# Basic behaviour study of cement treated Singapore marine clay

Mohanadas H. C.
*Department of Civil Engineering, National University of Singapore*
*Block E1A #07-03, 1 Engineering Drive 2, Singapore 117576*

## ABSTRACT

A study was conducted to investigate the effects of curing time on the basic behaviour of cement treated Singapore marine clay. Specimens were prepared in two different soil-cement-total water content ratios and left to cure under water for periods of 7 days, 4 weeks and 3 months. After curing, they were subject to a series of triaxial tests—unconfined compressive strength tests (UCT), isotropic compression tests (ICT), isotropically consolidated undrained tests (CIU) and isotropically consolidated drained (CID) tests. The effects of curing time on stress-strain and strength behaviour was investigated.

## INTRODUCTION

Singapore Upper Marine Clay located 4–5 m beneath the seabed, retrieved from a dredge site in Pulau Tekong, Singapore was used in this study. The specimens were mixed in soil-cement-total water content ratios of 2-1-4 and 5-1-6. To prepare the clay-cement mixture, the required amount of cement slurry was added to 100% water content remoulded clay and mixed in a Hobart mixer for about 10 min. The clay-cement mixture was then cured under water in PVC split molds of diameter 50 mm and length 100 mm. The specimens were trimmed down to diameter 38 mm by length 76 mm before testing. Parameters for the triaxial tests are given in Table 1. The UCT, CIU and CID tests followed standards for soil testing from the British Standards Institute (BSI, 1990).

Table 1: Parameters for triaxial tests.

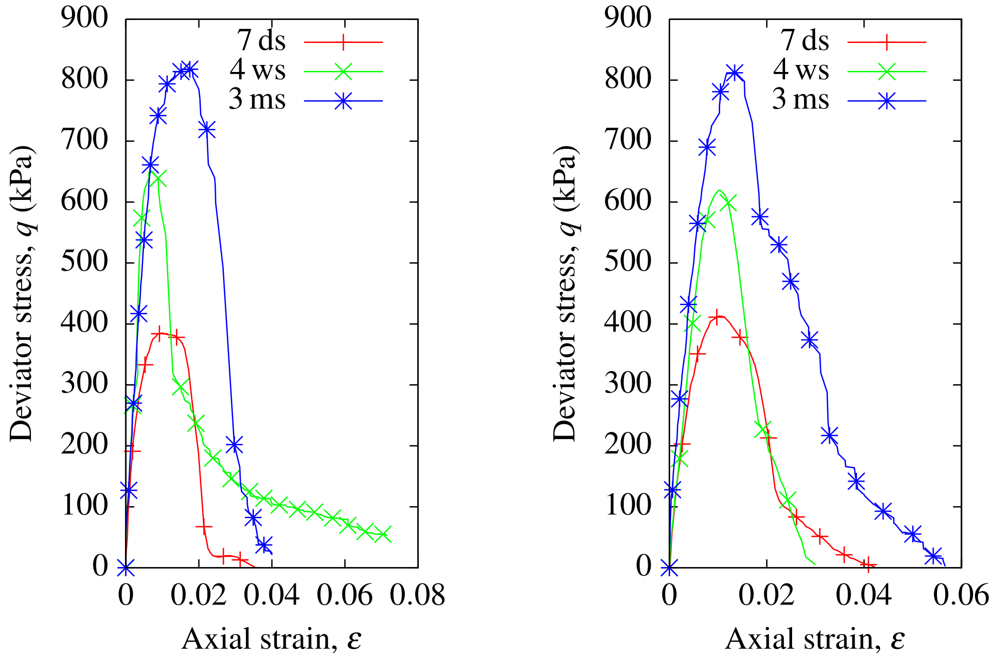
| | UCT | ICT | CIU | CID |
|---|---|---|---|---|
| Membrane thickness (mm) | | 0.2 | 0.2 | 0.2 |
| Axial displacement rate (mm/min) | 1 | | 0.01 | 0.007 |
| Isotropic loading rate (kPa/min) | | 1 | | |

## LITERATURE SURVEY

The soil-cement reaction mechanism involves two distinct reactions resulting in primary and secondary cementitious products. There is a rapid hydration reaction and a much slower pozzolanic reaction. The rapid hydration reaction occurs from the moment water is added to cement. It results in the primary cementitious products of hydrated calcium silicates ($C_2SH_x$, $C_3S_2H_x$), hydrated calcium aluminates ($C_3AH_x$, $C_4AH_x$) and hydrated lime $Ca(OH)_2$. The hydrated lime then dissociates and raises the pH value of the pore water. This causes the pozzolanic reaction in which silica and alumina in the soil dissolve and react with the now free $Ca^{2+}$ ions. The products of the pozzolanic reaction are the secondary cementitious products of hydrated calcium silicates and hydrated calcium aluminates.

It has been shown that an increase in the curing time of cement treated Singapore marine clay from 7 days to 4 weeks resulted in a higher unconfined compressive strength (Chew et al., 2004). Findings from (uniaxial) oedometer consolidation tests on Singapore marine clay revealed that the change in the compression index, $C_c$, and recompression index, $C_r$, between 7 days and 4 weeks was "rather insignificant" (Chew et al., 2001). The current study explores the effects of curing time on specimens under triaxial conditions with curing times of up to 3 months.

Cement treatment can be done in the practice through deep mixing and jet grouting. Both the mixing ratios used in this study were within the range of mixing ratios used in some previous studies on deep mixing and jet grouting (Lee et al., 2005).




(a) 2-1-4 specimens

(b) 5-1-6 specimens

Figure 1: Results of UCT tests for (a) 2-1-4 specimens and (b) 5-1-6 specimens.

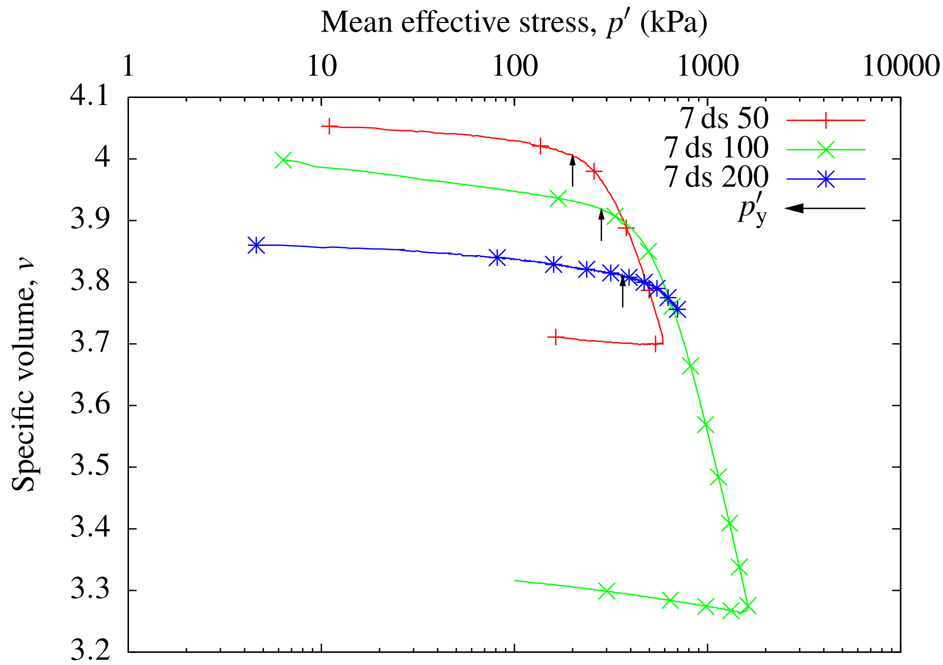
## RESULTS AND DISCUSSION

### Unconfined compressive strength tests

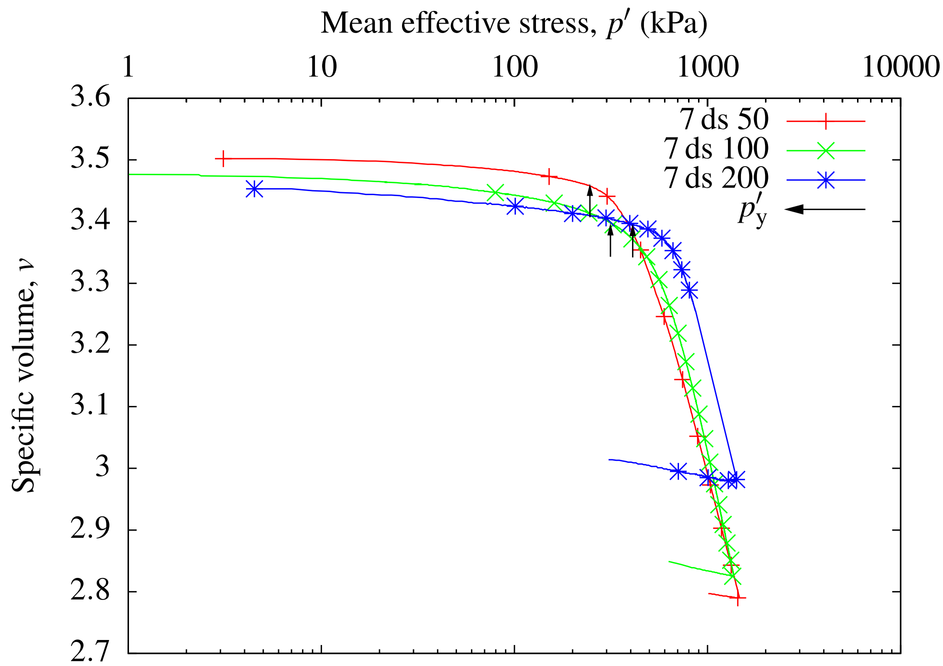
Results from the UCT tests are given in Figure 1. They show a significant increase in the unconfined compressive strength from 7 days to 4 weeks and a further increase from 4 weeks to 3 months. The average rate of this increase between 4 weeks and 3 months is lower than $\frac{1}{3}$ of the average rate between 7 days and 4 weeks. Thus, there seems to be a modulation the curing time effect on unconfined compressive strength after 4 weeks of curing.

### Isotropic compression tests

Figure 2 shows the results from the ICT tests. The isotropic yield stress, $p'_y$, was determined according to the method used in Rotta et al. (2003). It shows an increase in the isotropic yield




(a) 2-1-4 specimens




(b) 5-1-6 specimens

Figure 2: Compression space curves from ICT tests on (a) 2-1-4 and (b) 5-1-6 specimens.

stress with an increase in the curing time. However, the average rate of this increase between 4 weeks and 3 months is lower than the average rate between 7 days and 4 weeks. Thus, there seems to be a modulation in the curing time effect on the isotropic yield stress after 4 weeks of curing.

On the other hand, the effect of curing time on the isotropic recompression and isotropic compression indices is rather insignificant. This is similar to findings for the uniaxial case by Chew et al. (2001)

**Consolidated-undrained triaxial compression tests**

Figure 3 shows the stress-stain curves from the CIU tests. There is a significant increase in the peak strength from 7 days to 4 weeks and a further increase from 4 weeks to 3 months. The average rate of this increase is much lower between 4 weeks and 3 months than between 7 days and 4 weeks. This suggests that there is a modulation in the curing time effect on the peak strength under undrained triaxial compression after 4 weeks of curing.

Longer curing times also result in an increase in the stiffness of the specimens. The average rate of this increase is much lower between 4 weeks and 3 months than between 7 days and 4 weeks. Thus, there seems to be a modulation in the curing time effect on the stiffness under undrained triaxial compression after 4 weeks of curing.

**Consolidated-drained traiaxial compression tests**

Figure 4 shows the compression space curves from the CID tests. At longer curing times, there is a reduction in the instantaneous compression index. This can be observed by comparing the instantaneous slope of the compression space curves for different curing times. This curing time effect on the instantaneous compression index seems to modulate after 4 weeks of curing.

Figure 5 shows the deviator stress-strain curves from the CID tests. It can be seen that curing time has no effect on the residual strength of the specimens tested. However, there is a significant increase in the stiffness of specimens with an increase in curing time. The average rate of this increase between 4 weeks and 3 months is lower than that between 7 days and 4 weeks. Thus, there seems to be a modulation in the curing time effect on the stiffness under drained triaxial compression after 4 weeks of curing.

## CONCLUSION

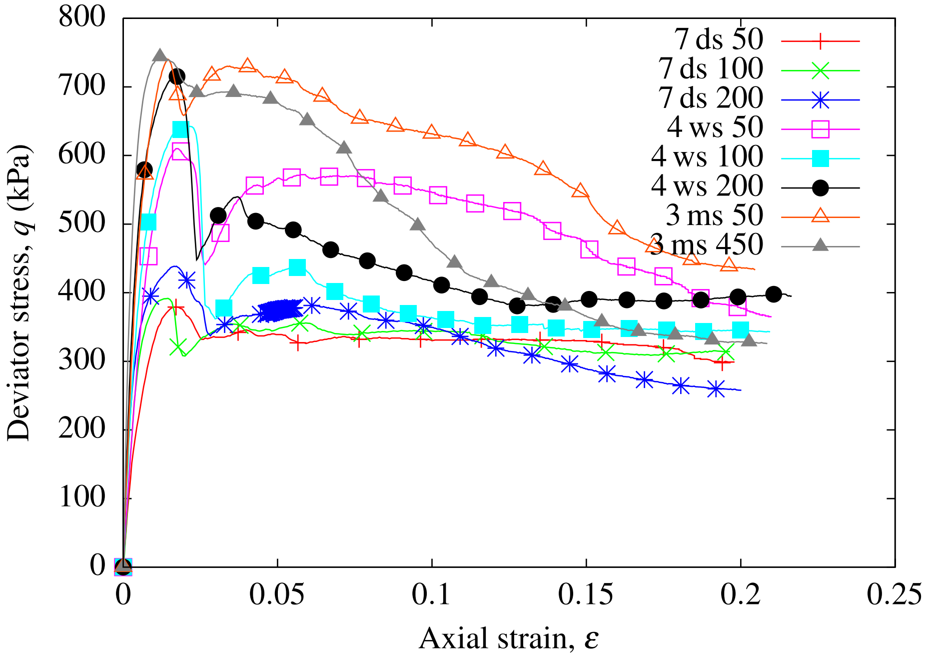
In the UCT tests, an increase in the curing time resulted in an increase in the unconfined compressive strength. There seemed to be a modulation in this curing time effect after 4 weeks of curing.

In the ICT tests, an increase in the curing time resulted in an increase in the isotropic yield stress. This curing time effect seemed to modulate after 4 weeks of curing. However, curing time had a rather insignificant effect on the isotropic recompression and isotropic compression indices.

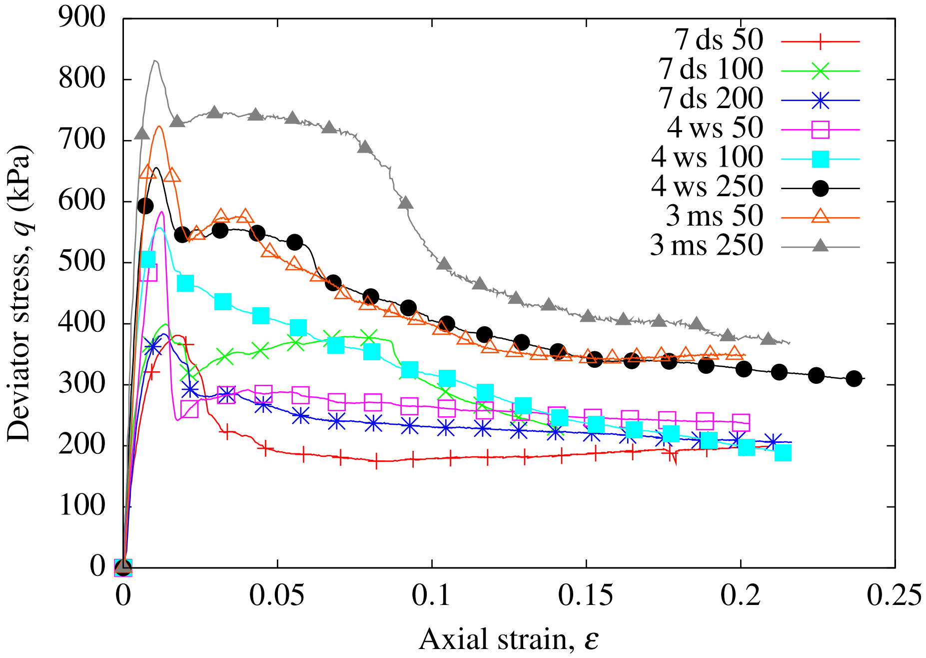
In the CIU tests, an increase in the curing time resulted in an increase in the peak strength and in the stiffness. Both these curing time effects seemed to modulate after 4 weeks of curing.

In the CID tests, an increase in the curing time resulted in an decrease in the instantaneous compression index and in an increase in the stiffness. Both these curing time effects seemed to modulate after 4 weeks of curing. It was also found that curing time had no effect on the residual strength.

Based on the consistency of the above results, it can be concluded that generally, the effects of curing time on stress-strain and strength behaviour of cement treated Singapore marine clay seem

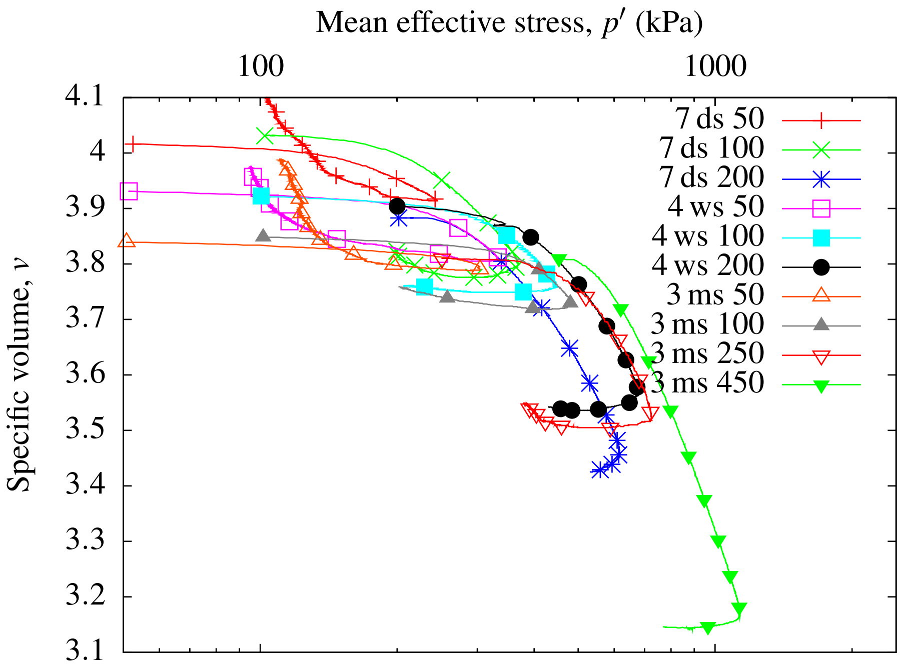


(a) 2-1-4 specimens

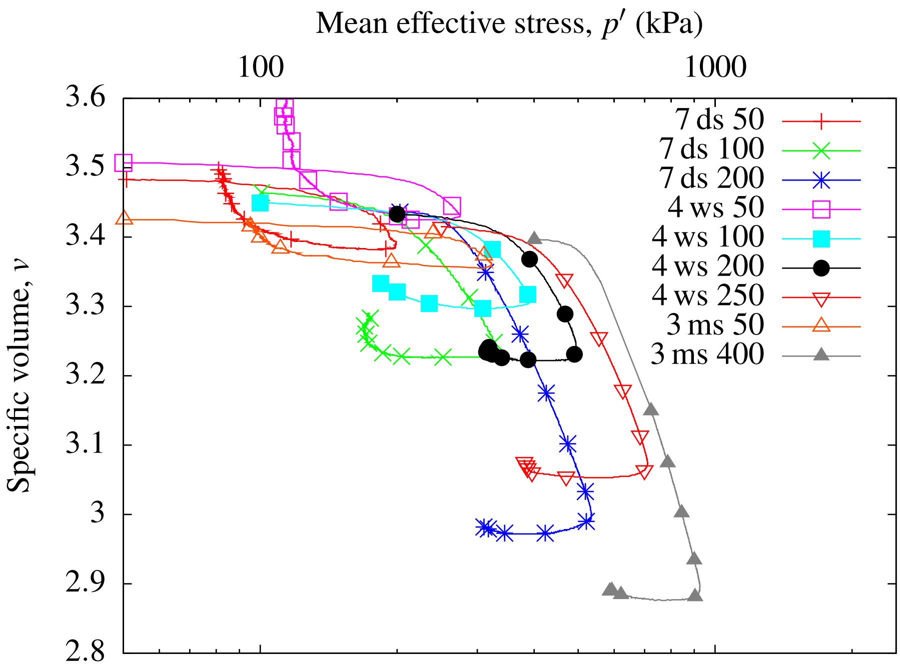


(b) 5-1-6 specimens

Figure 3: Stress-strain curves from CIU tests on (a) 2-1-4 and (b) 5-1-6 specimens. Effective consolidation pressure is given next to curing time.

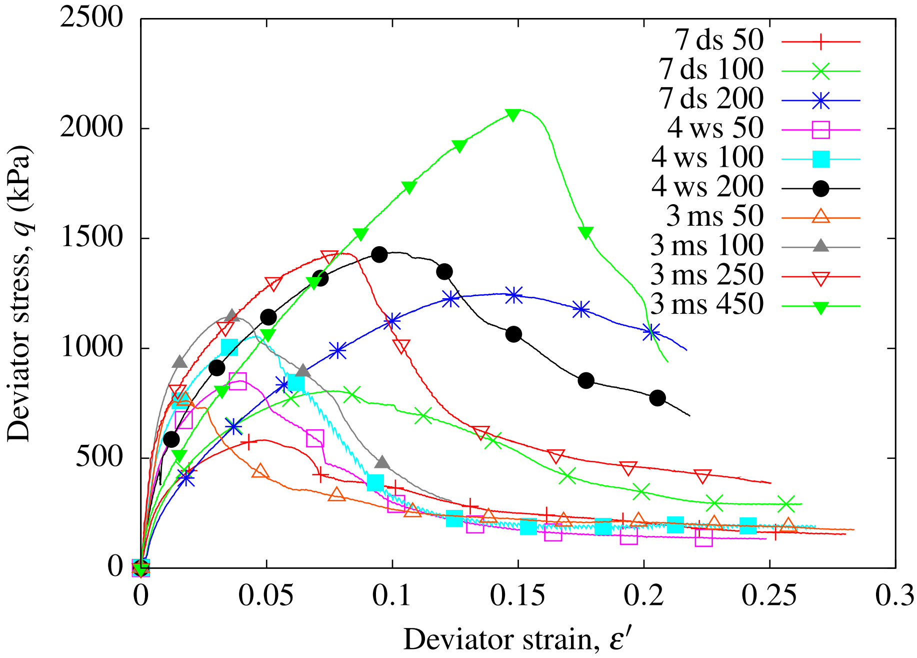



(a) 2-1-4 specimens

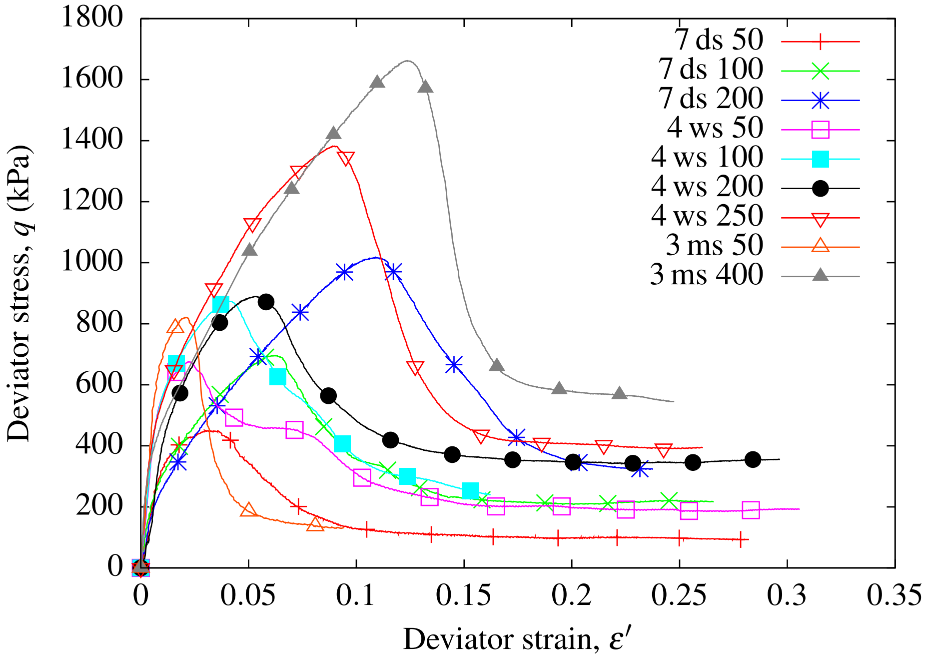



(b) 5-1-6 specimens

Figure 4: Compression space curves from CIU tests on (a) 2-1-4 and (b) 5-1-6 specimens. Effective consolidation pressure is given next to curing time.




(a) 2-1-4 specimens




(b) 5-1-6 specimens

Figure 5: Deviator stress-strain curves from CID tests on (a) 2-1-4 and (b) 5-1-6 specimens. Effective consolidation pressure is given next to curing time.

to modulate after 4 weeks of curing. Notable exceptions include the isotropic recompression and isotropic compression indices and the residual strength under drained triaxial compression.

Further studies can be done on specimens consolidated to higher effective consolidation pressures, at and beyond the respective isotropic yield stresses. Such studies will complement the current study, which only included specimens subject to effective consolidation pressures below the respective isotropic yield stresses. Specimens with longer curing times could also be included.

## References


BSI (1990). British Standard methods of test for soils for civil engineering purposes. Technical Report BS 1377, British Standards Institution, United Kingdom.

Chew, S. H., Kamruzzaman, A. H. M., and Lee, F. H. (2001). Strength and deformation characteristics of cement treated marine clay. In *Geotechnical engineering: Meeting society's needs*, volume 1, pages 285–290. Taylor & Francis.

Chew, S. H., Kamruzzaman, A. H. M., and Lee, F. H. (2004). Physicochemical and engineering behaviour of cement treated clays. *Journal of Geotechnical and Geoenvironmental engineering*, 130(7):696–706.

Lee, F. H., Lee, Y., Chew, S. H., and Yong, K. Y. (2005). Strength and modulus of marine clay-cement mixes. *Journal of Geotechnical and Geoenvironmental Engineering*, 131(2):178–186.

Rotta, G., Consoli, N., Prietto, P., Coop, M., and Graham, J. (2003). Isotropic yielding in an artificially cemented soil cured under stress. *Geotechnique*, 53(5):493–501.