POST CYCLIC SHEAR STRENGTH OF FINE GRAINED SOILS IN ADAPAZARI – TURKEY DURING 1999 KOCAELI EARTHQUAKE

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ABSTRACT :

During the 1999 Kocaeli earthquake, many structural damages and ground deformation have occurred in the downtown of Adapazarı due to the loss of bearing capacity and liquefaction. To study cyclic and post cyclic monotonic axial stress behavior of fine grained soils, undisturbed soil specimens were obtained from boreholes drilled to a depth of 20m in the heavy damaged area. The plasticity index of undisturbed soils was in the range from non plastic to 40. Specimens were isotropically consolidated to 100kPa which was higher than effective geological loads. Both cyclic and monotonic tests have been conducted in triaxial test apparatus. Stress controlled dynamic tests at 0.1 Hz frequency were performed under different cyclic axial stress ratios, and following cyclic test monotonic tests were conducted on soil specimens controlling the strain rate. Cyclic axial strain history of fine grained soil varied from $\varepsilon=\pm0.4\%$ to 9%. The results have indicated the post cyclic monotonic strength of fine grained soils decreases by increasing cyclic axial strain level.

KEYWORDS: undisturbed soils, post cyclic monotonic strength, cyclic axial strain, plasticity index

1. INTRODUCTION

The August 17, 1999 Kocaeli Earthquake had a moment magnitude of M_w = 7.4 with a focal depth of 17 km. The Kocaeli earthquake occurred on 17 August 1999 in the northwestern part of Turkey along the North Anatolian fault. The bilateral strike-slip fault rupture involved displacement on four distinct segments of the North Anatolian fault. These strike-slip fault segments are separated by right-releasing stepovers, which accommodated significant normal-slip displacement (up to 2.4 m) during the earthquake (Lettis et al., 2002). Several cases of liquefaction in silt and sand layers and bearing capacity loss in fine-grained soils have been observed in Adapazarı City that is located on alluvial soil deposits. Such phenomenon resulted in tilting of buildings, excessive settlements and lateral displacements and caused several thousands of casualties and billions of dollars of losses consequently.

Saturated fine grained soils develop pore water pressure under dynamic loads. Increase in pore water pressure and reduction in shear strength results many hazards to structural systems: bearing capacity, slope stability, and settlement of foundation soil during dissipation of excess pore water pressure after dynamic excitement. In cohesive soils, it is recognized that although cyclic undrained loading would increase the pore pressure, their "cohesion" keeping the particles together, prevents the dramatic loss of shear strength (Kalafat, et al., 2003).

For the mitigation of such hazards, the determination of the cyclic behavior of the soils in the region, the mode and magnitude of displacements under cyclic loading conditions and ascertaining the displacements or deformations being whether within tolerable limits or not become very important. The main objective of soil dynamics and geotechnical earthquake engineering is to determine the amount and degree of these soil deformations which occur under different kinds of monotonic and cyclic loads.

Although silts are classified as fine-grained soils their cyclic behavior can be different from that of clays. The difference in the cyclic shear strength properties and the pore water pressure response during cyclic loading depends upon the plasticity of fines content. Pore pressure increases up to a certain amount in plastic silty clays, whereas it can reach the effective confining pressure in one cycle of loading in saturated sandy silts and silty sands. Thus, a large amount of deformation occurs in the soils due to the rapid increase of pore water pressure, resulting in the reduction of effective stresses that cause soil liquefaction (Seed and Martin, 1976; Sandoval, 1989; Vaid, 1994). The plasticity of fines content is one of the major parameters that affect the cyclic behavior of undisturbed silty soils (El Hosri et al., 1984; Zhu and Law, 1988; Erken and Ansal, 1994; Erken and Ülker, 2007). The cyclic strength of undisturbed non-plastic silts is lower than that of plastic silts. The cyclic behavior of fine-grained soils has been defined by the term "sand-like" for liquefaction and by the term "clay- like" for cyclic failure by Boulanger and Idriss (2004). Ansal and Erken (1989) discuss the cyclic yield strength level as having a critical cyclic shear strain level above which soils undergo rapidly large deformations at every cycle.

In this study, cyclic and monotonic tests were conducted on undisturbed soil specimens, by using the cyclic triaxial test apparatus. The cyclic behavior of silty and clayey soils was determined according to test results, and post-cyclic monotonic strengths were evaluated after various numbers of cycles of dynamic loading. Stress controlled dynamic tests were performed under different cyclic axial stress ratios, and post cyclic monotonic tests were conducted on undisturbed soil specimens controlling the strain rate in order to determine the post-cyclic undrained static strength of fine-grained soils.

2. EXPERIMENTAL PROCEDURE

2.1. Soil Tested

To achieve the objectives of this study, undisturbed soil specimens obtained from the boreholes drilled at the sites of a collapsed and removed structure in Adapazarı Centrum following the August 17, 1999 Kocaeli Earthquake. First index properties of undisturbed soils were determined. As shown in Table 1 the fines content of undisturbed soils are between FC = 56-100 % and plasticity index values change from NP to 40. Figure. 1 shows the grain size distribution of the soils.

For the determination of geological loading history of soil layers, oedometer tests were conducted on soil samples. According to the results of oedometer tests soil samples taken from near surface (3.5 m depth) overconsolidation ratio (OCR) was in the range between 2.75 to 3.85, due to due to past surcharges from structures and fluctuations of ground water level in the central part of Adapazari City. The other soils obtained below the 4.0m depth were normally consolidated or lightly over consolidated.

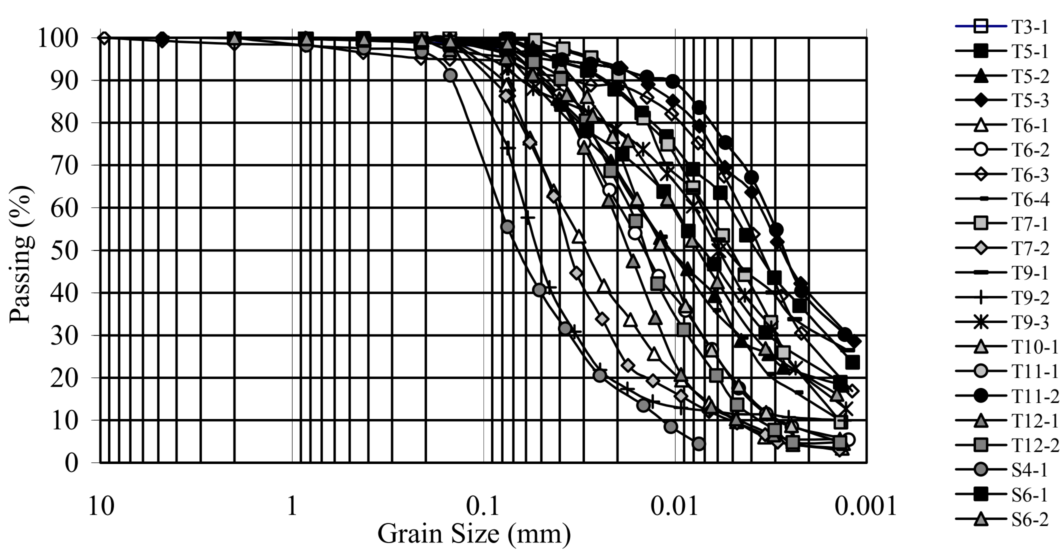


Figure 1 Grain size distributions of soils tested

Table 1 Index properties of soils tested

Borehole No	Sample No	Depth (m)	w_n (%)	w_l (%)	PI (%)	FC (%)	Group
BH4	S4-1	3.00-3.50	22	NP	NP	56	ML
BH6	S6-1	3.00-3.50	45	50	23	97	CH
BH6	S6-2	3.00-3.50	42	59	28	99	MH
BH4	T3.1	6.0-6.5	22	40	NP	98	ML
BH1	T5-1	5.00-5.50	38	66	40	99	CH
BH1	T5-2	5.00-5.50	32	40	16	98	CL
BH1	T5-3	5.00-5.50	41	71	40	98	CH
BH2	T6-1	7.20-7.70	25	31	NP	89	ML
BH2	T6-2	7.20-7.70	31	37	16	97	CL
BH2	T6-3	7.20-7.70	50	68	39	95	CH
BH2	T6-4	7.20-7.70	33	45	20	99	CL
BH6	T7-1	7.50-8.00	38	43	19	99	CL
BH6	T7-2	7.50-8.00	27	26	NP	86	ML
BH8	T9-1	7.50-8.00	48	68	28	98	CH
BH8	T9-2	7.50-8.00	22	29	7	74	CL-ML
BH8	T9-3	7.50-8.00	44	50	29	99	CL
BH9	T10-1	9.5-10.00	30	48	25	100	CL
BH1	T11-1	9.50-10.00	39	70	26	100	CH
BH1	T11-2	9.50-10.00	43	56	27	100	CH
BH1	T12-1	4.0-4.50	33	31	17	98	CL
BH1	T12-2	4.0-4.50	38	34	11	95	CL

2.2. Testing Apparatus

The stress-controlled cyclic triaxial test was used to evaluate the cyclic behavior of undisturbed soil samples. The size of triaxial test samples varies between 50 mm and 75 mm in diameter, and 100 mm to 150 mm in height. In the apparatus, a pneumatic stress controlled system is capable of generating cyclic axial triaxial stresses at frequencies between 0.001 Hz and 2 Hz. The testing system individually enables the measure and the record of axial vertical load, axial vertical displacement, pore water pressure and the specimen volume change. The stress–strain relationships of the soil specimens can be determined under isotropic and anisotropic conditions by applying sinusoidal loads.

2.3. Specimen Preparation

The soils sampled with thin walled tubes of 75 mm in diameter were extruded by cutting the tubes with a special technique in order to minimize the disturbance. The specimens were trimmed of 50 mm in diameter and 100 mm in height according to designation: JGS T 520-1990 to be set on the triaxial apparatus. The consolidation pressures applied 20-40% bigger than in-situ effective pressure in order to minimize sample disturbances during preparation. All samples consolidated to the 100 kPa which is close the effective geological pressure in situ. For the purpose of earlier completion of the consolidation and in order to make accurate measurement of the excess pore water pressure during the test, filtration strips were introduced around the specimen. The samples were isotropically consolidated in the triaxial cell and a backpressure of ranging between 200-300 kPa applied in order to provide the saturation. The B values were between 95-100 %. The frequency of cyclic load 0.1 Hz during the tests.

3. TESTING PROGRAM

In order to determine the shear and strain behavior of Adapazarı soils under cyclic loading conditions and the post-cyclic monotonic axial stress, dynamic triaxial test was conducted on undisturbed fine grained soils. The diameter and the height of samples were 50mm and 100mm respectively. All samples were isotropically consolidated to 100 kPa effective confining stress and cyclic tests were performed at a frequency of 0.1 Hz under different cyclic shear stress ratios in order to eliminate the effects of consolidation pressure and the loading frequency.

At the first step, undrained cyclic triaxial tests at different cyclic stress ratio were applied to specimens for 20 loading cycles. The test conditions of all the cyclic tests and the properties of fine grained soils are listed in Table 2.

At the second step, post cyclic monotonic axial stress tests which is strain controlled test with a strain rate of 0.20mm/min, were applied following the cyclic axial tests to determine the effect of cyclic axial strain on monotonic stress reduction. Cyclic axial strain levels vary from 0.4 to 10.7 at the end of 20 cycle repetition of loading.

Table 2 Cyclic triaxial shear test properties of undisturbed fine grained soils

Test No	Borehole	F.C (%)	After Consolidation γ_c (kN/m³)	PI	Group	B (%)	$\sigma_d/2\sigma_c$	N $\varepsilon=\pm2.5$	N=20		σ_π kPa
									ε	r_u	ε=%10
S4-1	BH4	55	17	-	ML	96	0.32	19.3	2.8	1	187
S6-1	BH6	97	14.2	23	CH	100	0.42	-	2.1	1	129
S6-2	BH6	99	12.8	38	MH	96	0.48	18.3	2.7	1	121
T3-1	BH4	98	18.72	NP	ML	96	0.32	-	0.4	0.8	315
T5-1	BH1	99	17.55	40	CH	96	0.4	-	1.34	0.9	128
T5-2	BH1	98	18.42	16	CL	95	0.34	-	0.51	0.8	182
T5-3	BH1	98	17.2	40	CH	99	0.45	5.5	6.1	0.9	93
T6-1	BH2	89	17.63	NP	ML	96	0.42	20	2.65	1	282
T6-2	BH2	97	18.32	16	CL	96	0.38	-	1.11	0.8	228
T6-3	BH2	95	16.79	39	CH	98	0.41	-	1.36	0.9	94
T6-4	BH2	99	17.76	20	CL	96	0.45	1	9.0	0.8	34
T7-1	BH6	99	17.79	19	CL	100	0.4	-	1.63	0.9	154
T7-2	BH6	86	17.15	NP	ML	96	0.360	2.5	4.90	1.00	328
T9-1	BH8	98	16.67	40	CH	95	0.430	7.5	4.15	0.71	109
T9-2	BH8	74	18.96	7	CL-ML	95	0.380	-	1.55	0.81	349
T9-3	BH8	99	18.07	29	CL	95	0.404	-	1.47	0.95	142
T10-1	BH9	100	17.91	23	CL	95	0.318	-	0.68	0.66	164
T11-1	BH1	100	17.76	44	CH	96	0.464	-	1.30	0.88	127
T11-2	BH1	100	17.83	30	CH	96	0.490	20	2.42	1.00	157
T12-1	BH3	98	13.71	16	CL	98	0.346	28	1.97	0.95	206
T12-2	BH3	95	12.66	15	CL	95	0.315	42	1.50	0.85	160

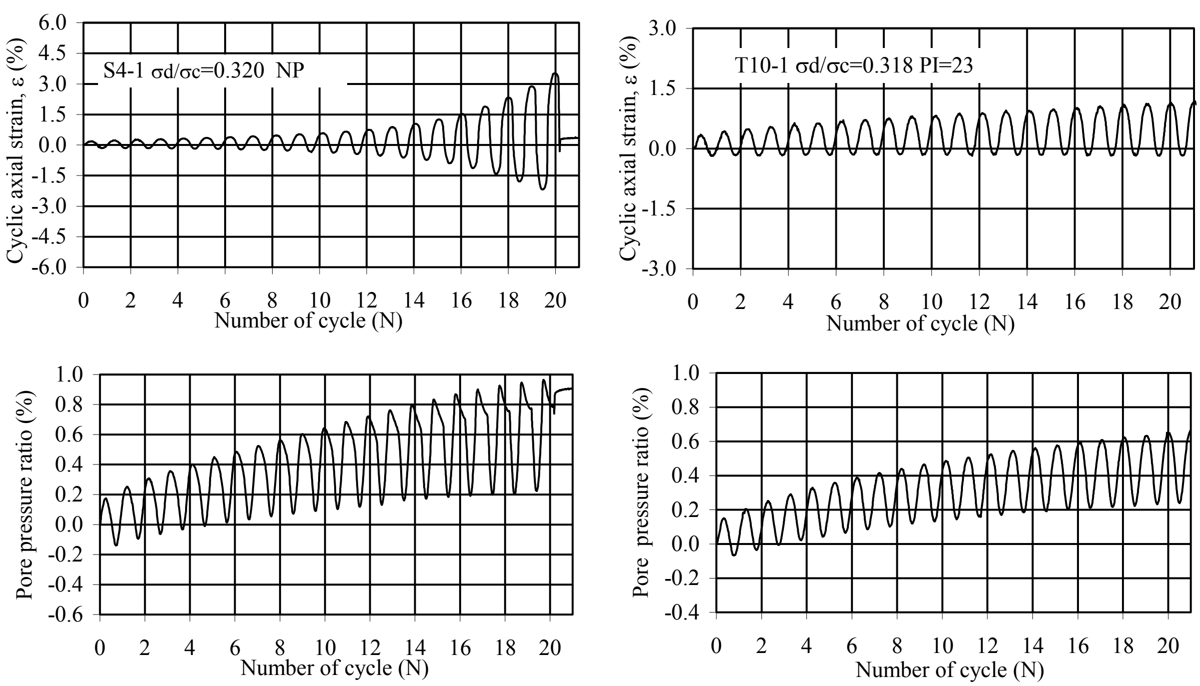
4. CYCLIC BEHAVIOR OF UNDISTURBED SILTY AND CLAYEY SOILS

To determine the cyclic behavior of silts and clays, stress controlled cyclic triaxial test has been conducted on undisturbed soil samples with a plasticity index of ranged from NP to 40. Figure 2 shows a typical cyclic axial test result of undisturbed non plastic silt and plastic clay specimens. Cyclic triaxial test was conducted as stress controlled on both specimens with a cyclic stress ratio of $\sigma_d/2\sigma_c = \pm 0.320$. As can be observed in Figure 2 a, pore water pressure increased gradually with the repetition of cyclic loads. Pore pressure ratio was 0.96 at 20th cycle while axial deformation was $\varepsilon=\pm2.85\%$ non plastic silt underwent a strain level of $\varepsilon = \pm 2.5$ at 19th of number of cycle. As shown in Figure 2.b, the induced pore water pressure and cyclic axial deformation were limited in clay specimen under the same cyclic stress ratio of $\sigma_d/2\sigma_c = \pm 0.318$ due to the effect of plasticity index. The cyclic axial strain and pore water pressure ratio at N=20 were 0.68 and 0.66 respectively.

Figure 3 presents the relation between cyclic axial stress ratio and number of cycles. Non plastic silts have the lowest cyclic strength. The plasticity index affects the behavior. Soils with high plasticity index have more cyclic strength comparing to low plastic soils.

5. POST-CYCLIC UNDRAINED MONOTONIC STRENGTH OF FINE GRAINED SOILS

It is necessary to determine the effect of earthquake loads on monotonic shear strength for the design of structure to mitigate earthquake effects. In this part of the research, the static triaxial tests have been conducted after ending the cyclic tests. Figure 4 shows the both cyclic triaxial loading and post cyclic monotonic axial loading tests results obtained from T7-1 test. Plasticity index of soil is 19. After 20 repetition of $\sigma_d/2\sigma_c = \pm0.40$ cyclic axial stress level, cyclic test was terminated and the post cyclic monotonic axial test was applied until the axial strain level reached to 10%. While the induced pore water pressure during cyclic loading decrease by monotonic loading axial stress increases due to dilation.



a) Non plastic silt specimen

b) Plastic clay specimen

Figure 2 Cyclic triaxial test results of the undisturbed soil specimens

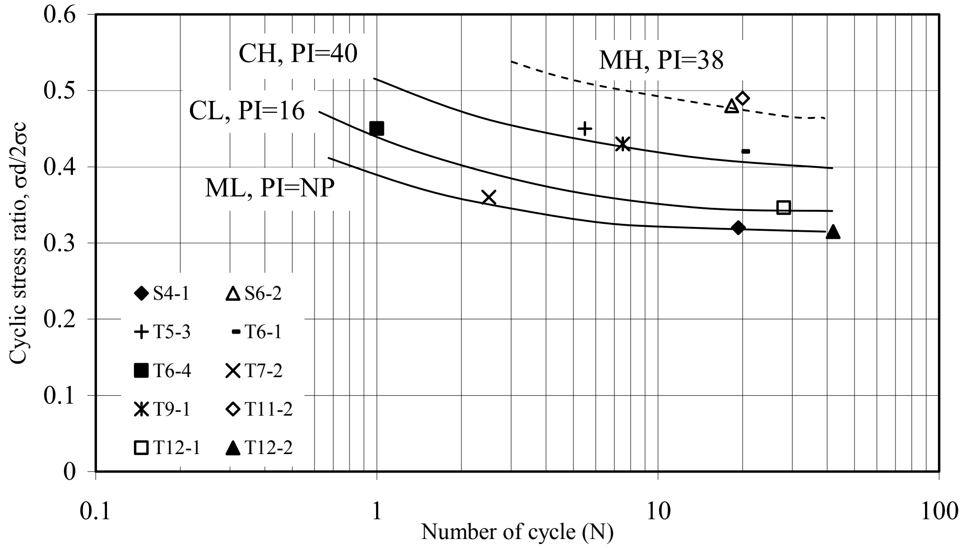
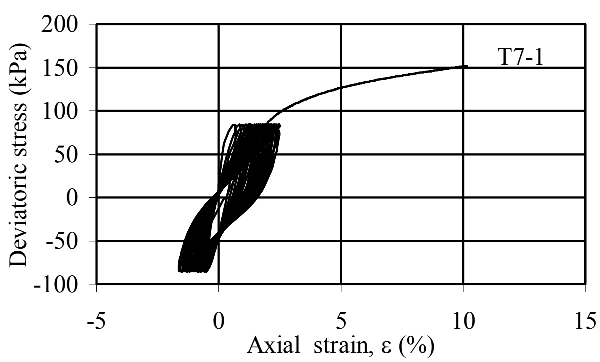
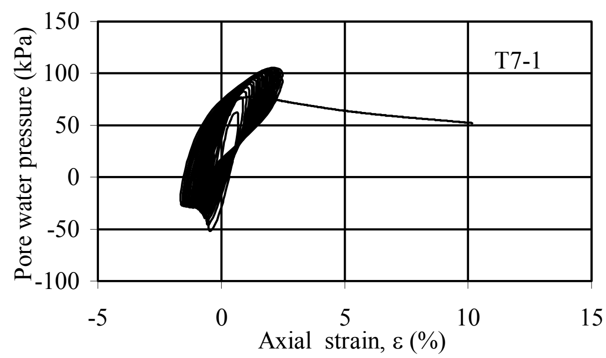


Figure 3 Cyclic stress ratio versus number of cycle



a) Deviatoric stress versus axial strain

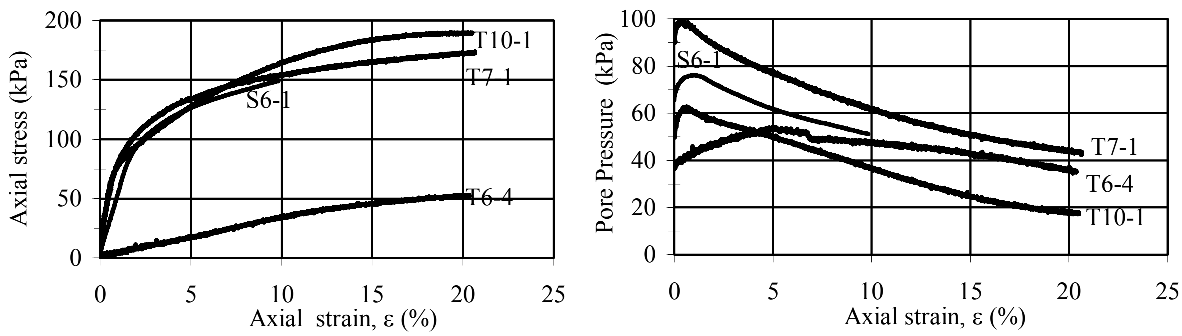


b) Pore water pressure versus axial strain

Figure 4 Cyclic and post cyclic monotonic axial stress test results

Post cyclic monotonic test results are shown in Figure 5. The plasticity index of soils is between 19 and 23 (Table 2). The monotonic axial stress was applied following cyclic test which was the range between 0.318 and 0.45. During cyclic test specimens underwent to different cyclic axial strain levels. The induced cyclic axial strain in T7-1 and T10-1 specimens are ε=±1.63% and ε=±0.68% respectively. T6-4 specimen underwent to large cyclic strain level with ε=±9.0%. Static test result has shown that the post cyclic monotonic strength of soils depends on the cyclic axial strain past.

As illustrated in Figure 6 the relationship between post cyclic monotonic strength and cyclic axial strain of fine grained soils is similar, regardless of plasticity index. If cyclic axial strains develop in fine grained soils than post cyclic monotonic strength of soil decreases depending on the cyclic axial strain level.



a) Axial stress versus axial strain　　b) Pore pressure versus axial strain

Figure 5 Post cyclic monotonic axial stress and pore water pressure

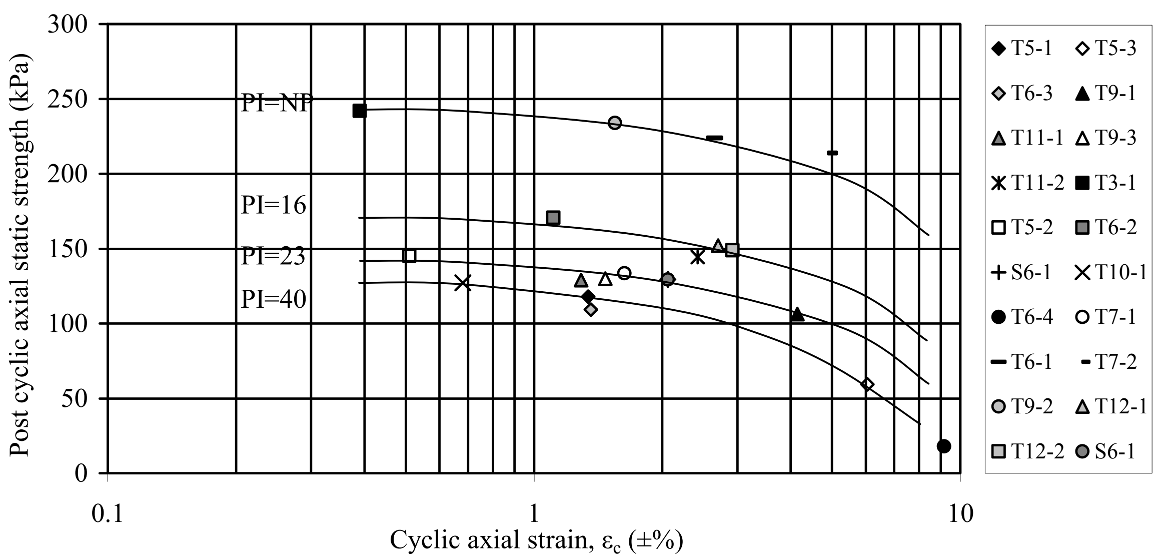


Figure 6 The relationship between post cyclic monotonic strength and cyclic axial strain

6. CONCLUSIONS

On the basis of the tests reported in this paper regarding the cyclic and the post-cyclic monotonic behaviors of fine grained soils by using cyclic triaxial test apparatus, the followings were found:

1. The cyclic undrained axial strength of undisturbed low plastic silts is considerably low than that of plastic clays.
2. The monotonic undrained axial stress of undisturbed fine grained soils depends on the cyclic axial strain history and decreases by increasing of cyclic axial strain level.
3. The relationship between the post cyclic monotonic undrained shear strength and cyclic axial strain is obtained similar for the undisturbed fine grained soils with the plasticity index from NP to 40.

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