Albaisa (1974) and De Alba et al. (1975) found that the pore pressure ratio \( r_u \) is related to the number of loading cycles:

\[
 r_u = \frac{1}{2} + \frac{1}{\pi} \sin^{-1} \left[ 2 \left( \frac{N}{N_L} \right)^{1/\alpha} - 1 \right] \quad (1)
\]

where \( N_L \) is the number of cycles required to produce initial liquefaction \( (r_u = 1.0) \) and \( \alpha \) is a function of the soil properties and test conditions.
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