Pore pressure generation of mon plastic silt-sand mixtures

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ABSTRACT: In the literature, excess pore water pressure generation characteristics of silt-sand mixtures are not clearly explained. In this study, cyclic triaxial tests were carried out on silt-sand mixtures for the investigation of the pore pressure response effects. An experimental programme utilizing around 27 stress controlled cyclic triaxial tests was carried out on the specimens with a diameter of 50 mm and a height of 100 mm at a frequency of 0.1 Hz. Some of the specimens were prepared at constant relative density and the others were prepared at constant gross void ratio. The effect of relative density and confining pressure on the cyclic soil behavior was also studied. The effect of relative density was as expected, but the effect of confining pressure decreased with increasing number of cycle, up to fine content smaller than 25%. All test results show that the previous studies are compatible with the pore water pressure band of sand-silt mixtures.

1 INTRODUCTION

The silt-sand mixtures can liquefy and the amount of excess pore water pressure generated cyclic loading affects its strength and stiffness. Most of the researchers were focused on clean sand with generating of excess pore water pressure but this idea was changed because in the last three decades, liquefaction was occurred in silty sand deposits during the earthquakes. Generations of excess pore water pressure properties of silty sands are completely different because of fine contents.

Two different types of procedure are employed to investigate the excess pore water pressure response of soils as reported in the literature. The excess pore pressure against cycle ratio is suggested by Lee and Albaisa (1974). They made many experiments with different values of consolidation pressures and relative densities, but the excess pore water pressure ratio against cycle ratio was obtained within a narrow range. In addition, Dobry et al. (1982) analysed the excess pore water pressure in terms of strains. The extensive laboratory research are made of the pore water pressure generation of clean sand as well as sand with some amount of fines (Silver and Seed (1971), Dobry (1985), Erten and Maher (1995), Xenaki and Athanasopoulos (2003), Ravishankar (2006)). Some researchers have found cyclic resistance increased with increasing silt content (Chang et al. 1982; Amini and Qi 2000), the others have found cyclic resistance decreased with increasing silt content (Finn et al. 1994), and some of them have found cyclic resistance initial decrease till limiting silt content and thereafter increase (Polito and Martin 2001; Xenaki and Athanasopoulos 2003; Ravishankar 2006). In view of these conflicting conclusions, a detailed laboratory investigation programme was carried out to study the effect of nonplastic fines on the undrained pore water pressure response of silt sand mixtures.

2 EXPERIMENTAL PROGRAMME

2.1 Material

The material used in the testing programme was artificial sand-silt mixtures. Sand-silt mixtures were generated from clean sand and nonplastic silt. Samples were prepared by mixing the sand with at percentages of 11, 15 and 22. The physical properties of tested materials are presented in Table 1. Also, Figure 1 shows the grain size distribution of 3 silt-sand mixtures.

Table 1. Physical properties of Tested Materials

Soil Properties	Mixture 1	Mixture 2	Mixture 3
(D_{10}) mm	0.060	0.058	0.045
(D_{30}) mm	0.180	0.123	0.132
(D_{60}) mm	0.780	0.285	0.250
C_u	13	4.91	5.55
C_c	0.69	0.920	1.55
Soil Type	SM	SM	SM
G_s	2.674	2.695	2.707
e_{min}	0.42	0.44	0.47
e_{maks}	0.85	0.87	0.90

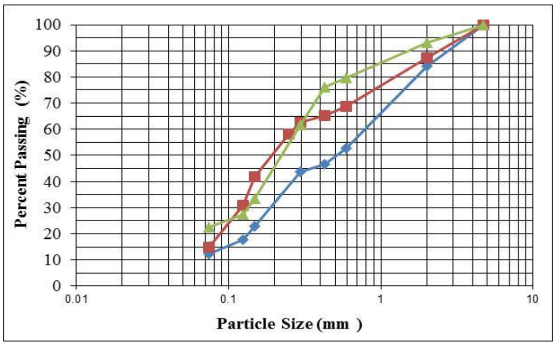

Figure 1. Grain size distributions of materials

2.2 Specimen Preparation, Saturation and Consolidation

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. Each specimen was prepared in 3 layers. Depending on 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. Initial saturation of the specimen was done by passing carbon dioxide followed by de-aired water through the specimen. 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 50 and 100 kPa.

2.3 Experiment Details

The detailed experimental programme corresponding to all approaches and parameter effects are presented in Table 2. The results of around 27 cyclic triaxial tests on specimens with different silt contents have been utilized to understand the pore pressure generation characteristics of sand–silt mixtures in this study.

3 RESULTS AND DISCUSSIONS

3.1 Typical Test Results

The results of a typical cyclic triaxial test, performed on a specimen with 15% silt content prepared to a post consolidation gross void ratio (e_c) of 0.630, σ_0'=100 kPa and loaded at a cyclic stress ratio of 0.134, are presented in Fig. 2. The effective stress path of the specimen is presented in Fig. 2a and 2b where it can be seen that the specimen looses all its strength and stiffness corresponding to 100% excess pore water pressure generation. The constant deviator stress applied to the specimen till 100% excess pore water pressure is reached and this behavior is presented in Fig. 2c. The corresponding axial strain induced on the specimen against the cycles of loading is presented in Fig. 2d. It is noted here that the specimen achieved 100% excess pore water pressure at the 50th cycle of uniform loading. The pore water pressures generated in the specimen as a result of the induced axial strains is presented in Fig. 2c and Fig.2d, respectively.

Table 2. Experimental Programme

Test No	Specimen Size		Mixture No	Gross Void Ratio	Skempton's Parameter	Hücre Basıncı	Back Pressure	Consolidation Pressure	CSR	Cycle Number
	D	H								
	(mm)	(mm)		ec	B	(kPa)	(kPa)	(kPa)		
1	49.83	99.81	1	0.72	1.00	250.7	200.9	49.8	0.1377	7
2	49.74	99.79	1	0.72	0.99	210.2	160.8	49.4	0.2644	2
3	49.8	99.81	1	0.72	0.99	233.7	184	49.7	0.1572	63
4	49.82	99.8	1	0.72	0.97	230.4	181	49.4	0.1158	131
5	49.61	99.57	1	0.72	1.00	221.2	121.3	99.9	0.2134	5.5
6	49.65	99.55	1	0.72	0.98	415.4	316.9	98.5	0.1400	56
7	49.67	99.58	1	0.72	0.99	319.2	220.9	98.3	0.0909	184
8	49.48	99.66	1	0.72	0.97	274.1	175.1	99	0.1213	101
9	49.87	99.9	2	0.63	0.99	264.6	214.2	50.4	0.2549	35
10	49.93	99.88	2	0.63	0.99	301.4	250.5	50.9	0.1759	210
11	49.91	99.89	2	0.63	0.99	250.2	200.6	49.6	0.3665	8
12	50.06	99.87	2	0.63	0.98	300.6	251	49.6	0.2330	2.5
13	50.49	99.77	2	0.63	0.95	400.8	300.2	100.6	0.2734	23
14	49.67	99.75	2	0.63	0.98	275.3	175.7	99.6	0.2095	53
15	50.01	99.79	2	0.63	0.99	200.4	101.3	99.1	0.1570	112
16	49.04	99.77	2	0.63	1.00	128	32	96	0.2107	17.5
17	49.74	99.89	2	0.63	0.97	200.3	100.1	100.2	0.1977	109
18	50.35	99.57	3	0.71	1.00	451.4	351.2	100.2	0.1479	142
19	50.1	99.61	3	0.71	1.00	450.7	350.6	100.1	0.2733	6.5
20	50.77	99.62	3	0.71	0.97	450.2	349.8	100.4	0.2090	31
21	50.25	99.7	3	0.71	0.97	450.4	350.9	99.5	0.1793	350
22	49.79	100.13	3	0.71	1.00	400.1	349.8	50.3	0.2189	575
23	49.97	99.81	3	0.71	1.00	400.7	350.6	50.1	0.4295	16
24	49.97	99.85	3	0.71	1.00	400.5	350.4	50.1	0.3297	20
25	49.94	99.81	3	0.71	1.00	400.8	350.3	50.5	0.2451	31
26	49.94	99.79	3	0.71	1.00	400.3	349.8	50.5	0.1845	650
27	50.84	99.85	3	0.71	1.00	400	350	50	0.4997	14

3.2 Constant Gross Void Ratio Approach

The gross void ratio (e) of a soil specimen is the ratio of the volume of void (V_V) to the volume of the soil solids (V_S) in the specimen. It can be expressed as a function of dry density (γ_d) of the soil specimen and the specific gravity (G_S) of the soil solids. The void ratio (e) of the specimens tested was found to be essentially independent of the silt content, except for the small effect that the amount of silt present has on the specific gravity (G_s) of soil solids. Specimens with various silt contents at constant post consolidation gross void ratios of 0.63, 0.71 and 0.72 were tested at various cyclic stress ratios as seen in Table 2. It is seen that, the number of cycles of loading required for the development of 100% excess pore water pressure (or R_u = 1) varied with silt content, cyclic stress ratio (CSR), and also the gross void ratio of the specimen.

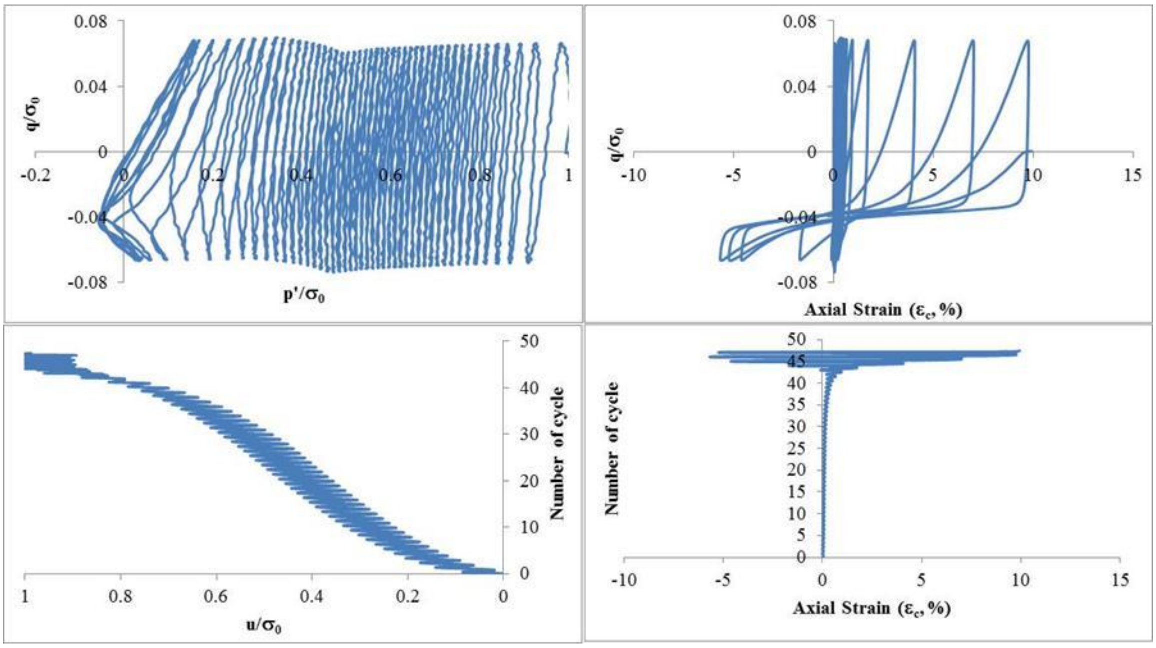

Figure 2. **a)** q/σ_0- p'/σ_0 **b)** q/σ_0- Axial Strain, **c)** Number of cycle-u/σ_0, **d)**Number of cycle- Axial Strain,

3.3 Method Suggested by Lee and Albaisa

Lee and Albaisa accomplished 22 cyclic triaxial tests with varying parameters on Monterey river sand to study the pore pressure response of sand. They varied from loose to very dense soils and confining pressure from 100 to 1300 kPa and cyclic stress ratio from 0.24 to 0.38.They showed that the pore pressure responses against the cycle ratio fall within a relatively narrow band. This investigation was used to study the limitations of this band when non-plastic fines are added to sand. For this purpose, peak pore pressures generated in sand and silt mixture specimens prepared at various relative densities corresponding to constant gross void ratio approaches over a wide range of parameters is presented as a function of cycle ratio (N/N_L) in Fig.3 to assess the upper and lower bound values as suggested by Lee and Albaisa (1974). These values are suggested over a relative density range of 25–70%, confining pressure at a range of 50–100 kPa, frequency is 0.1 Hz, with a silt content range of 11, 15, 22%, and cyclic stress ratio range of 0.0909–0.4997. The values may readily be used for assessing pore pressure generation characteristics of similar sand–silt mixture soil specimens. These values are also compared with that of upper and lower bound values of Monterey sand specimens as suggested by Lee and Albaisa (1974). The upper bound values of Monterey sand appears to be conservative and the upward deviations in upper bound values of sand–silt mixture specimens from that of Monterey sand is because of effect of non-plastic fines. The initial higher peak pore pressure generation, as observed in sand–silt mixture specimens with various silt content, is a special characteristic of this sand implying its high potential to liquefaction.

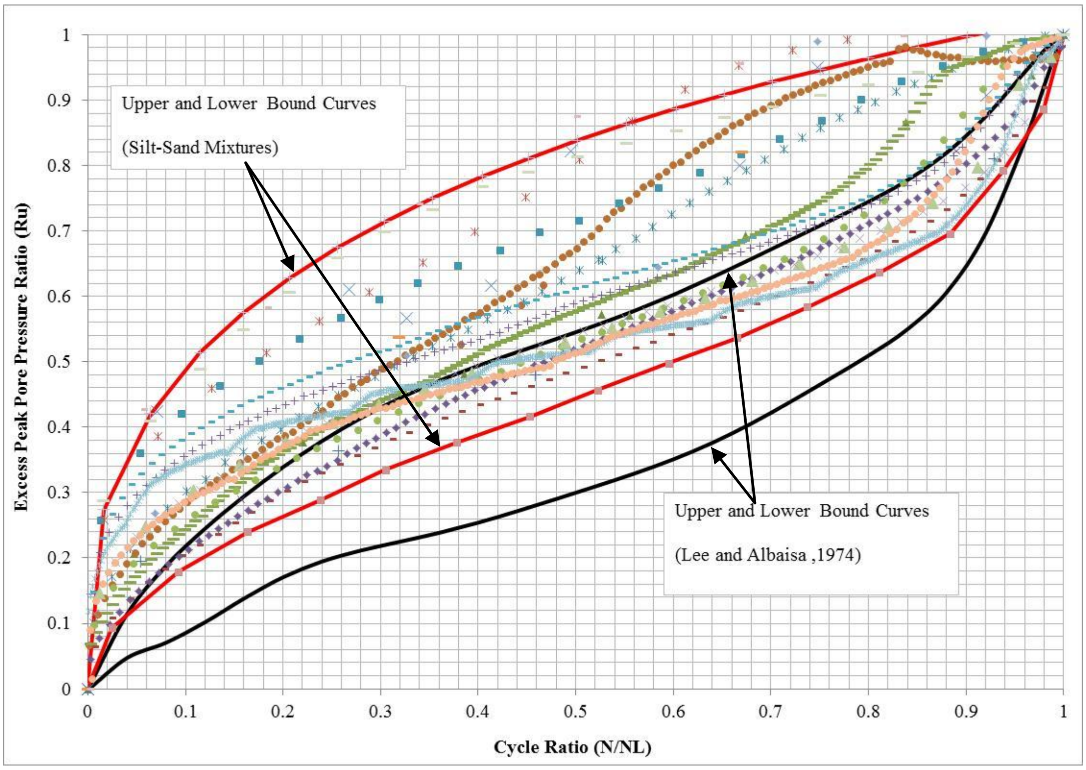

Figure 3. Maximum and minimum peak pore pressure generation in sand and silt mixture specimens over a wide range of parameters and compared with Lee and Albaisa (1974)

4 CONCLUSIONS

The typical pore pressure response analysis is presented in Fig. 3. The pore pressure response in specimens prepared to a constant post consolidation gross void ratio is presented in Fig. 3 with the method suggested by Lee and Albaisa (1974). The peak excess pore water pressure ratio corresponding to various cycles of loading has been plotted in Fig. 3. against the cyclic ratio. Excess pore water ratio (R_u) is defined as the ratio of excess pore water pressure generated during a particular cycle of loading to the initial effective confining pressure.

The rate of generation of excess pore water pressure with respect to cycles of loading was found to increase with increase in silt content till the limiting silt content is reached and thereafter it reverses its trend when the specimens were tested at a constant gross void ratio. This behavior was found to be due to corresponding initial decrease and then increase in relative density of the specimens. The cyclic resistance behavior was observed to be just the opposite of pore pressure response. It was observed that the relative density either increases or decreases with increase in silt content and this relative density controls the cyclic resistance and pore pressure generation characteristics.

It was also observed that the effect of fines in generating excess pore water pressure is not felt for higher relative density values, however; the presence of fines influences excess pore water pressure generation to a great extent at relative densities less than this value. All the test results over a wide range of parameters were utilized to suggest new pore pressure bands in line with Lee and Albaisa (1974) which can readily be used by researchers and field engineers to readily assess the pore pressure response under similar conditions. Maximum and minimum peak pore pressure response at a particular cyclic ratio or shear strain can be obtained from these bands and approximate estimation of pore pressure response can be determined.

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