8. Liquefaction strength of sands containing fines compared with cone resistance in triaxial specimens

Background:
It is not seldom that sand contains a measurable amount of low-plasticity fines. In such case, liquefaction strength for a given SPT or CPT resistance is normally raised in accordance to fines content \( F_C \) in most of current liquefaction potential evaluations. In contrast, however, laboratory tests show that liquefaction strength of sand having the same relative density \( D_r \) decreases with increasing \( F_C \). Thus, a wide gap remains between the current practice for liquefaction potential evaluation and the laboratory experiment on the modification of the liquefaction strength in sand containing fines despite its importance in design.

Objective:
In order to establish direct correlations for exactly the same sand between cone resistance and liquefaction strength considering the effect of \( F_C \), a systematic experimental study was undertaken, in which a miniature cone penetration test and subsequent undrained cyclic loading test were carried out on the same triaxial test specimen.

An innovative simple mechanism was introduced in a normal cyclic triaxial apparatus (Fig. 1) enabling a miniature cone to penetrate the sand specimen at a constant speed (Fig. 2). Results from the two sequential tests on the same specimen were compared to develop direct correlations between penetration resistance \( q_t \) and liquefaction strength \( R_L \) for sands of various \( F_C \).

Major findings:
In the earlier stage of the research, sand specimens with different \( D_r \) and \( F_C \) were tested to reveal the followings;
1) Cone penetration tests performed prior to cyclic undrained tests have little effect on liquefaction strength of specimens, demonstrating that direct and reliable comparison between penetration resistance \( q_t \) and liquefaction strength \( R_L \) is possible (Fig. 3).
2) For river sand with or without low plasticity fines, a good correlation between relative density and cone resistance has been found. Furthermore, the correlation is basically consistent with previous research on clean sand using a prototype cone despite a large difference in the cone size.

Fig. 1 Photograph (top) and cross-section (bottom) of the modified pedestal in the lower part of the triaxial apparatus

Fig. 2 Penetration length versus time relationships for the miniature CPT

Fig. 3 Comparison of liquefaction strength (\( R_L \) versus \( N_c \) curve) between specimens with or without cone rod.
3) This indicates that liquefaction strength for a given cone resistance is constant despite the difference in fines content, which is contrary to the current liquefaction evaluation practice.

Then a small amount of cement was added to the fines mixed with sand in order to emulate long-time geological effect in short-time laboratory tests;

4) Cone resistance $q_t$ plotted versus the penetration length clearly indicates that $q_t$ increases with increasing $C_c$ under the same fines content $F_c$ (Fig. 4(a)).

5) The stress ratios $R_L$ plotted versus number of loading cycles $N_c$ show obvious increase with increasing $C_c$, though increasing $F_c$ tends to reduce $R_L$ in specimens without cement (Fig. 4(b)) as already demonstrated by previous research.

6) Specimens with higher value of $C_c/F_c$ (emulating longer geological age) under the same $F_c$ tend to give higher liquefaction strength for the same cone resistance, indicating that the aging effect tends to raise the $R_L$ - $q_t$ line from that for short time consolidation (Fig. 5).

7) For the same $C_c/F_c$-value (emulating the same geological age), higher fines content results in higher liquefaction strength for the same cone resistance (Fig. 5), which is consistent with the trend previously found in the field investigation by Suzuki et al. (1995).

8) The liquefaction strength $R_L$ increases more than the $q_t$-value due to chemical bonding between sand particles and this effect is more pronounced for higher fines content even under the same $C_c (=1\%)$ (Fig. 6).

This is why the $q_t$ - $R_L$ curves tend to shift upward due to the increase of fines content in the field, which is not observed for reconstitute soils by short-term consolidation in the laboratory.

**Key papers:**