Chapter 12
Determination of the Cyclic Properties of Silty Sands

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ABSTRACT
Liquefaction may be triggered by cyclic loading on saturated silty sands, which is responsible of severe geotechnical problems. Development of excess pore water pressure in soil results in a liquid-like behavior and may be the reason of unavoidable superstructural damage. In this study, in order to investigate the behavior of saturated silty sands exposed to cyclic loading under undrained conditions, a systematic testing program of stress-controlled cyclic triaxial tests was performed on specimens of different silt contents, under different loading conditions and environment. The effect of parameters such as silt content on the liquefaction behavior of specimens was studied. Pore water pressure and shear strain curves were obtained for the silty sands. Furthermore, the boundaries existing in the literature on sands are compared with the results current research, on silty sands. Conclusively, the outcomes of this study were useful to develop insight into the behavior of clean and silty sands under seismic loading conditions.

1. INTRODUCTION
While the cyclic behavior of clean sands has been investigated in-depth over the fifty years, this phenomenon in silty sand containing varying amounts of fines, stimulated a real interest in recent twenty years. The number of researches on this subject are quite limited and the studies claim that this type of soil is more susceptible to liquefaction, in comparison with clean sand. However, the reported results are still contradictory due to effect of fines content on the shear strength of silty sands.

The effect of fines content on the cyclic liquefaction potential of sands has been investigated extensively in geotechnical literature. Several investigations in the field shows that the presence of fines increases liquefaction resistance (Seed and Lee 1966; Seed et al., 1985) while laboratory tests results show different trends, for the fine content less than 30% (Koester et al., 1994; Troncoso, 1990). Koester (1990)

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claimed that fine content is more important than the plasticity index (PI), contrary to Ishihara (Ishihara, 1993) and Prakash and Guo (1999), claiming that high plasticity fines might change the liquefaction behavior. Finn et al. (1993) indicated that many of the past studies used different criteria for comparison of the effect of fines on liquefaction resistance, resulting different conclusions.

The effect of fines content on liquefaction resistance are based on mechanisms of deformation in the particle size level. Laboratory test results suggest that fines in small percentages (F.C<30%) take up the space between sand particles without contributing to soil strength. This result in a decrease of global void ratio (e). Thus, liquefaction resistance of soils with the same global void ratio decrease with increasing fines content and not the same intergranular void ratio of the sand skeleton $e_{sK}$, a more representative index of behavior (Polito and Martin, 2001; Thevanayagam, 1998; Thevanayagam and Mohan, 2000; Vaid, 1994). Similarly, for larger fine values, the fines dominate over the sand matrix and the overall behavior depends greatly on the included fines.

Erten and Maher (1995), studied pore pressure generation effect of both plastic and non plastic silty sand. They found the limit fine content up to 30%. They concluded low plasticity silty sand is not significantly effective on pore pressure generation.

El Hosri et al., (1984) showed that increase in plasticity index caused a reduction in liquefaction resistance of silty soil, in a low plasticity index range. They also found that for soils of a high plasticity index range, an increase in plasticity index increases the liquefaction resistance for undisturbed silt-clay mixtures. It is also clear that plasticity index has a considerable effect on liquefaction resistance.

Altun et al., (2005) showed a decrease of liquefaction resistance up to a certain limiting fines content followed by an increase in liquefaction resistance. Amini and Qi (2000) reported that as fines content increases, the cyclic resistance of sand silt mixtures can continuously increase, however, Belkhatir et al., 2010; Stamatopoulos, 2010 found that as fines content is increased, the cyclic resistance of sand silt mixtures can decrease. On the other hand, Koester, 1994; Papadopoulou and Tika, 2008; Polito and Martin, 2001; Xenaki and Athanasopoulos, 2003 observed that increasing fines content, caused reduction in cyclic resistance of sand silt mixtures, up to a certain fines content value and a subsequent increase. Belkhatir et al. (2011) found that the liquefaction resistance decreases with the increase of the intergranular void ratio.

The value of $F_{C_{th}}$ is an important parameter, determining the transition from the sand become effective to the silt become effective of the mixture. It should be mentioned that the threshold fines content value, $F_{C_{th}}$ is depend on sand type, fines type (non-plastic, low plastic, high plastic) as well as global void ratio. For that reason, different conclusions for the effect of fines on the liquefaction resistance of silt sand mixtures may be drawn when using the constant global void ratio approach. Especially, Troncoso (1990) found that the liquefaction resistance of sand fine mixtures decreases with increasing $F_{C_{th}}=30\%$. On the other hand, Xenaki and Athanasopoulos (2003), concluded that the critical value of fines content ($F_{C_{th}}$) is 44%. The resulted reported by Polito (1999) revealed that, for most sand non plastic fine mixtures, threshold value of the fines content ranged between 25%<$F_{C_{th}}<$45%.

At low fine contents, some of the finer grains may remain inactive and float in the void spaces. For that reason, it is very important to use new index parameters such as the intergranular and interfine void ratios to assess the shear strength of silt sand mixtures (Thevanayagam, 1998; Monkul 2005). As a result, two submatrices (coarse-fine grain matrices) are needed to gain insight regarding the influence on stress strain behavior.

The effect of fines content is an important parameter, investigating the cyclic behavior of silty sands. Nevertheless, inconsistent results exist in the literature regarding to the effect of fines content on the
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