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## Aging Effects on One Way Cyclic Loading Resistance of Loose Silty Sand

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### Abstract

This research investigated creep induced aging of loose non-plastic (15% fine content) silty sand via triaxial testing. Aging effect on cyclic resistance under undrained one way cyclic loading, which have been relatively little investigated, was studied. Following  $K_0$  consolidation at 60 kPa confining pressure, the samples were aged for creep observation and then sheared. The results showed that the number of cycles required triggering cyclic softening and liquefaction for one way cyclic loading condition increases with the aging duration. In addition the aging effect is more pronounced at lower cyclic stress ratio. Observation of creep from local strain measurements shows that during creep, the soil is contractive.

**Keywords:** Aging;  $K_0$ ; loose; silty sand; undrained; one way cyclic.

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### 1. INTRODUCTION

Time has been known to affect the behaviour of soils. Over geological time, soils can turn into rock (e.g. sand into sandstone), and rock weather to form soils. It has been observed that over a shorter period, e.g. weeks, months, and years, soils properties and behaviour can also change. Some laboratory studies [1] have even shown that the time effect in the range of minutes could also be significant.

Sand aging is a macroscopic phenomenon which describes the increase in stiffness [e.g. 2, 3, 4] and strength [e.g. 5, 6] of sands over time following disturbance or deposition. Aging effects under two-way cyclic loading have been relatively well investigated by previous researchers [7, 8]. For instance, Saftner [7] performed two-way cyclic loading tests of loose moist tamped clean sand ( $CSR=0.225$  and  $CSR=0.175$ ) and found that increasing holding time, i.e. aging following isotropic consolidation, increased the number of cycles to initiate liquefaction across different values of  $CSR$ . Investigation of aging effects on cyclic resistance under one-way cyclic loading is relatively limited, thus this study focuses on this matter. One-way cyclic loading is relevant, for example, to the development of deformations in natural slopes, embankment slopes, dams and quay wall backfills during earthquake loading [9].

In this study, one-way cyclic loading of triaxial tests were performed to evaluate the number of cycles to trigger strain-softening ( $N$ ) at a given cyclic stress ratio ( $CSR$ ), where  $CSR$  is defined as the ratio of shear stress (equal to half of deviator stress) to initial effective confining pressure. The number of cycles ( $N$ ) in this study was taken as the number of

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cycles to trigger strain softening and consequent liquefaction as illustrated Figure 1. Besides investigating the aging effects, this study also observed creep behaviour during aging.

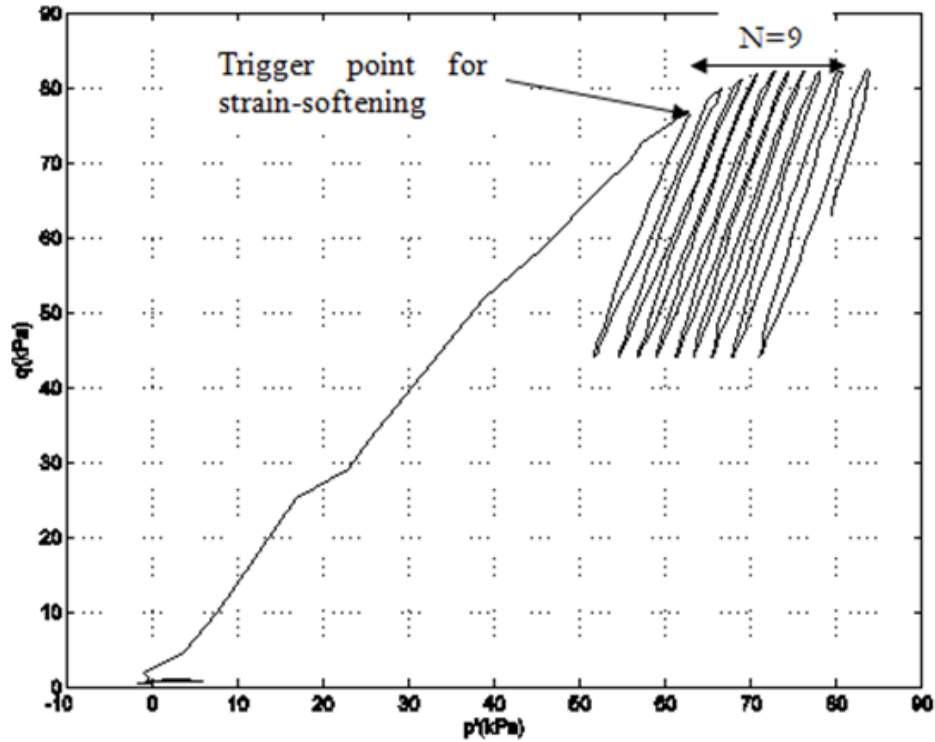


Figure 1 Definition of number of cycles to trigger strain-softening (N) used in this study

## 2. EXPERIMENTAL PROGRAM

### 2.1. Material

The material used in this research program is silty sand. Silty sand was chosen considering that majority of previous laboratory research on sand ageing has been performed on clean sand while sands containing fines are far more common in nature. Silty sand was reconstituted in the laboratory by mixing sand and fine fractions ( $<75\mu\text{m}$ ). The sand fraction was collected from a site that liquefied during the Canterbury Earthquake, Christchurch, New Zealand in 2010[10, 11]. Sand particle diameters range from  $75\mu\text{m}$  to  $300\mu\text{m}$ . The fine fraction is non-plastic silica flour with diameter range from  $32\mu\text{m}$  to  $75\mu\text{m}$ . The percentage of fine fraction used in this study is 15. The specific gravities  $G_s$  of the sand and silt ranged from 2.64 to 2.65. Maximum and minimum void ratios of the silty sand are 0.973 and 0.565 respectively. Figure 2 shows the particle size distribution of the combined soils.

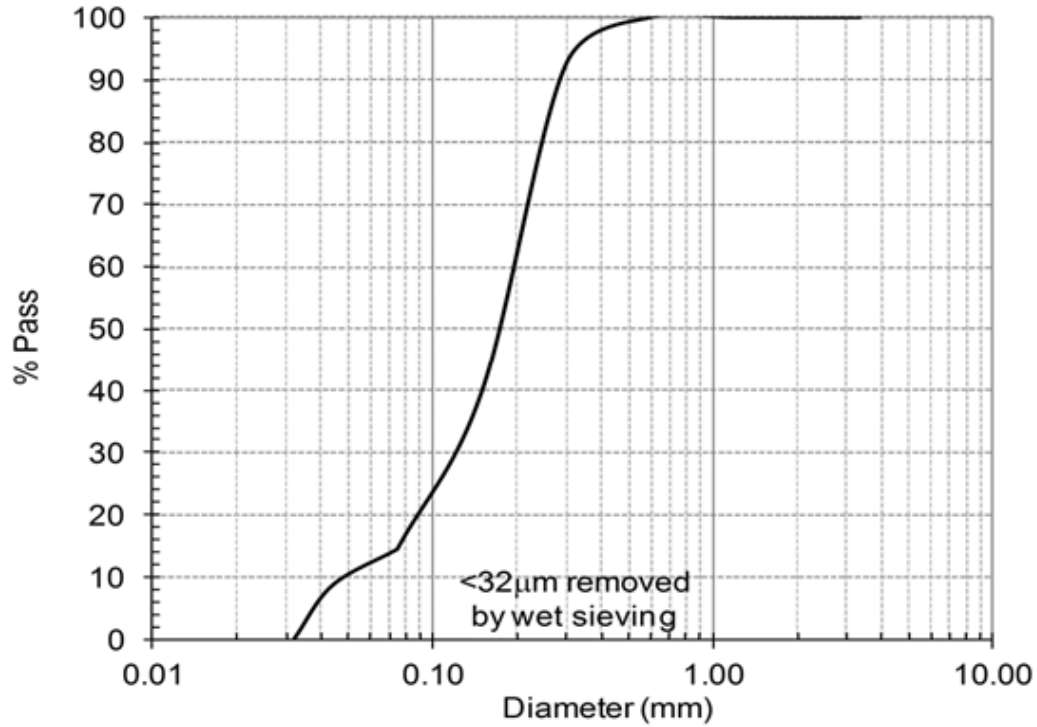


Figure 2 Combined particle size distribution.

## 2.2. Triaxial test

Triaxial tests were conducted using a Geotechnical Digital System (GDS) triaxial machine that has been enhanced by adding a local Linear Variable Differential Transformer system (1 radial LVDT and 2 axial LVDTs). Enlarged platens were used along with the lubricated ends. Samples were reconstituted by under compaction moist tamping [12]. Figure 2 shows example of the sample after being prepared and instrumented by local LVDTs. After initial vacuum of 15kPa the samples were saturated by slowly percolating CO<sub>2</sub> for 1.5 hours (2-3 air bubbles per second). Water then was percolated through the sample from the bottom under 0.3m head to minimize loss of fines.  $B > 0.98$  was obtained for all the samples.

The sample then was  $K_0$  consolidated to 60 kPa effective confining pressure. The loading rate was chosen as 15kPa/hour. In this study, the consolidation was considered to be complete when no pore pressure was observed during and at the end consolidation. During  $K_0$  consolidation, the radial strains from external and local system were much lower than 0.05% as required by Japan Geotechnical Standard [13]. At the end of consolidation, the obtained  $K_0$  value was 0.48.

Following the consolidation stage, back pressure, cell pressure and deviator stress were held constant for a certain period of time i.e. 1 hour and 1 week. This is referred to as creep stage. In the last stage, the samples were sheared at under stress control at a loading rate of 2 min per loading cycle under undrained one way cyclic loading condition. This loading rate was chosen considering the logging rate of the GDS data acquisition system [14]. Two cyclic stress ratios were used i.e. 0.12 and 0.18. Table 1 presents the list of cyclic tests in this study.

Table 1 Triaxial samples tested

No	Dr (%)	$\sigma'_3$ (kPa)	$K_0$	Test ID	Aging Time (min)	CSR
1	40.56	60	0.479	OWKoU-28	1 min	0.12
2	38.76	60	0.480	OWKoU-29	1 day	0.12
3	40.28	60	0.476	OWKoU-30	1 week	0.12
4	39.85	60	0.479	OWKoU-31	1 min	0.18
5	39.71	60	0.480	OWKoU-32	1 day	0.18
6	40.11	60	0.476	OWKoU-33	1 week	0.18

### 3. RESULTS AND DISCUSSION

Figure 3 shows the stress-strain relationship for one-way cyclic loading of samples with a mean effective stress of 60kPa and CSR=0.12 (OWKoU-28, OWKoU-29 and OWKoU-30) for 1 min, 1 day and 1 week of aging time. The corresponding stress path is shown in Figure 4. Figure 5 and Figure 6 show aging effects on cyclic resistance at CSR =0.18 and the corresponding stress path, respectively.

Figure 4 to Figure 6 show that all samples experience strain softening and reach zero deviatoric stress at different levels of strain. Regardless the level of the strain it can be seen in general that the number of cycles to trigger strain softening and liquefaction are greater as the samples are aged more as illustrated in Figure 7. It appears from the figure that the aging effect is more pronounced at lower CSR. For CSR=0.12 samples, the number of cycles increases from N=9 for 1 minute of aging to N= 12 and N=31 for 1 day and 1 week of aging sample, respectively. For CSR=0.18 samples, the number of cycles increases from N=1 for 1 minute of aging to N=4 and N= 9 for 1 week 1 day and 1 week of aging sample, respectively. Smaller CSR value means smaller strains thus more cycles are needed to destroy aging effects. Wang *et al.* [4] reported that the effects of aging can gradually diminish when shear strains are higher.

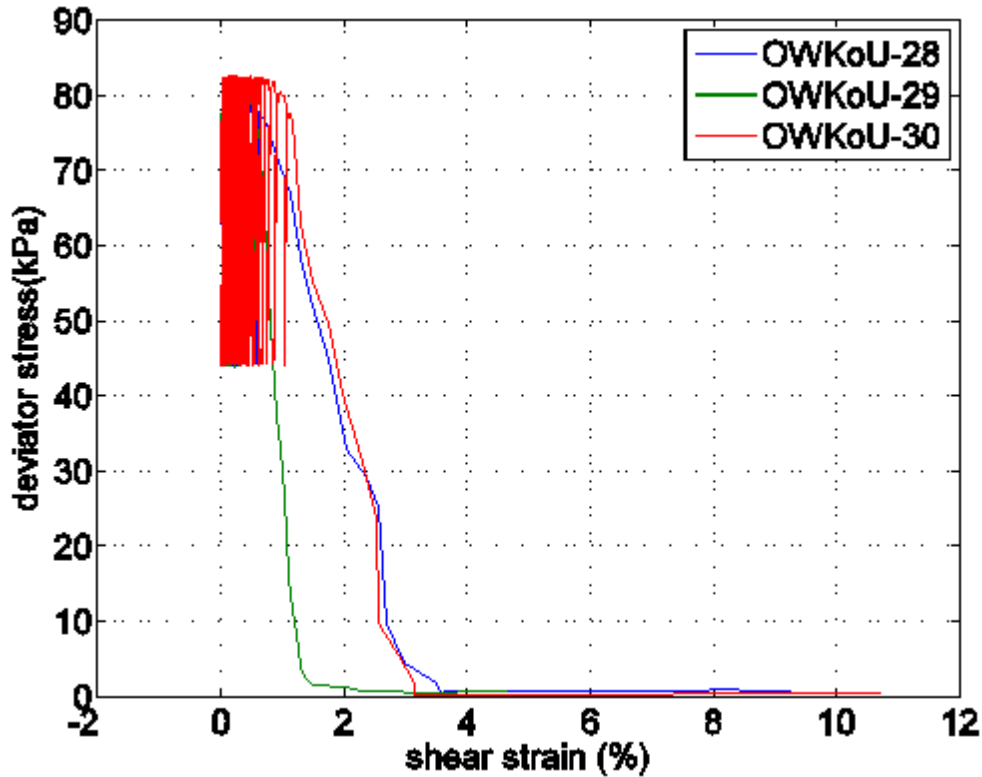


Figure 3 Stress-strain relationship of  $K_0$  consolidated samples under one-way cyclic loading at  $\sigma'_3=60$ kPa; CSR=0.12 for 1 min (OWKoU-28), 1 day (OWKoU-29) and 1 week (OWKoU-30) of aging time

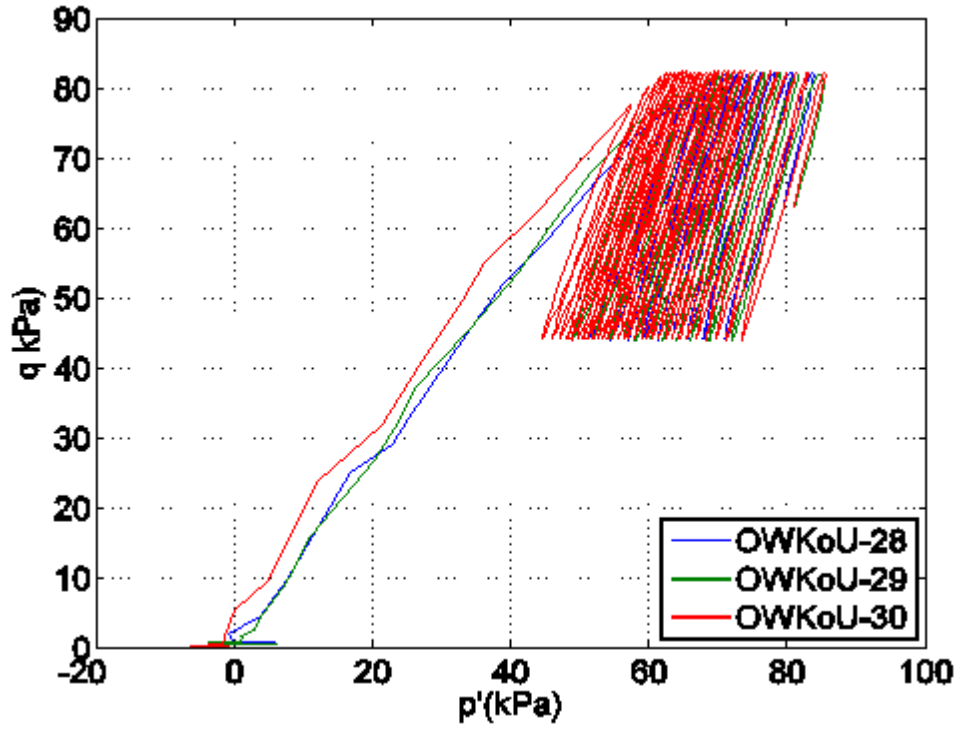


Figure 4 Stress path of  $K_0$  consolidated samples under one-way cyclic loading at  $\sigma'_3=60\text{kPa}$ ;  $\text{CSR}=0.12$  for 1 min (OWKoU-28), 1 day (OWKoU-29) and 1 week (OWKoU-30) of aging time

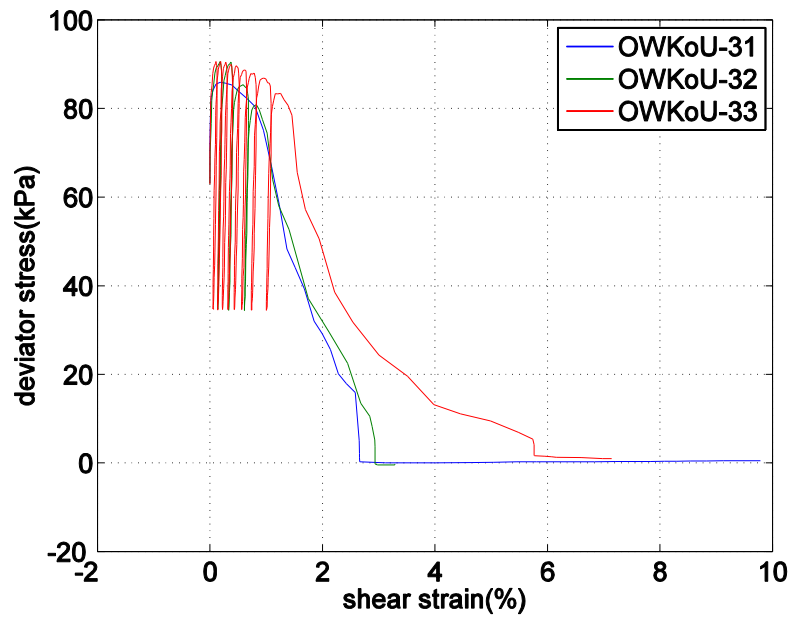


Figure 5 Stress-strain of loose  $K_0$  consolidated samples at  $\sigma'_3=60\text{kPa}$  under one-way cyclic loading;  $\text{CSR}=0.18$  for 1 min (OWKoU-31), 1 day (OWKoU-32) and 1 week (OWKoU-33)

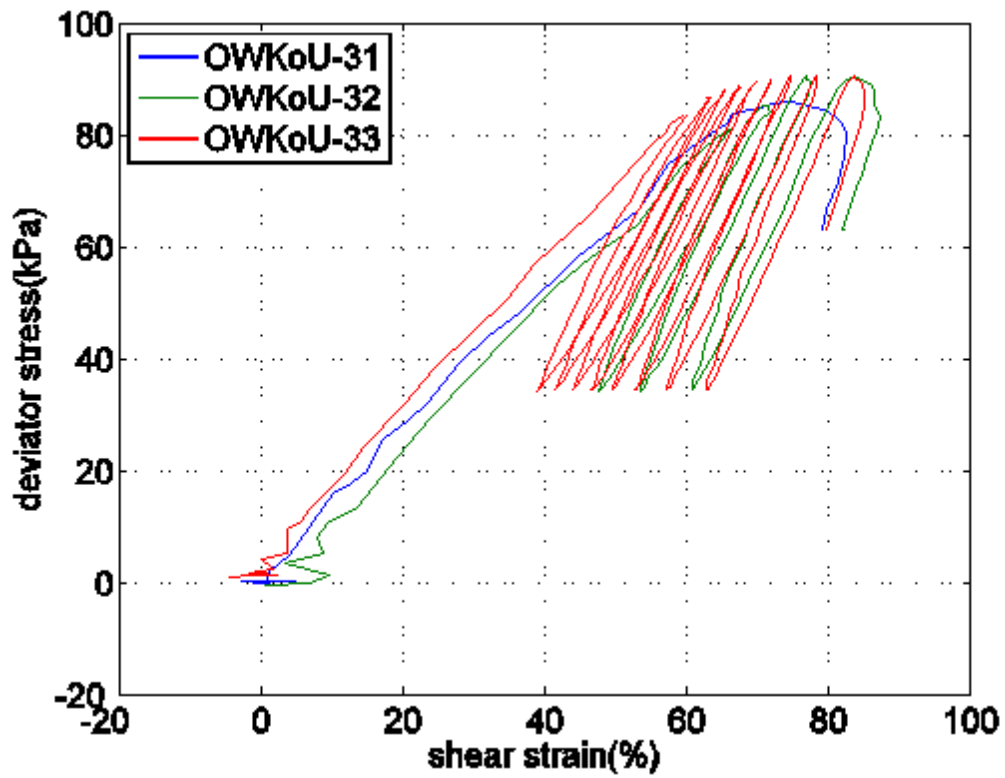


Figure 6 Stress path of  $K_0$  consolidated samples under one-way cyclic loading at  $\sigma'_3=60\text{kPa}$ ;  $\text{CSR}=0.18$  for 1 min (OWKoU-31), 1 day (OWKoU-32) and 1 week (OWKoU-33) of aging time

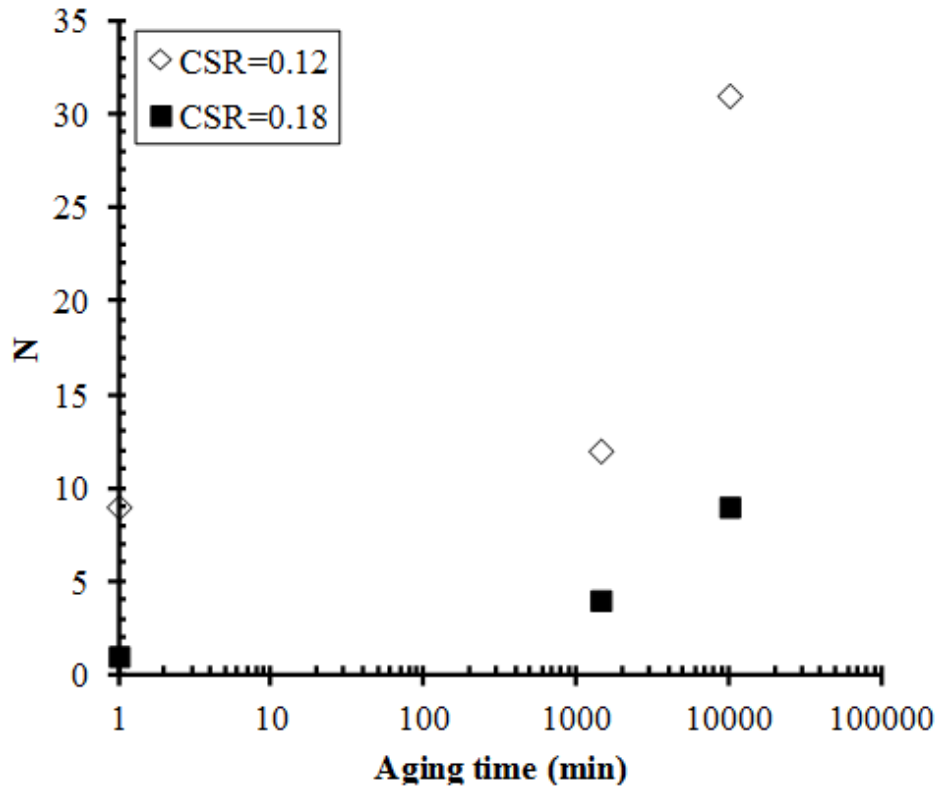


Figure 7 Aging effects on number of cycles to trigger strain-softening and consequent liquefaction under one way cyclic test

Figure 8 presents volumetric and shear strain observations from during the creep stage of triaxial tests. In terms of volumetric strain development, all loose samples, for up to one week of aging contract with at a decreasing rate with time, as shown by Figure 8(a). Figure 8 (b) shows that shear strains are in the positive direction and also increase at a decreasing rate with time.

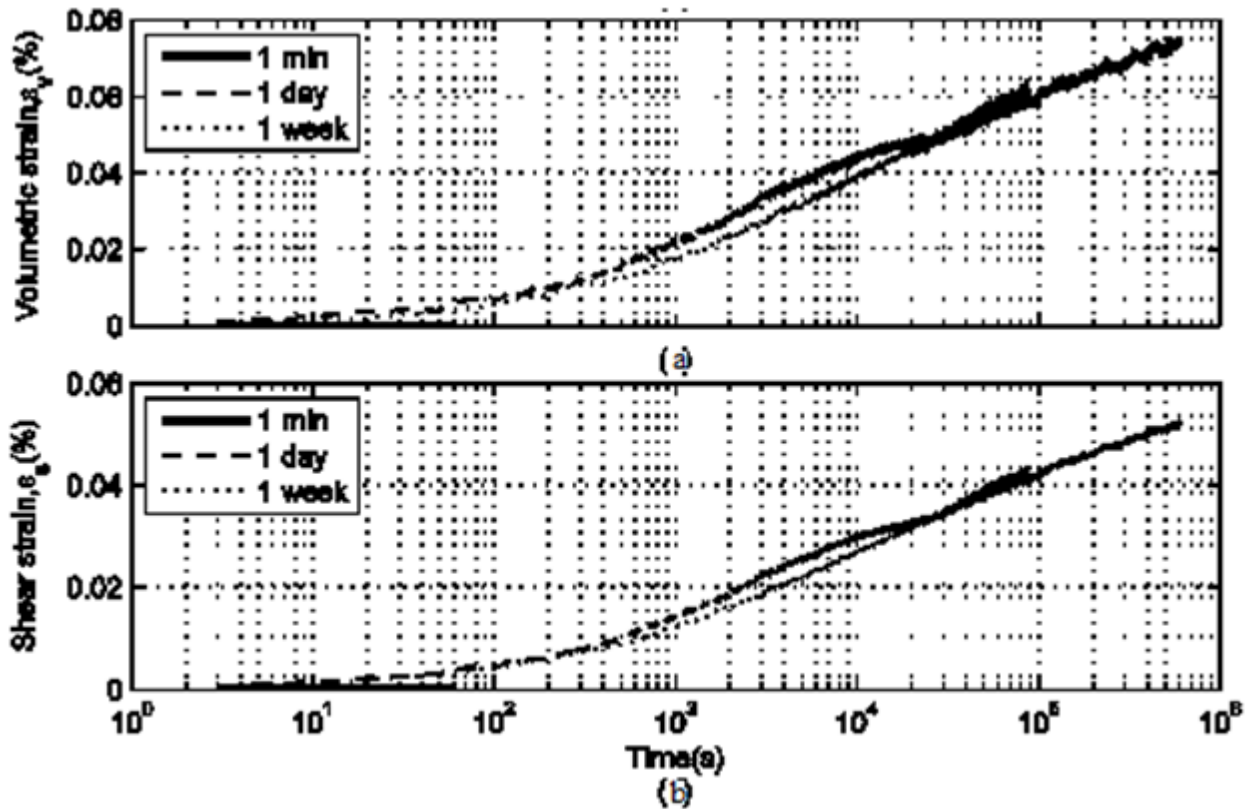


Figure 8 Development of strain during creep following  $K_0$  consolidation

#### 4. CONCLUSION

This study has shown that the number of cycles required triggering cyclic softening and liquefaction for one way cyclic loading condition increases with the aging duration. In addition the aging effect is more pronounced at lower CSRs. Contraction of loose silty sand in this study was observed during aging and creep under  $K_0$  condition.

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