Post-Cyclic Behaviour of Soil – A Critical Review

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***Abstract*— An analytical study for determining the post-cyclic behavior effect on shear strength of the soil has been carried out previously. It is well known that the static and dynamic loading results in build-up of strains that are manifested as excess strength in the soils. This paper is rooted in the past studies by many researchers in static and dynamic loading and the main purpose of this paper is to describe the presentable data and method were used in case studies to show how the cyclic loading may play a role in development of shear strength by critically examining and documenting the current state of practice. The proposed laboratory frequencies approximately incorporate with the real or undergo dynamic cyclic loadings. This paper are discussed the variation in strength of post-cyclic sample from peat, clay and sand in variety of several case histories are presented. Further analyzes the stress-strain response of these samples in undrained triaxial loading. A dynamic triaxial testing concurrently was used to investigate the soil behavior. The results after cyclic loading may be an important parameter in determining the subsequent stress path under static and dynamic loading tests to enhance the knowledge method in designing the infrastructure and comprehensive technique.**

Keywords*— *cyclic loadings, triaxial test, static and dynamic test, post-cyclic.

I. INTRODUCTION

Malaysia, comprising the regions of Peninsular Malaysia, Sabah, and Sarawak, supports some of the most extensive tropical peatlands in the world. Tropical peat forest is found mainly in Southeast Asia (Phillips, 1998) and was estimated at about 20 million hectares, two-third of the total area of the world's tropical peat swamps (Kyuma, 1992). The synthesis of problem faced in development on unstable lands is a major concern in some affected areas and research on soft soil is fundamental to overcome this issue. A factual study, method and analysis isolates the relevant implementation to solve numerous cases have held soil engineers to the same standard of effective design. Therefore, it is essential to find an alternative to improve the strength of soil since the post-cyclic was introduced as one of the improvement technique.

The post-cyclic studies were undertaken to gain insight into the effectiveness of two mechanisms of shear and stress on soil. This study is essentially a comprehensive review of available academic literature on post-cyclic behaviour on peat soil utilizing this approach. Furthermore, applications of these methods are illustrated in a variety of conditions and several case histories are presented. There are three types of soils was presented in this paper from peat, clay and sand while comparison between each type performed to enable a more practical design to be carried out.

According to Kramer (2000), cyclic triaxial testing indicated that the modulus reduction and damping behaviour of peat was significantly influenced by strain amplitude and effective confining pressure and was weakly influenced by loading frequency and over consolidation ratio. Apart from that, Das (2011) elaborated the type of dynamic loading in soil or the foundation of a structure depends on the nature of the source producing it. Moreover, dynamic loads vary in their magnitude, direction or position with time. Furthermore, the characteristic of static load differ than dynamic loading whichever static loading produced from foundation carried load in large amount of a structure in a constant magnitude and direction generated from dead weight of the structures.

Previous study have shown that, the effective stress paths under post-cyclic monotonic loading may take on different forms depending on the mean effective stress state of the specimen at the end of the cyclic loading phase (Goh and Lee, 2013). In this paper, based on the study to examine the soil properties and identify the effect of post-cyclic loading exerts a key role in soil stability the following objectives therefore set out for this paper to determine the effect of mechanical behaviour of soils cyclically or dynamically loaded when large strains as well as a large spectrum of frequencies take into consideration and shear irreversible strains is analysed.

This paper also discussed on how to examine the post-cyclic test as a rational way to make a reliable measurement of dynamic soil properties for unstable soil and determine dynamic properties of soils as key parameters in predicting the response of soils to dynamic loading.

II. TESTING METHOD

There are 3 types of soils were used in this comparison paper from various researchers. A combined triaxiall cell test and dynamic actuator being applied. This study is essentially a comprehensive review of available academic literature on post-cyclic behaviour on peat soil utilizing this approach. Furthermore, applications of these methods are illustrated in a variety of conditions and several case histories are presented.

III. STATIC TEST

The review of soils in this study carried out by various researcher and several tests in context with extracting general properties and intrusive data. Researcher was performed and expand command to observe and determine the shear strength of soil by using triaxial test. Whitlow (2004) concludes that, the triaxial test is commonly used for determining the shear strength of soil and suitable for all types of soil except for very sensitive clays and allows a number of different test method. Consolidated Undrained Triaxial test has been used as reliable method to this test for determining shear strength parameters.

IV. CONSOLIDATED UNDRAINED TRIAXIAL TEST

Farrel (2012) stated that, laboratory methods used to determine the strength properties of peat are generally the same as for mineral soils, without special consideration given to the fibre content, high compressibility or relatively high permeability and gas content of fibrous peats. Kelly and Zhang (2013) stated that, triaxial testing is one of the routinely used methods in practice because its repeatability is generally good. They also mentioned that, standard triaxial testing arise difficulties in applying on peat soil. However, the triaxial apparatus provides close control of the specimen stress and boundary conditions, and it is also possible to measure pore-water pressure and other parameters.

Landva and LaRochelle (1983) in its study and reported that, triaxial compression of fibrous peats produces very high values of the effective angle of shearing resistance (ϕ') in the range of 40^o to $60^o$and comparison has been made by using soft clay and silt compositions by others researchers it has stated less than 35^o.

The assessment of shear strength of peat soil extended by many researchers. In a review of the subject on the shear strength of peat, Hanrahan (1987) concluded that the structure of remoulded peat was unlikely to be representative of undisturbed peat and the shear strength of peat was of a cohesive nature ($\phi' = 0$). Moreover, Hanrahan and Walsh (1967) reported on a comprehensive tiaxial shear test on remoulded peat samples, it was concluded that the qualitative behaviour of peat was frictional (c′) ranges from 5.5 kPa to 6.1 kPa and affective angle for shear resistance (ϕ') ranges from 36.6^o to 43.5^o.

Subsequently, normal compression of peat in the vertical direction mobilizes internal tensile reinforcement provided by the presence of peat fibres (Hendry *et al.* 2012). Farrel and Hebib (1998) had an investigation due to the presence of fibres in peat that developed under consolidated-undrained (CU) triaxial test compression of high excess pore-water pressures at failure and approximately equal the magnitude of the confining pressure.

Farrel 2012 once again concluded that, the induced pore-water pressures increase very rapidly under compression and, at axial strains (ε_a) beyond 5% to 10% in fibrous peat and approximately aqual to the applied cell pressure on account of the low Poisson's ratio of fibre content. These responses make any interpretation of ϕ' from CU triaxial compression testing of fibrous peat difficult.

The parameters determined in undrained triaxial tests with pore pressure measurements for relatively low organic contents were considerably higher in compression than extension and also considerably higher than those determined from the shear box test according to Grever (1987).

A study on triaxial test for peat has been carried out by Zainorabidin and Bakar (2003) for Original Hemic peat (VHP) and Modified Hemic peat (MHP) where the researchers concluded that, the shear strength parameters of triaxial test which are effective cohesion and angle of internal friction for both types of samples as shown in Table 1. Table 1 shows the engineering properties of Natural Hemic peat(VHP) and Modified Hemic peat (MHP).

The effective-stress strength parameters c′ and ϕ' determined and post-cyclic behaviour of soil which after in results will define the c_{cyc} and ϕ_{cyc} that appropriate for soil and that these parameters can be obtained from CU triaxial compression tests.

Table 1 shows the engineering properties of Natural Hemic peat (VHP) and Modified Hemic peat (MHP) presented by Zainorabidin and Bakar (2003). This result showed the comparison between MHP and VHP that obviously indicated that natural Hemic Peat has the highest cohesion compared to the Modified sample. This samples clearly stated by Zainorabidin and Bakar (2003) undergone through the agricultural activities and have been grinded and mechanically compressed by agricultural machineries to form a stable soil structures, this is the major cause of the higher reading in result. Long (2005), concluded that one geotechnical peculiarity of the shear strength of peat is the effect of fibres. The shear strength parameters of peat vary according to the type of test used. The triaxial test tends to yield higher angles of shearing resistance than the direct simple shear and this is believed to be due to the reinforcing effect of fibres.

Figure 1 above showed, the Vane tests and UC triaxial tests on macerated peat of different water contents and empirical relationship for peat strength briefed by Long (2005). The researcher found that, the results of vane tests were very similar to laboratory tests which is triaxial tests conducted when the fibre effect was eliminated as shown in figure 2.3. In fibrous peat, where *w*stands for the water content, works well for peat and sample used in Swedish peat. While, the particular water content (s_u) values are estimated lower.

V. Dynamic Loading Test

The increasing need for regional development has led engineers to find safe ways to construct the infrastructure of transportation on soft soils. Soft soil is not able to sustain external loads without having large deformations.

depends on the nature of the source producing it. Moreover, dynamic loads vary in their magnitude, direction or position with time. Furthermore, the characteristic of static load differ than dynamic loading whichever static loading produced from foundation carried load in large amount of a structure in a constant magnitude and direction generated from dead weight of the structures.

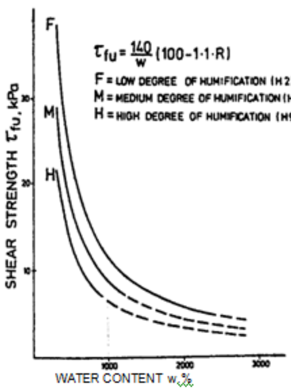
Table 1: Engineering properties of Natural Hemic peat (VHP) and Modified Hemic peat (MHP) (Zainorabidin and Bakar, 2003)

Parameter	Natural Hemic peat (VHP)	Modified Hemic peat (MHP)
Moisture Content, m (%)	460	236
Von Post degree of Humification	H5	H6
Specific Gravity, G_s	1.38	1.51
Organic Content (%)	91.5	83.5
Fibric Content (%)	62	42
Liquid Limit, LL (%)	224	137.2
Compaction	$(OMC)_{2.5}$ = 55.2%	$(OMC)_{2.5}$ = 55.2%
	$(OMC)_{4.5}$ = 52.0%	$(OMC)_{4.5}$ = 52.0%
	$(\square dmax)_{2.5}$ = 0.469Mg/m^3	$(\square dmax)_{2.5}$ = 0.469Mg/m^3
	$(\square dmax)_{2.5}$ = 0.615Mg/m^3	$(\square dmax)_{2.5}$ = 0.615Mg/m^3
pH value	3	5
Cohessionless Effective, c' (kPa)	7.8	5.1
Effective internal Angle, ϕ' (deg)	23	30
Column Friction Law, τ (kPa)	$7.8 + \sigma' \tan 23^o$	$5.1 + \sigma' \tan 23^o$

In pavement engineering, highway or runway as an infrastructure, a pavement encompasses three important parts namely traffic load, pavement and subgrade. Traffic load generated from tire pressure of vehicle and or airplane wheelson the surface of the pavement. On the traffic load, there are two types of load to take in consideration during designing and analysis stage in pertaining the problems that generally related to the static and dynamic loading. Significant rate dependent behaviour was also observed in lateral load test. The understanding of the static and dynamic behaviour of peat is still embryonic and need intensive understanding to overcome the issue on peat soil.

According to Kramer (2000), cyclic triaxial testing indicated that the modulus reduction and damping behaviour of peat was significantly influenced by strain amplitude and effective confining pressure and was weakly influenced by loading frequency and over consolidation ratio.

Apart from that, Das (2011) elaborated the type of dynamic loading in soil or the foundation of a structure



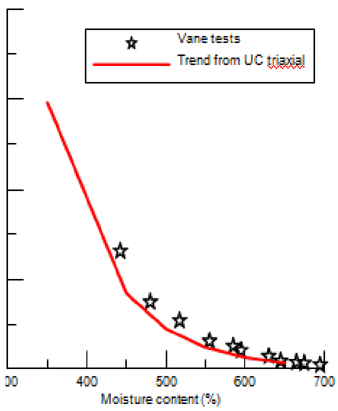


Figure 1: Vane tests and UC triaxial tests on macerated peat of different water contents and empirical relationship for peat strength. (Carlsten, 2000)

It increases with increasing magnitude of cyclic shear strain, whereas shear modulus decrease with increasing magnitude of cyclic shear strain. It is also known that dynamic properties of soil are influenced by the plasticity index, void ratio, relative density and number of cycles (Cabalar and Cevik, 2008). The foundation must be safe both for the usual static loads as well for the dynamic loads imposed by the earthquakes and therefore the design of either type of foundation needs special considerations compared to the static case. The response of a footing to dynamic loads is affected by the nature and magnitude of dynamic loads, number of pulses and the strain rate response of soil.

To account for the effect of dynamic nature of the load, the bearing capacity factors are determined by using dynamic angle of internal friction which is taken as 2^o less than its static value (Das, 1992). Soil behaviour under dynamic loads has attracted the attention of several researchers.

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Comparison of the behaviour of peat suggests a trend of response analysis indicated strong response at low frequencies with spectral shapes that needed more understanding. Saran (1999) describes that, the pattern of vibrations that stimulated from dynamic loading are varies on its frequencies and different frequencies induced different impacts.

Traffic vibration is experienced by many people living alongside heavily trafficked roads, and there is a need to understand the nature of this problem so that predictions of nuisance can be made and remedial treatments can be devised. Yang and Tze (2011) reveals, in the triaxial test, sample is consolidated under hydrostatic conditions and then subjected to a cyclic deviatoric stress, which alters between positive and negative values of the same magnitude.

As shown in figure 2 (a), cyclic deviatoric stress alters in positive and negative values of the same magnitude. Yang and Tze (2011) through the experimental study investigated the undrained behaviour of soil in non-symmetrical cyclic loading, and clarify the role of initial static shear in liquefaction resistance under triaxial conditions. On the plane of interest in soil sample, superposition of a cyclic shear stress $_{cyc}$ then produces a cyclic loading that is non-symmetrical about the hydrostatic stress state in figure 2 (b) and figure 2 (c). Yang and Tze (2011) summarized that, the figure 2 (b) is the proven and it is evident that shear stress reversals will occur if the magnitude of the cyclic shear stress is greater than the initial static shear stress that can called as post-cyclic. In figure 2 (c) researchers stated that there are no stresses reversals will appear. Yang and Tze (2011) in their study also stated that the symmetrical loading represents level ground conditions in the free field, where no initial static shear stresses act on the horizontal planes of the elements of soil. In many major projects involving earth dams, embankments or slopes, however, soil elements are subjected to static, driving shear stresses on the horizontal planes before the earthquake loading effect is developed.

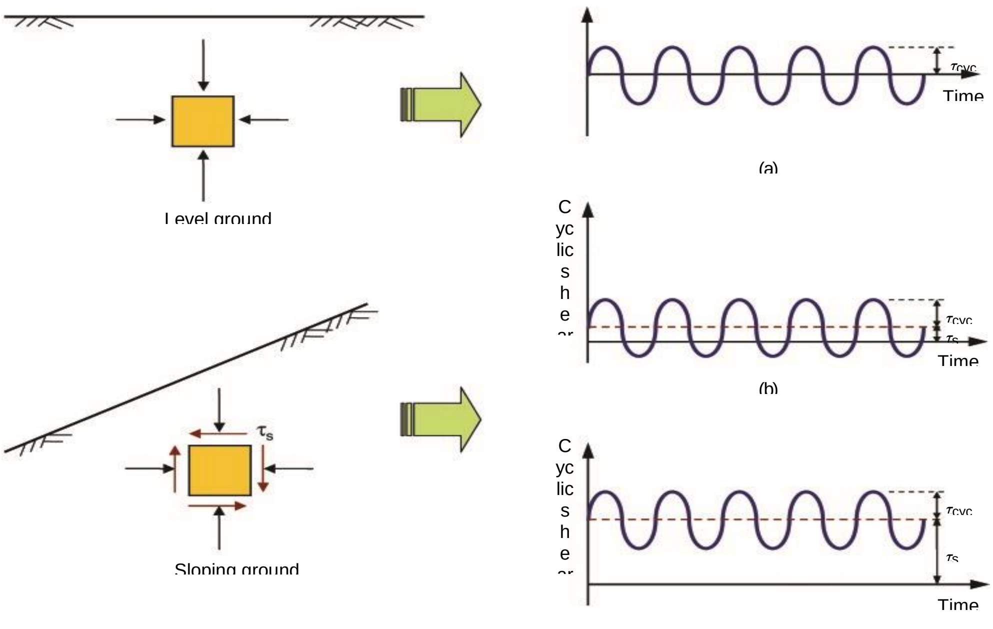


Figure 2: Cyclic loading conditions in the laboratory to simulate level ground and sloping ground conditions: (a) symmetrical loading; (b) non-symmetrical loading with stress reversal; (c) non-symmetrical loading without stress reversal. (Yang and Sze, 2011).

VI. POST-CYCLIC ON PEAT SOIL

Soil structures are often comprised or supported by soils that are mixtures of cohesive and granular geomaterials that explained by Soroush and Jigheh (2009). Peat soil samples from Sherman Island, California was taken as study materials and have through laboratory testing in order to investigate the volume change characteristic in their study under static condition including consolidation for secondary compression and post-cyclic conditions. The researcher used triaxial testing. In their study, the strain-controlled cyclic triaxial testing of the peat soil found the generation of cyclic pore pressures for cyclic shear strain levels beyond approximately 0.5-1.0% with largest residual pore pressure ratios (r_{ur}) or more clearly stated as cyclic residual pore pressure normalized by pre-cyclic consolidation stress being approximately 0.2-0.4.

Shafiee, Brandenberg & Stewart (2013) stated that, post cyclic volume change occurs from pore pressure dissipation and secondary compression.The level of post-cyclic secondary compression increases with (r_{ur}). Many of these phenomena have not been documented previously and suggest the potential for seismic freeboard loss in levees due to mechanisms other than shear failure.Shafiee, Brandenberg & Stewart (2013) in their study also introduced new concepts on the 'resetting' of secondary compression as a result of loading that generates pore pressure and the effects of cyclic pore pressure generation on post-cyclic volume change.

Incremental consolidation tests indicate the material to be highly compressible (C_c = 3.9, C_r = 0.4) and prone to substantial ageing from secondary compression (C_a/C_c = 0.05 following virgin compression) presented by Brandenberg *et al.* (2013).

Table 2 showed the testing plan for undisturbed and bulk samples taken from a depth of 1.3-3.0 m that conducted by Shafiee, Brandenberg & Stewart (2013). In table 2.5, various types of samples testing used are summarized. Index tests indicate water contents ranging from 410% to 700% and specific gravity of 1.85. Cyclic triaxial (CTX)] was performed in several stages. In the first stage, the peaty organic soils were consolidated to the stresses indicated in Table 2.5, which are either the in situ free-field effective stresses at the sample depth (σvc′) or the 32 estimated consolidation stress beneath the crest of Sherman Island peat. These consolidation stresses correspond to anisotropic conditions for the DSS tests and isotropic conditions for the CTX tests.

In the stage of consolidation, they were performed strain-controlled multi-stage cyclic shearing in stages having shear strain amplitudes ranging for axial strains of 1.3×10-3 to 2.4% in the CTX tests to equivalent shear strains of 1.9×10-3 to 3.6%.Each stage of loading consisted of 15 uniform strain cycles at a loading frequency of 0.1 Hz. Undrained conditions were maintained during shearing for the CTX tests by closing the drain taps to the specimen (Shafiee *et al.*, 2013).

Table 2: Testing plan for undisturbed and bulk samples taken from a depth of 1.3-3.0 m. (Shafiee, Brandenberg & Stewart, 2013)

Specimen	**Borehole**	**Organic content (%)**	**Test**	**specific gravity (Gs)**	**σ c ′* (kPa)**	**Time allowed for post-cyclic volume change measurement**
3-1a	3	70	1 D-Consoliddation	1.85	13 to 195	
8-1a	8	63	1 D-Consoliddation	1.85	13 to 195	
8-3a	8	58	1 D-Consoliddation	1.85	13 to 195	
8-4a	9	55	1 D-Consoliddation	1.85	13 to 195	
9-3b	8	53	1 D-Consoliddation	1.85	13 to 195	
9-4a	8	52	1 D-Consoliddation	1.85	13 to 195	
8-3c	8	58	Cyclic CTX (after 1 week consolidation)	1.85	8	40 min
9-3a	9	53	CTX	1.85	9	24 hrs
9-3a	9	53	CTX	1.85	18	40 min
9-3a	9	53	CTX	1.85	42	40 min

Note:-
CTX = cyclic triaxail
DSS = direct simple shear

For each stage of cyclic shearing, the specimen was allowed to reconsolidate to its initial consolidation stress and volume changes were monitored. Strain controlled tests were preferred over stress controlled tests to be able to relate post-cyclic volume change values to the cyclic shear strain amplitude.

Figure 3 shows Cyclic behaviour of specimen 9-3a under cyclic loading in cyclic triaxial device. The results showed of typical cyclic triaxial test sequences. According to (Shafiee, Brandenberg & Stewart, 2013) during cyclic loading, pore pressure ratio u vc ru σ ′= Δ increases and the soil stiffness degrades as evidenced by reductions in the shear stress to achieve the uniform strain amplitude. The researcher also found and concluded that the pore pressure generation markedly increases for cyclic strain amplitudes larger than 0.5-1.0% and tend to be higher for the direct simple shearing than in the cyclic triaxial shearing.

Zainorabidin (2011) and Das (1992) expressed that, the dynamic loading or known as cyclic loading are depends on the stresses and frequencies imposed during the loading onto the soil. Saran (1999) presented that, there are large strain and small strain amplitude response in dynamic loading whereby the large strain amplitude responses are from the strong motion such as earthquakes, blast, nuclear explosions and fast moving traffic and cause the strain amplitude ranging from 0.01% to 0.1%.

Figure 4 showed the results at the end of cyclic loading for post-cyclic behaviour of the tested peat soil.

The volume change was allowed by restoring the original vertical load direct simple shear test specimens while the drain valve was opened in cyclic triaxial specimens and post-cyclic volumetric strain was monitored as a function of time.

Figure 5 indicated the post-cyclic volume change from primary consolidationaccording to the (Shafiee, Brandenberg & Stewart, 2013). This results which shows a match due to the observed volumetric strain data attributed to primary consolidation and the triaxial specimens were not completely saturated.

On the other hand, Masawi (2004) was conducting an investigation on peat soilto the effect of organic content on coefficient of consolidation and then the researcher concluded that, the organic content in peat soil also influences the parameters of consolidation. The low value of compression also influence the physical properties that show in coefficient of secondary compression, coefficient of compression index and coefficient of volume compressibility is higher. While, the workability of peat soil has a low compaction characteristic.

A study conducted by Vucetic and Dobry (1985) stated that, the higher plasticity soils generally exhibit a more liner cyclic stress-strain response. A study was carried out by Bakowska (2008) on dynamic triaxial testing system was used to investigate the undrained shear resistance of undisturbed soil samples taken from the Nowoursynowska, Warsaw. The finding on that study was presenting cyclic loading causes a substantial decrease in the shear resistance of tills. Post-cyclic shear stress decreases with increasing the number of cycles of stress application. The researcher also concluded the values of pore water pressure change in the monotonic shearing phase decrease with the number of cycles of stress application.Bakowska (2008) widely discuss the values of cohesion c' get reduced with the numbers of cyclic loads, while the values of angles of internal friction ϕ' increase.

Testing programme conducted by Bakowska (2008) on post-cyclic study shear strength to investigate a particular effect of the undrained static and post-cyclic behaviour of the Nowoursynowska, Warsaw peat. The results presented in figure 6 where the Relationships between deviator stress σ1–σ3, pore water pressure change Δu. The researcher had conducted several series of tests, but in this study, there two (2) results are used in comparison as shown in figure 6 (a) series I and figure 6 (b) series II. The specimens were consolidated isotropically with a desired effective stress and the consolidation loading was applied monotonically in the static test and cyclically in dynamic test.

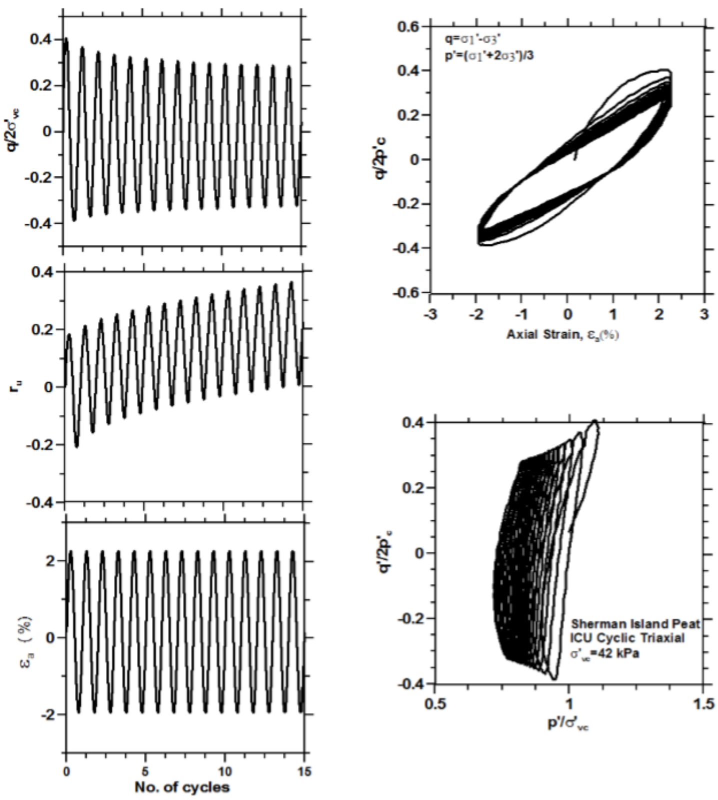


Figure 3: Cyclic behaviour of specimen 9-3a under cyclic loading in CTX device.
(Shafiee, Brandenberg & Stewart, 2013)

water pressure change is up to 100 kPa, after 20,000 cycles (series II) the pore water pressure change is not higher than 25 kPa.

In cyclic triaxial shear test study highlighted by Erken, Kaya & Sener (2008), the researcher come up with presentable testing study on post-cyclic shear strength in order to determine the shear and strain behaviour of Adapazar, Turkey soils under cyclic loading conditions, test was conducted on undisturbed soils.

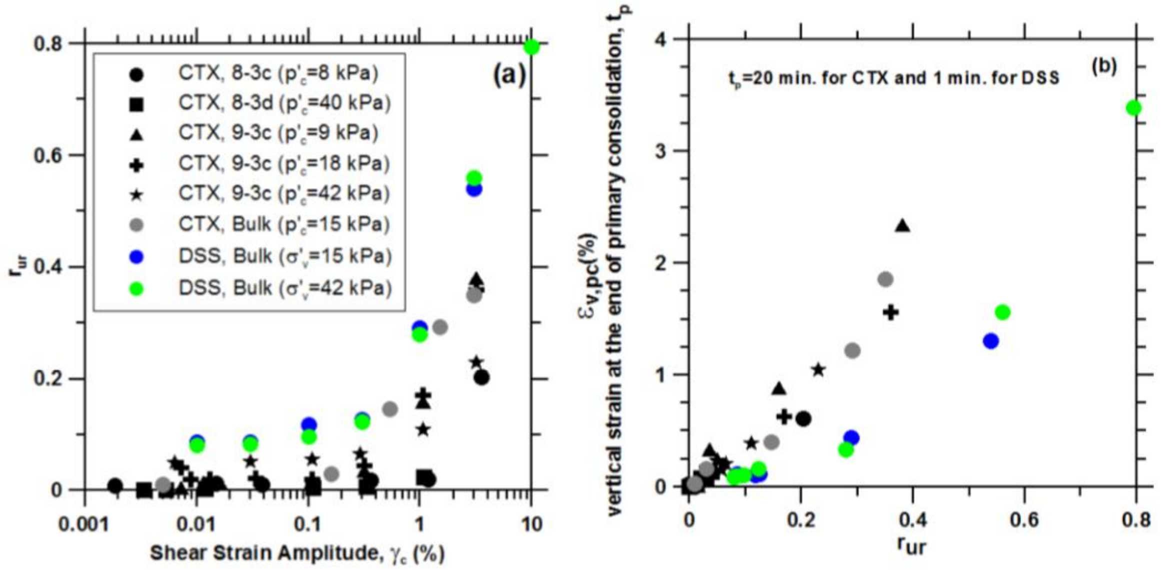


Figure 4: Post-cyclic behaviour of the tested peat
(a) Residual pore pressure
(b) Post-cyclic volume change at end of primary consolidation.
(Shafiee, Brandenberg & Stewart, 2013)

Figure 6 on undrained static shear test are shown for the relationships deviator stress σ1–σ3 versus axial strain ε, principal stress ratio σ'1 / σ'3 versus axial strain ε, and pore water pressure change Δu versus axial strain ε for each series. According to Bakowska (2008), the shear strength parameters for each series were derived from a set of points representing the moment of failure in terms of effective stresses for each series.

A study on cyclic behaviour by Head (1986), the researcher considered that for each specimen the maximum value of principal ratio σ'1 / σ'3 was located and denoted as a moment of failure by $(\sigma'1 / \sigma'3)_f$.The values of the pore water pressure change in the monotonic shear test phase, as shown in figure 2.8 for series I and II. The researcher found in the test and set the values where decrease with the number of cycles of stress application. In the static conditions (series I) the pore

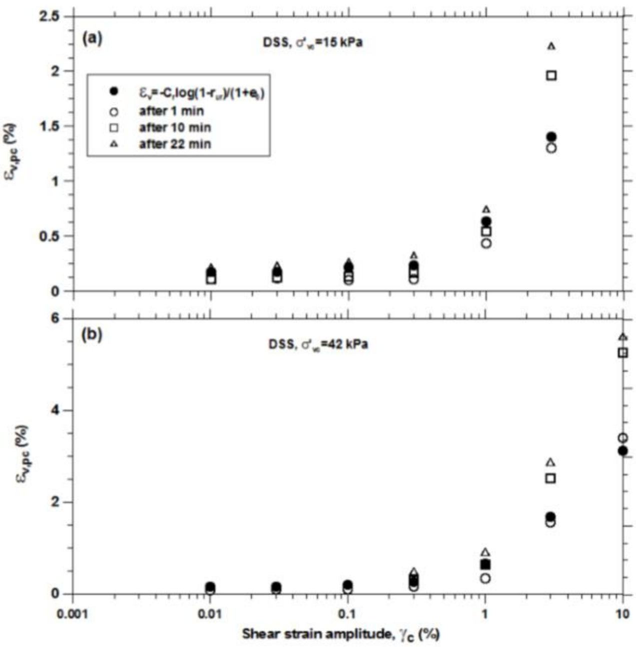


Figure 5: Post-cyclic volume change from primary consolidation (Shafiee, Brandenberg & Stewart, 2013)

Several criteria of the study a set to determine the behaviour of soil samples. The specimens isotropically consolidated at 100 kPa and test have been conducted in triaxial test apparatus where the stress controlled in dynamic test at 0.1 Hz frequency wereperformed under different cyclic axial stress ratios. Ansal and Erken (1989) discuss the cyclic yield strength level as having a critical cyclic shear strain level which soils undergo rapidly large deformations at every cycle.

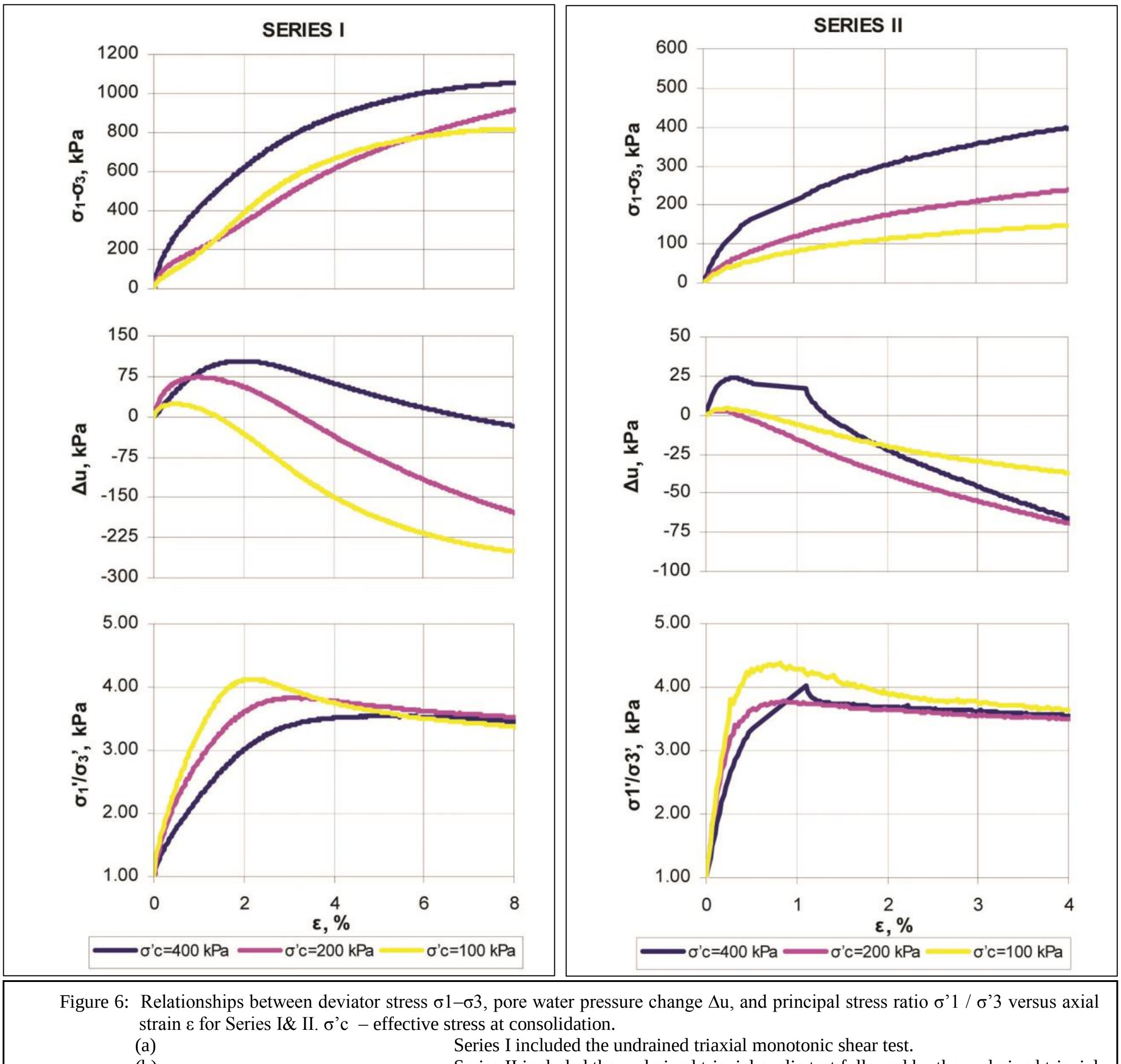


Figure 6: Relationships between deviator stress $\sigma 1–\sigma 3$, pore water pressure change Δu, and principal stress ratio $\sigma' 1 / \sigma' 3$ versus axial strain ε for Series I& II. $\sigma' c$ – effective stress at consolidation.

(a) Series I included the undrained triaxial monotonic shear test.

(b) Series II included the undrained triaxial cyclic test followed by the undrained triaxial monotonic shear test. 20,000 cycles were applied in the dynamic phase.

(Bakowska, 2008).

Table 3 shows the index properties of soils tested and the fines content of undisturbed soils are between fibre content 56 to 99 % and plasticity index values change from undefined to 28 %. Samples taken out from near surface to depth 3.00m to 3.50m ground level. Overconsolidation ratio (OCR) was in the range between 2.75 to 3.85.Table 4 showed cyclic triaxial shear test properties of undisturbed fine grained soils. The diameter and height of the samples were 50mm 100mm respectively. Samples isotropically consolidated in 100 kPa effective confining stress and cyclic test performed at 0.1 Hz frequency. The frequency used under different cyclic shear stress ratios to eliminate the effects of consolidation pressure and loading frequency. The test conducted in undrained cyclic triaxial test at different cyclic stress ratio that applied to specimens for 20 loading cycles and strain rate 0.20mm/min.

Based on the Erken, Kaya & Sener (2008) the researcher reported that, regarding the cyclic and the post-cyclic behaviours using cyclic triaxial test apparatus, monotonic undrained axial stress of undisturbed fine grained soils depends on the cyclic axial strain and decreases by increasing of cyclic axial strain level. While other researcher, the organic content in peat soil also influences the parameters of consolidation. Peat shows the higher value of coefficient of consolidation compares to clay.

settlement and stability. Huat (1994), describe the definition of soft clays are of low strength and high compressibility, sensitive and, in their strength is reduced by disturbances. Review of the basic and engineering properties of some of these deposits have been widely discussed by Ting *et al.*, (1987) where thick deposits of soft clays in coastal areas and major river valleys and varying thickness from 5m to 30m.

Previous studies have shown that, during undrained compression loading, the effective stress path of a normally consolidated clay after cyclic loading is similar to the effective stress path of an overconsolidated clay (Hyde and Ward, 1985. Matsui *et al.*, 1992, Yasuhara *et al.*, 1992).

Figure 7 shows the cyclic undrained test results of the reconstituted and undisturbed silty clays performed by Erken and Ulker (2008). The specimens conducted in cyclic and

Table 3: Index properties of soils tested (Erken *et al.*, 2008)

Borehole No	Sample No	Depth (m)	I_p (%)	w_L (%)	w_P (%)	Fibre Content (%)
BH4	S4-1	3.00-3.50	22	-	-	56
BH6	S6-1	3.00-3.50	45	50	23	97
BH6	S6-2	3.00-3.50	42	59	28	99

Table 4: Cyclic triaxial shear test properties of undisturbed fine grained soils. (Erken *et al.*, 2008)

Test No	Borehole	Fibre Content (%)	After Consolidation γ_c (kN/m³)	PI	B (%)	$\sigma_d/2\sigma_c$	N $\varepsilon=\pm2.5$	N=20 ε	N=20 r_u	σ_m kPa ε=%10
S4-1	BH4	55	17	-	96	0.32	19.3	2.8	1	187
S6-1	BH6	97	14.2	23	100	0.42	-	2.1	1	129
S6-2	BH6	99	12.8	38	96	0.48	18.3	2.7	1	121

VII. Post-Cyclic On Clay Soil

Soils vary enormously in characteristics. The measurement and selection of soil parameters for geotechnical design is very important and poorly determined parameters can have significant safety and economic consequences. Clay classified as soft soil in itself class. The behaviour of soft alluvial soils is influenced by the source of the parent material, depositional processes, erosion, redeposition, consolidation and fluctuations in groundwater levels (Tan *et al.*, 2004). In addition, Tan, Ng & Lee (2004) stated, there are two (2) main geotechnical problems in soft clay engineering, namely

monotonic tests on reconstituted and undisturbed silty and clayey soil. Figure 7 (a) indicated as reconstitute sample with plasticity index is 18 and figure 7 (b) using undisturbed sample with plasticity index 9. At the first step of the study, researcher stated all samples were isotropically consolidated to 100kPa effective confining stress and cyclic tests were performed at a frequency of 0.1Hz under different cyclic shear stress ratios in order to eliminate the effects of consolidation pressure and the loading frequency.

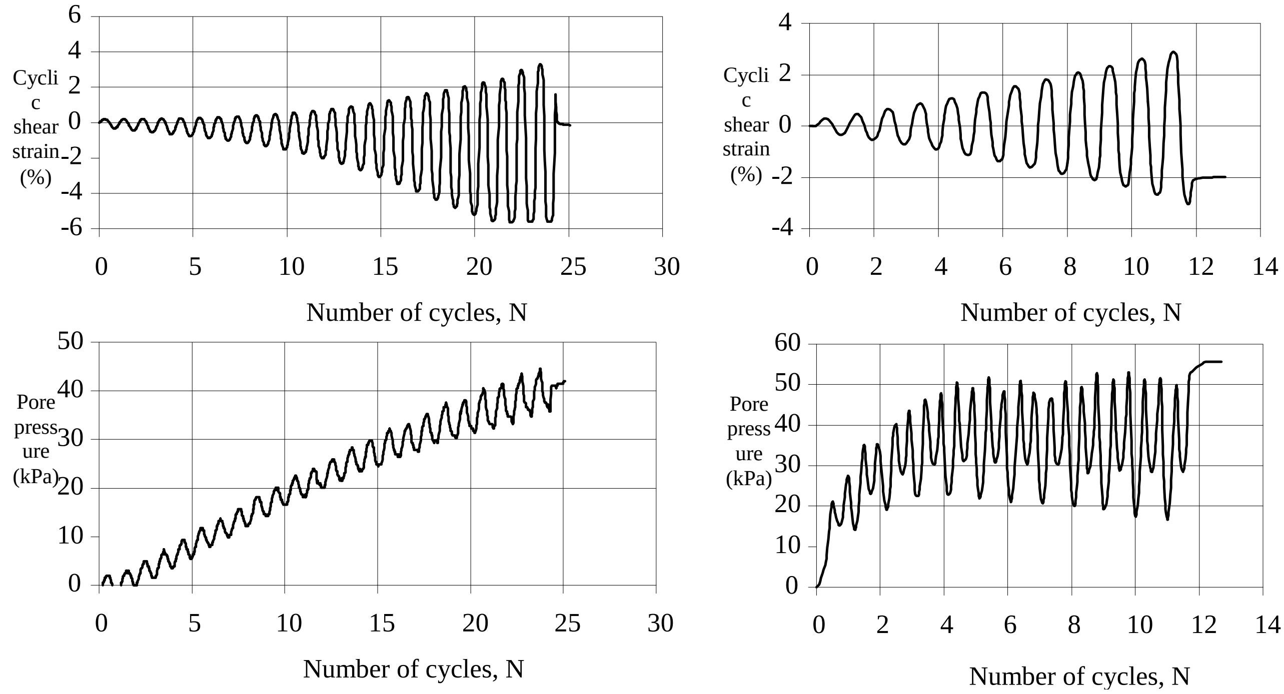
However, Ho, Goh and Lee (2004) has explained that one possible limitation in past studies is the relatively fast rates of cyclic loading used which typically ranges from 0.5 Hz to 1 Hz. In this situation, figure 7 (a) shows the relationships between shear strains versus the number of cycles, and pore water pressure versus the number of cycles (N) of reconstituted soil specimens and a plasticity index (PI) stated of 18 and under τd/σc = 0.185 cyclic shear stress level. Researcher found the end conclusion during the procedure of test where, Shear strain increases by the

number of cyclic loadings, and exceeds a failure limit in 17 cycles with 5% DA shear strain, allowing the pore water pressure (Δu/σc) an increase of only 33kPa and 44 at the end of the test.

Apart from the post-cyclic undrained shear strength, the induced apparent overconsolidation ratio from cyclic loading was also used to determine how the subsequent monotonic effective stress path approaches the critical state

The figure 7 (b) of undisturbed sample has shown different behaviour rather than reconstitute sample. From the pattern of amplitude till the pore water pressure. Thus, when the excess pore water pressure increased steadily with each cycle and reached 50kPa, that issmaller than the effective confining pressure, shear strain was 2%. Pore pressure remained constant even shearstrains already exceeded the failure limit of 5%.

The silty undisturbed specimens have considerably more cyclic strength resulting from reconstituted specimens with a plasticity index of 18. The researcher describes when the ratio of natural water content to liquid limit (wn/wl) exceeds 0.90, undisturbed soils become more collapsible due to strain



(a) Reconstitute sample PI=18 τ/σ=0.185 (b) Undisturbed sample PI=9 τ/σ=0.240

Figure 7: Cyclic undrained test results of the reconstituted and undisturbed silty clays (Erken and Ulker, 2008)

line (Yasuhara *et al.*, 1992). In figure 7 (b) it shows, the typical cyclic test result of undisturbed silty soil specimen with a plasticity index of 9. With allowable pore water pressure to remain at 50kPa, Shear strains increase rapidly with the number of cycles.Monotonic loading was applied at a 0.50mm/sec loading rate, and lasted till the soil specimens exhibited a shear strain of 10%. The porepressure behaviour of undisturbed soil, with an anisotropic soil structure, was compares and different from reconstituted soilsamples.

The silty undisturbed specimens have considerably more cyclic strength resulting from reconstituted specimens with a plasticity index of 18. The researcher describes when the ratio of natural water content to liquid limit (wn/wl) exceeds 0.90, undisturbed soils become more collapsible due to strainsoftening within 20 cycles with a pore pressure ratio ranging from 0.52 to 0.60.

Figure 8 shows and presented data from cyclic undrained test results of the reconstituted and undisturbed clays specimen performed by Erken and Ulker (2008). The researcher are compared in between two cities specimens obtained from Adapazari and Izmir to determine the cyclic behaviours of undisturbed soils. The undisturbed specimens had fines content between 52% and 95%, and the plasticity index ranged from 5 to 13. The increased cyclic shear stress ratio can be seen in figure 2.10 (b) causes it to reach the failure limit of shear strain of 5% in less loading cycles. During initial cycles, Shear strains increase rapidly and the undisturbed soil specimen loses its cyclic strength through the test.

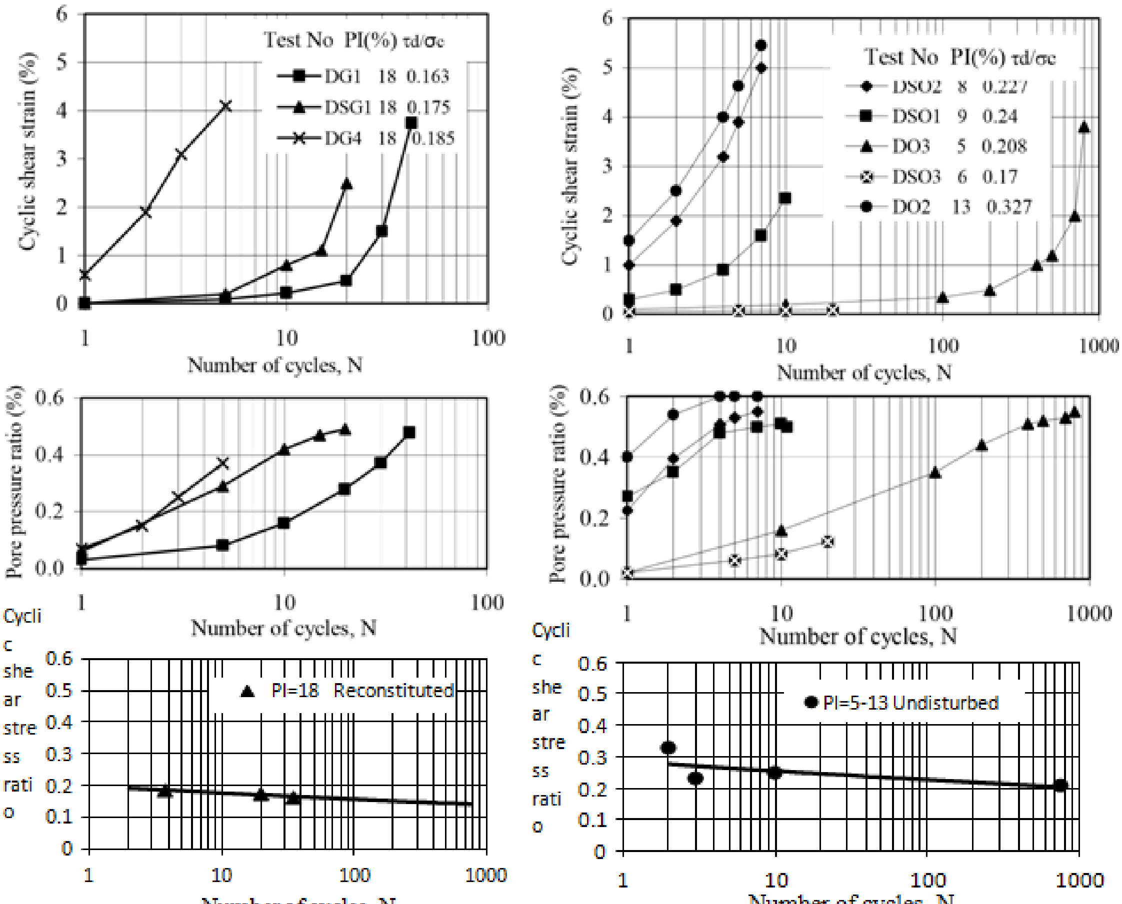
(a) Reconstituted samples

Figure 8: Cyclic undrained test results of the reconsti
(Erken and U

Table 5: Cyclic torsional shear test properties of reconstituted (I
(Erken and Ulker, 2008)

Specimen	Test No[a]	w_n (%)	w_n/w_l	PI (%)	γkc (kN/m^3)	τ_d/σ_c	N ($\gamma=\pm 2.5\%$)
U	DO2	37	0.99	13	13.9	0.327	1
U	DO3	19	0.61	5	14.6	0.208	760
U	DSO1	30	0.97	9	14.4	0.240	10
U	DSO2	29	0.85	8	14.4	0.227	3
U	DSO3	28	0.90	6	14.0	0.170	20*
R	DG4	15	0.38	18	15.2	0.185	5
R	DSG1	17	0.43	18	14.9	0.175	20
R	DG1	16	0.40	18	15.2	0.163	35

Note:-
The test is continued till 0.18 % DA strain
Symbols define the test conditions; D denotes cyclic test, DS denotes cyclic and post cyclic monotonic test.



At the early stage of the test for reconstituted samples as shown in figure 2.10 (a), the cyclic shear stress ratio of 0.175 as a corresponding stress value of N=20 cycles, the researcher stated it was considered for an earthquake magnitude with 7.5 at it was determine from the relationship of cyclic shear stress versus number of cyclic (N). The cyclic shear stress level was applied at different number of cycles to each specimen.

At the final study, the researcher have concluded the findings. There are some criteria cyclic behaviours and post cyclic monotonic shear strength of reconstituted and undisturbed fine grained soils have been studied in triaxial test apparatus. Erken and Ulker (2008) concluded that, the cyclic undrained shear strength of undisturbed soft silty soil is considerably higher than that ofreconstituted specimens depending on the aging and initial fabric and the monotonic undrained shear strengths of reconstituted and undisturbed specimens decrease with the cyclic shear stress history. The researcher also presented that, the reduction is significant when the soil specimen exceeds a certain yield strain level under the same shear stress amplitude prior to static undrained test, and reaches nearly 40% in silty soil.

According to Ho *et al.*, (2012), when undrained cyclic triaxial tests on clays are conducted at a sufficiently slow rate for pore pressure equilibration, intrinsic strain rate effects on pore pressure measurements, effective stress paths and stress-strain relationships are negligible. On the other hand, when the normalized mean effective stress state of the clay specimen at the start of post-cyclic monotonic loading falls below 0.5, stress reversal becomes evident and the effective stress path becomes similar to that of heavily overconsolidated clays (Ho *et al.,* 2012).

VIII. POST-CYCLIC ON SAND

Loose cohesionless materials can collapse during either static or dynamic loading, resulting in a rapid build-up of pore pressure and associated reduction in shear resistance. Gupta, Negi & Ashok (2013), describes the sand as a natural granular material composed of finely divided rocks an d mineral. The composition of sand varies according to the parent rock and the mode of transportation. Sand is transported by various agents like wind and water, and it is form of beaches, dunes, sand spits, sand bars and river.

Behaviour of sand also defined by Castro (1969) and classified as “soil liquefaction” as the behaviour of saturated, loose sand where increasing pore pressures due to undrained shear decrease the effective stresses resulting in a reduction in the shear resistance to a constant value, called steady state. There are many studies conducted in many years and experimental test series were performed to describe and highlighting the mechanical behaviour of sand soils under cyclic and dynamic loads both in drained and undrained conditions.

The experimental works in the present investigation inviting many researchers to established data were collected. With regard to that, the paper is concentrated at reviewing the results of previous laboratory investigation on sand behaviour under cyclic and dynamic loading related to this study is Suresh, Maheswari and Kaynia (2010). The researcher has go through the dynamic properties of Solani sand under cyclic loads. The samples Solani sand are investigated by a series of cyclic triaxial tests.

The researcher presented the effect of parameters such as relative density, amplitude of cyclic shear strain, confining pressure and frequency of cyclic loading on dynamic soil properties. Samples collected from bed of Solani River and cyclic triaxial test were carried out and conducted by varying different parameters that primarily concern such as number of cycles applied, confining pressure, relative density, frequency of loading and shear strain amplitude. Researcher in that study were used three types of sampling procedure techniques for triaxial testing on saturated sand called moist placement method or wet tamping, dry deposition and water sedimentation method.

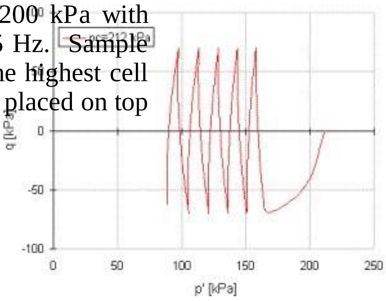
TABLE 6: COMBINATION OF PARAMETERS FOR TRIAXIAL TESTING ON SOLANI SAND

(Suresh *et al.*, 2010)

Test No.	Cell Pressure	Frequency
1 to 7	100 kPa	1.0 Hz
8 to 14	100 kPa	1.0 Hz
15 to 21		0.5 Hz
22 to 28	100 kPa	1.0 Hz
29 to 35		1.5 Hz
36 to 42	150 kPa	1.0 Hz
43 to 49	200 kPa	1.0 Hz

Table 6 shows the combination of Parameters for Triaxial Testing on Solani Sand(Suresh et al., 2010). There are three types of cell pressures 100 kPa, 150 kPa and 200 kPa with three different frequencies 0.5 Hz, 1 Hz and 1.5 Hz. Sample 43 to 49 imposed with 200 kPa and 1.0 Hz as the highest cell pressure used. Porous stone and filter paper was placed on top of the sample.

a) σ_a =0.059 kPa/s



c) σa =5.9 k

Figure 10: Numerical simulation of a standard un
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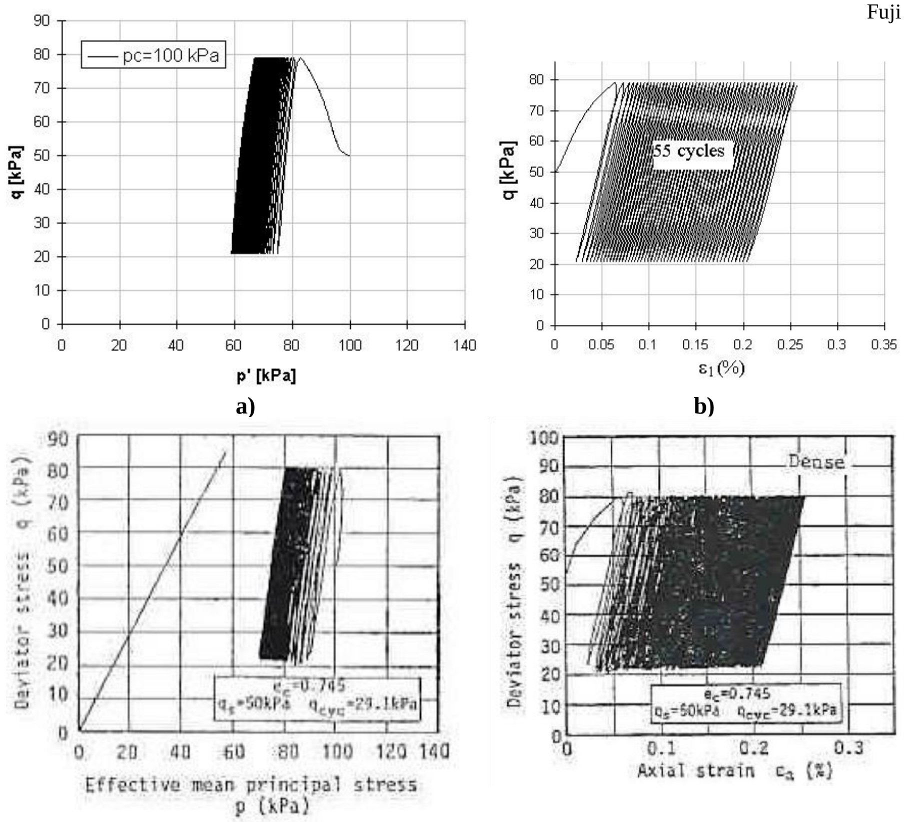
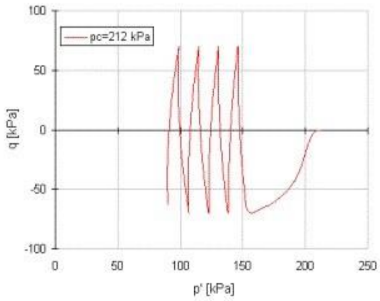
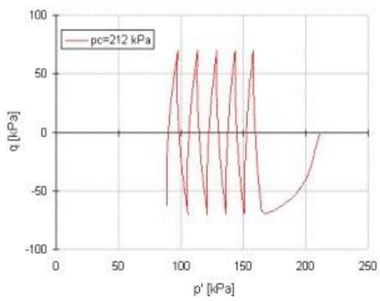


Figure 9: Undrained cyclic compression triaxial test on a Toyoura dense sand specimen:
a) and b) numerical simulation, c) and d) experimental data
(Prisco and Zambelli, 2003)





These findings are in close agreement with the results reported by Choudhary *et al.*, (2010) where the researcher concluded, when the confining pressure is increased, there is increase in shear strength of the soil sample. Pore water pressure builds up slow and there is triggering of liquefaction at higher cycles.

Prisco and Zambelli (2003) was observed that, the increase in the pore pressure is inhibited by the increase in the effective stress level and a sort of phenomenon of stabilisation takes place. Figure 9 shows the undrained cyclic compression triaxial test on a Toyoura dense sand specimen. (a) and (b) expressed the numerical simulation of sand while (c) and (d) is the end result of experimental data performed.In fact, on the contrary, when a loose sand specimen is cyclically loaded, liquefaction takes place.

Figure 10 shows the numerical simulation of a standard undrained triaxial cyclic test on Fuji River loose sand specimen at varying loading rate presented by Prisco and Zambelli (2003). Some numerical simulations of a standard undrained triaxial cyclic compression test performed at varying stress rates are shown in figure 10. Researcher considers that, these observations become very important when large strain cycles are triggered by seismic actions. According to Tatsuoka *et al.*, (1998), there are some triggers that can be observed by time effect during laboratory experimental tests on sand specimen as follows:-

a) Creep deformation at constant effective stress state,

b) Strain relaxation at constant axial strain,

c) Temporary overshooting and undershooting in stress immediately after change in constant strain rate.

d) Volumetric instabilities, sudden collapses, of loose sand specimens tested in load controlled conditions.

CONCLUCIONS

Based on the review of a number of available research about post-cycling loading results, it is concluded in different intensity of soil as a sample. There are many factors have to be considered. This paper presents the results from various researchers of consolidated undrained tests as well as post-cyclic triaxial compressions test on three sample peat, clay and sand. The main conclusions of the review are summarized, as follows:

1. Higher plasticity soils generally exhibit a more linear cyclic stress-strain response.
2. Based on clay sample tested, an effective stress reduces by generating excess pore water pressure and induces apparent overconsolidation in the specimens.
3. Post-cyclic monotonic tests showed that, the cyclic loading degrades undrained shear strength and secant deformation modulus of the clay and mixed specimens.
4. The post cyclic behaviour on clay soil, is governed by the normalized mean effective stress after cyclic loading. Independent of the effective consolidation pressure take in to account with cyclic strain amplitude and number of cycle that applied in the test.
5. On sandy soil, when the number of cycle is quite large or the material considered granular and loosely compacted, the essential factor influencing the mechanical response known as the evolution of relative density are main concerned.
6. Relative density for sand has significant effect on shear modulus values. At the lower shear strain levels, it become not so significant to the effect of large strain levels effect.
7. Shear modulus and the damping ratio of the sandy soil decreases when the number of cycles of loading increases.
8. In peaty soil, the values of angles friction ϕ' get increase when the cohesion c' reduced.
9. A substantial decrease in the shear resistance for cyclic loading. Increasing number in cycles of stress application will result in decreases of post-cyclic shear stress.

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