

# CHAPTER 4 RESULT AND ANALYSIS

## 4.1 Introduction

This chapter presents the result of monotonic loading and cyclic tests on air-cement treated soil. The influence of prime parameters; i.e. cement content,  $A_w$ ; total unit weight,  $\gamma_t$ ; water content,  $w$  and curing time,  $t$  on unconfined compressive strength, elastic modulus and Poisson ratio from monotonic loading, equivalent modulus and equivalent Poisson ratio from cyclic loading test characteristics were investigated.

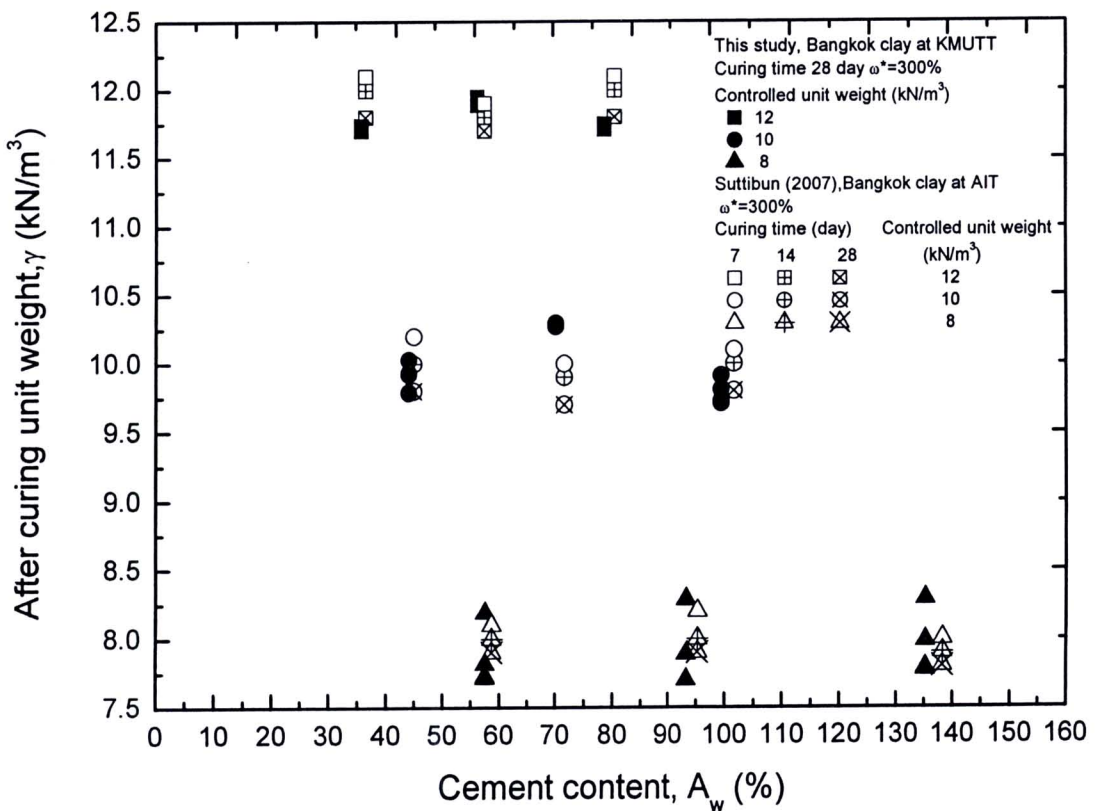
## 4.2 Physical Properties

### 4.2.1 Water content after curing

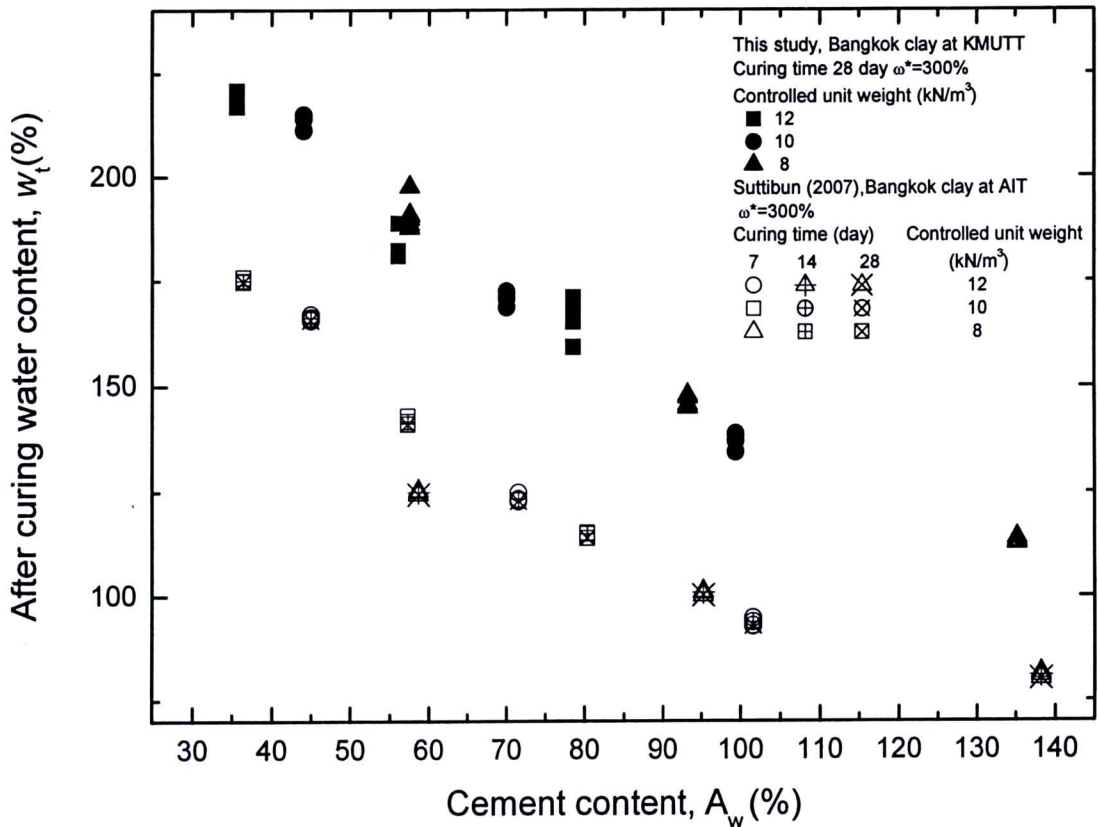
The relationship between after curing unit weight versus cement content at varying controlled unit weight and curing times, is shown in Fig 4.1. It demonstrates that the unit weights remain unchanged to increasing cement content because they were controlled with air-foam, and slightly increased due to the loss of water in the hydration process and pozzolanic process of cement with curing time (Miura et al., 2001).

Fig 4.2 illustrates the relation of after curing water content versus cement content. The after curing water content decreased significantly with increasing cement content, and it also decreased slightly with curing time. As expected, the higher unit weight and the lower cement content will result to the higher after curing water content.

However, curing time 28 day has used for this study.



**Figure 4.1** after curing unit weight of air-cement treated soil sample versus cement content

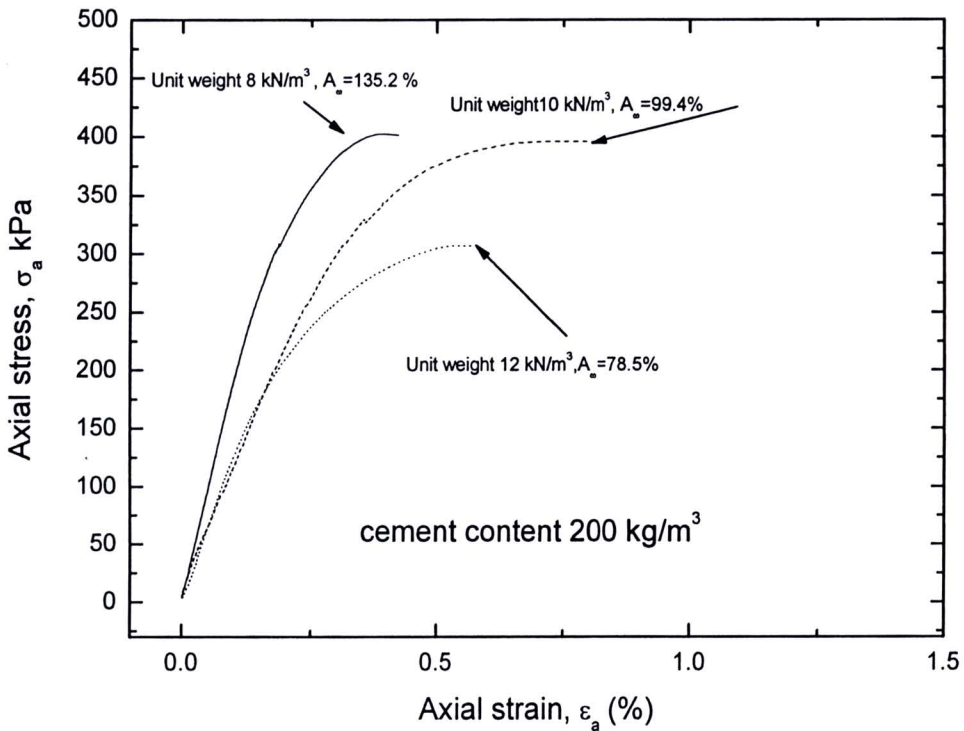


**Figure 4.2** after curing water content of air-cement treated soil sample versus cement content

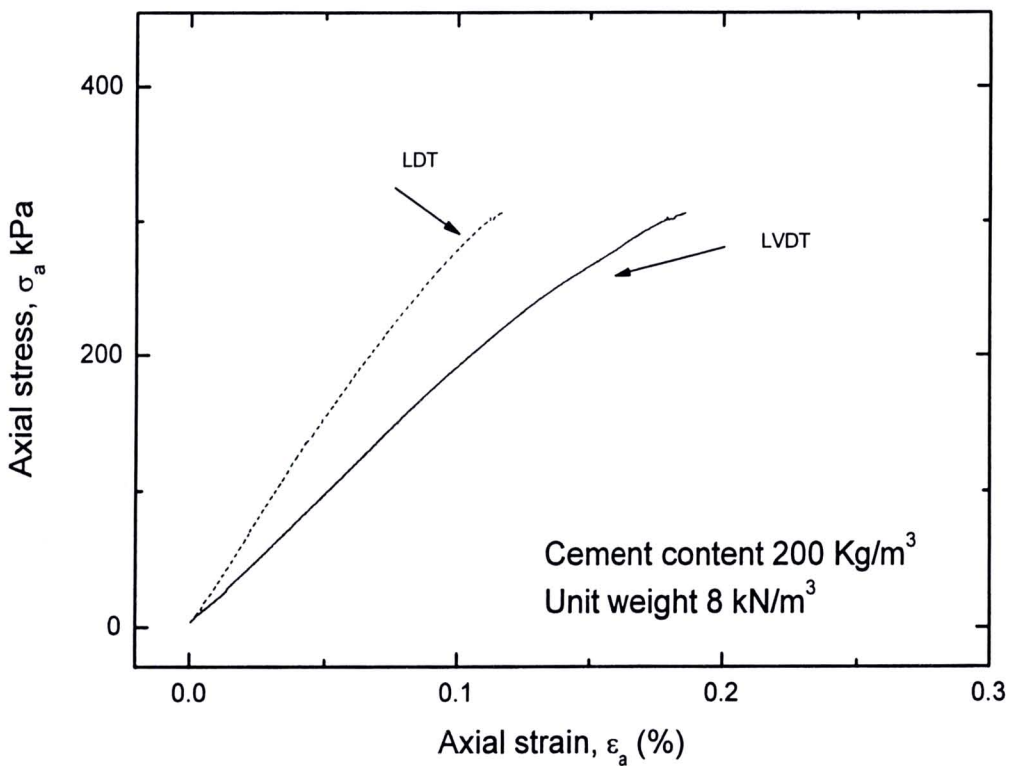
### 4.3 Significance of Small Strain Consideration

All of test in this investigation is necessary to considere about small strain measuring thus the vertical strain( $\epsilon_v$ ) were measured locally by means of local deformation transducers (LDTs) (Goto et al. 1991) placed in vertical directions to exclude possible strain errors due to bedding error . Firstly, the global measurement by LVDT were performed on monotonic loading test to determine the ultimate strength value (Figure 4.3) and then the monotonic loading is applied on another sample having the same mixing components for 70% of ultimate strength approximately. The vertical strain of specimen under monotonic loading up to 70% of ultimate strength was measured by LVDT and LDT, they were compared Figure 4.4(a) through Figure 4.3(c) showing the comparison of relationship between stress-strain behaviour of monotonic loading on unit weight of  $12 \text{ kN/m}^3$  cement content 100, 150, 200  $\text{kg/m}^3$ . All of results that show vertical strain ( $\epsilon_v$ ) value that measured by LVDT are always greater than are measured by LDTs.

However, to avoid LDTs damage, the LDTs were move out before reaching the ultimate state. Hence, the strains that ultimate state were measured by LVDT only.

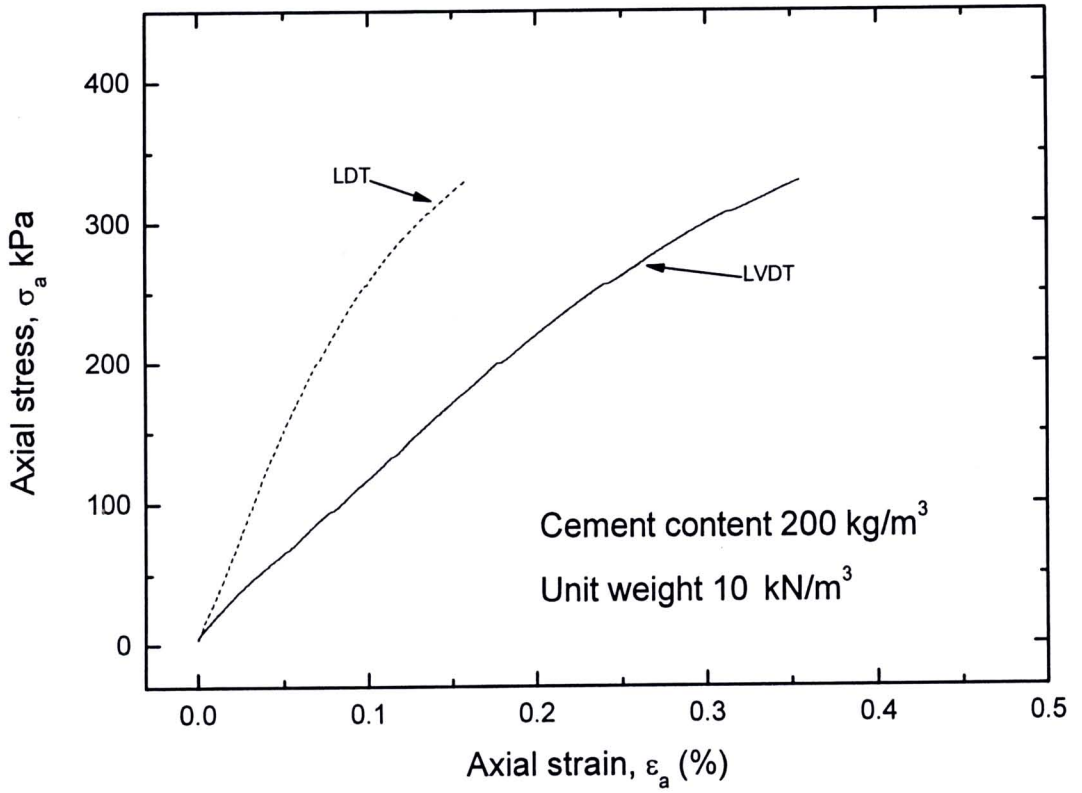


**Figure 4.3** Stress- strain relationship of monotonic loading test at 28 day of air-cement treated soil having cement content  $200 \text{ kg/m}^3$  measured by LVDT

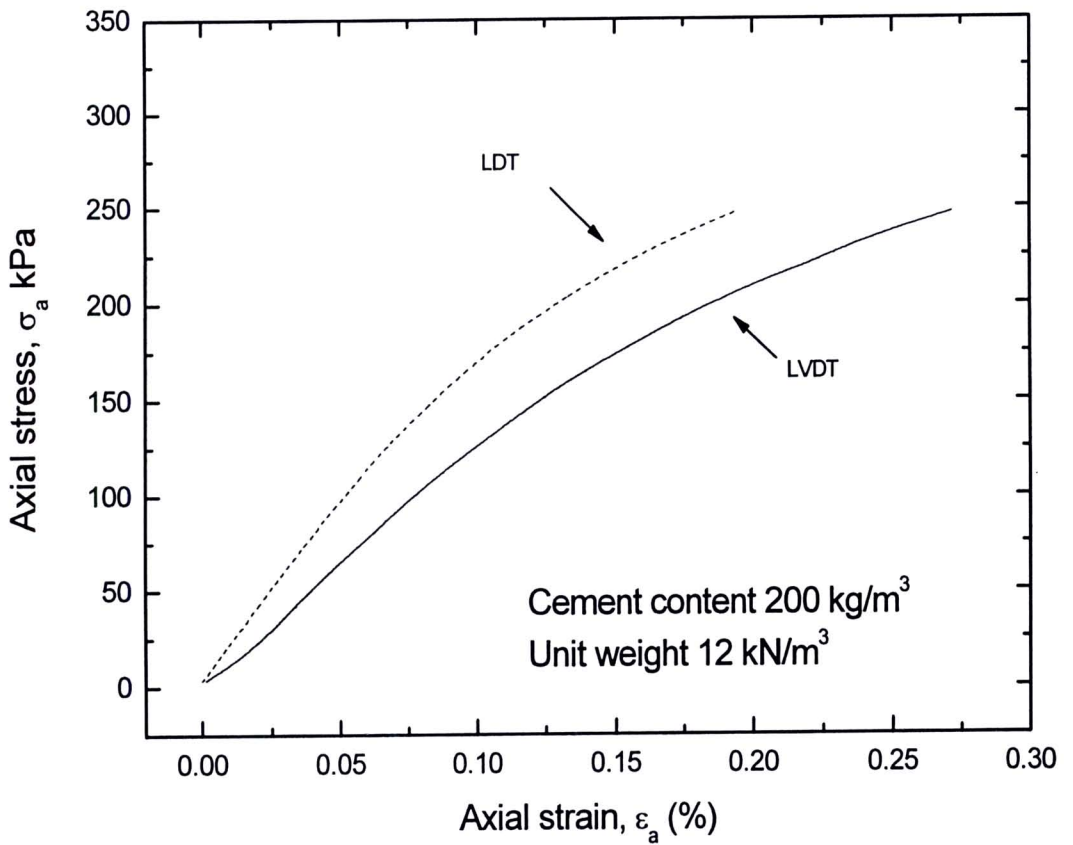


(a)

**Figure 4.4** Monotonic loading up to 70% of ultimate strength of Air-cement treated soil having cement content  $200 \text{ kg/m}^3$  measured by LVDT and LDTs : a) Unit weight  $8 \text{ kN/m}^3$



(b)



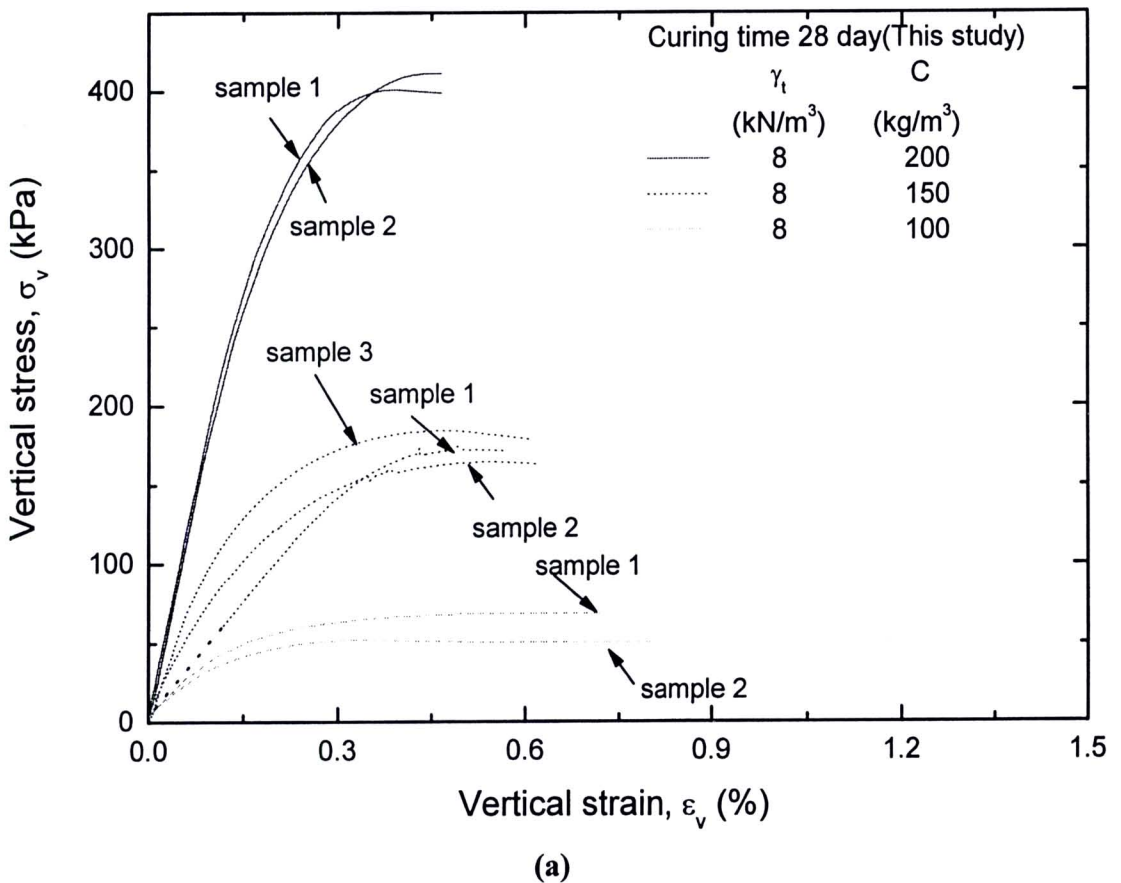
(c)

**Figure 4.4 (Cont.)** (b) Unit weight  $10 \text{ kN/m}^3$   
 (c) Unit weight  $12 \text{ kN/m}^3$

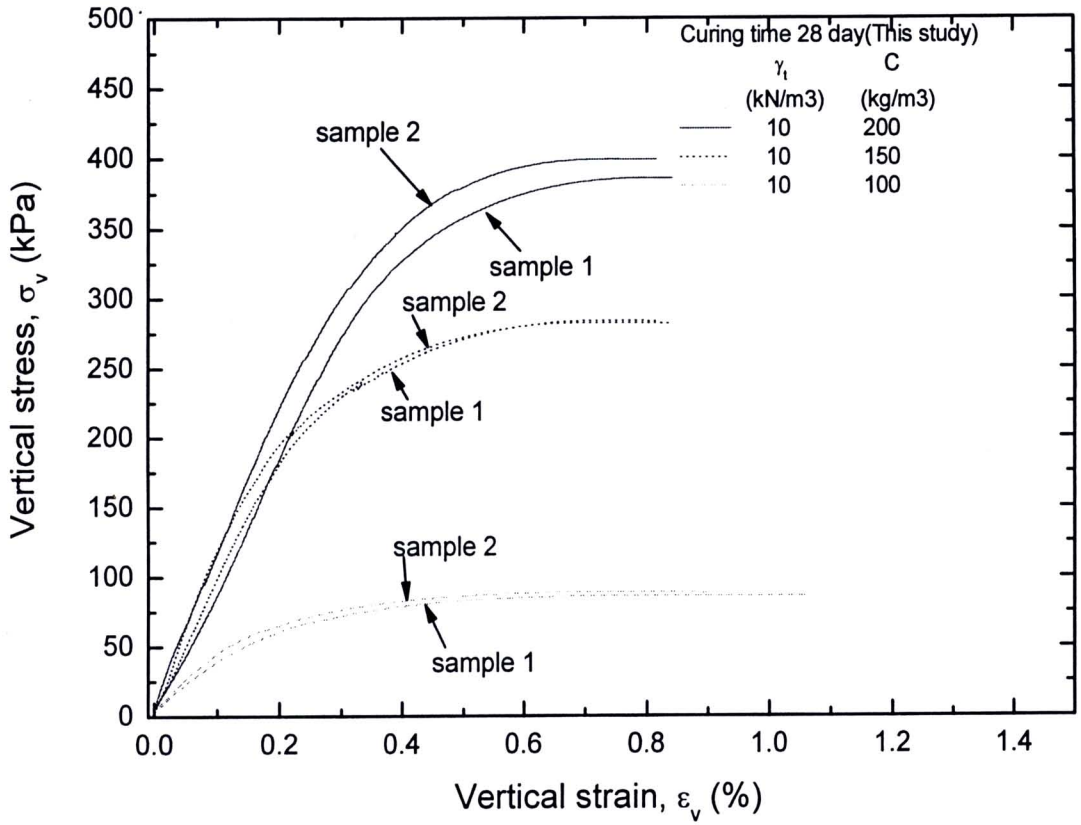
## 4.4 Unconfined Compression Test

### 4.4.1 Strength Characteristics of Air-Cement Treated Soil

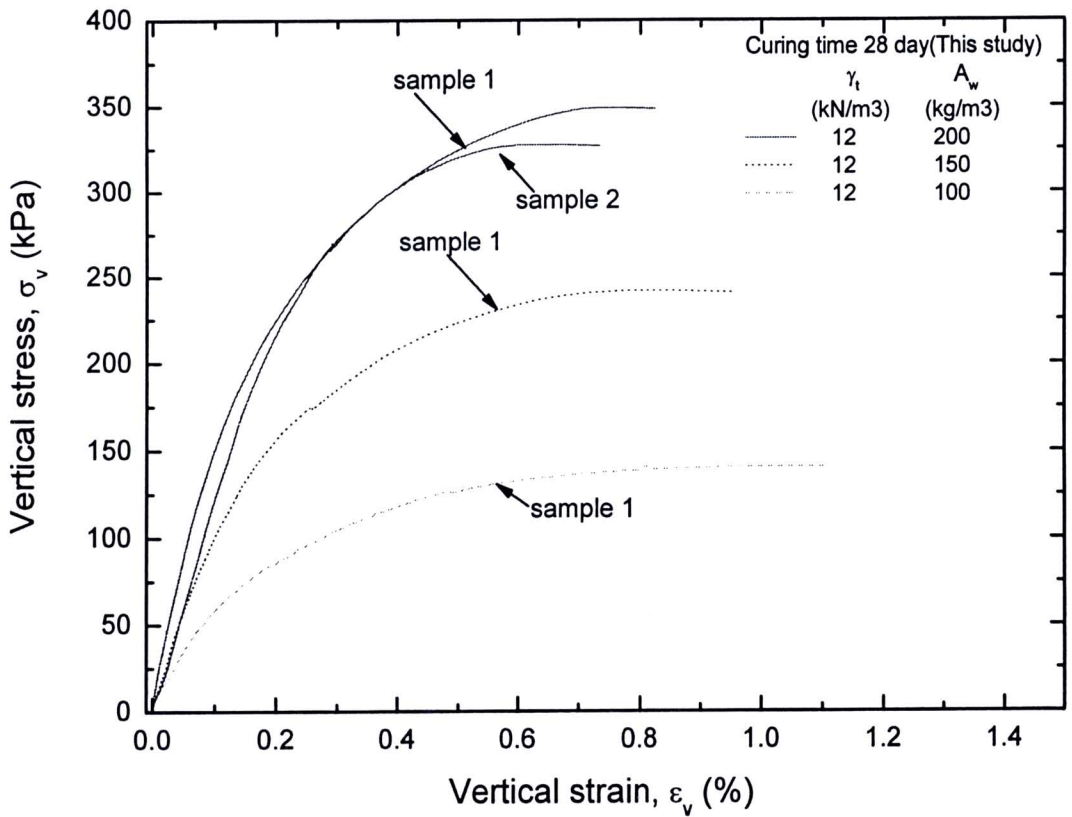
The Monotonic loading test compression tests of samples of Air-cement treated soil were conducted for different cement content, unit weight. Figs.4.5 (a) through 4.5(c), illustrate examples of stress-strain relationships of samples with different mixing components. The overall observations indicate that the maximum stresses from specimen increase with cement content and decrease with density. All sample reach the maximum stress at small values (less than 1%). Table 4.1 Summarize, All samples had rather same condition that is 28 days curing and water admixed at remolding water content ( $w^*$ ) 300 %. Consequently, their ultimate strength is under the control of cement quantity and unit weight



**Figure 4.5** Monotonic loading test result of Air-cement treated soil having cement content 100, 150, 200  $\text{kg/m}^3$  measured by LVDT : a) Unit weight 8  $\text{kN/m}^3$



(b)



(c)

**Figure 4.5 (Cont.)** (b) Unit weight 10 kN/m<sup>3</sup>  
(c) Unit weight 12 kN/m<sup>3</sup>

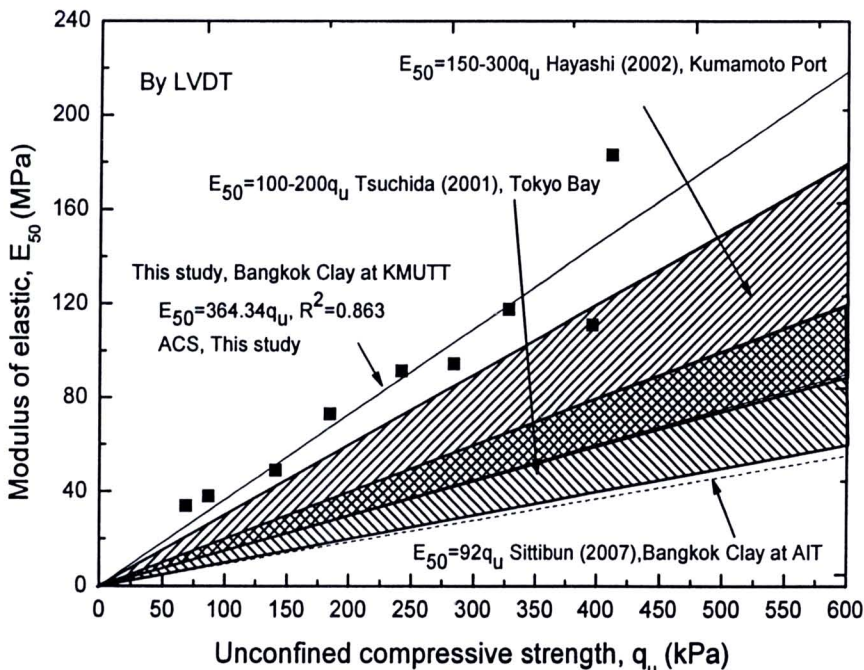
**Table 4.1** Summary of vertical stress and strain at ultimate stress of Air-cement treading soil.

Mix	$A_w$ (%)	$q_u$ (kPa)	strain failure (%)	$e_{st}$
8-100-1	57.55	68.8	0.716	9.739
8-100-2	57.55	51.9	0.812	9.881
8-150-1	93.26	164.5	0.617	7.41
8-150-2	93.26	172.3	0.572	7.241
8-150-3	93.26	184.3	0.502	7.183
8-200-1	135.19	411.2	0.415	5.748
8-200-2	135.19	401	0.465	5.604
10-100-1	44.03	86.3	0.904	9.09
10-100-2	44.03	86.6	0.904	9.05
10-150-1	70.03	282.4	0.822	6.93
10-150-2	70.03	283.8	0.82	6.976
10-200-1	99.37	384.5	0.79	5.521
10-200-1	99.37	396	0.815	5.63
12-100-1	35.66	140.8	1.106	8.603
12-150-1	56.07	241.66	0.951	7.022
12-200-1	78.55	349.1	0.825	5.728
12-200-1	78.55	327.4	0.731	5.725

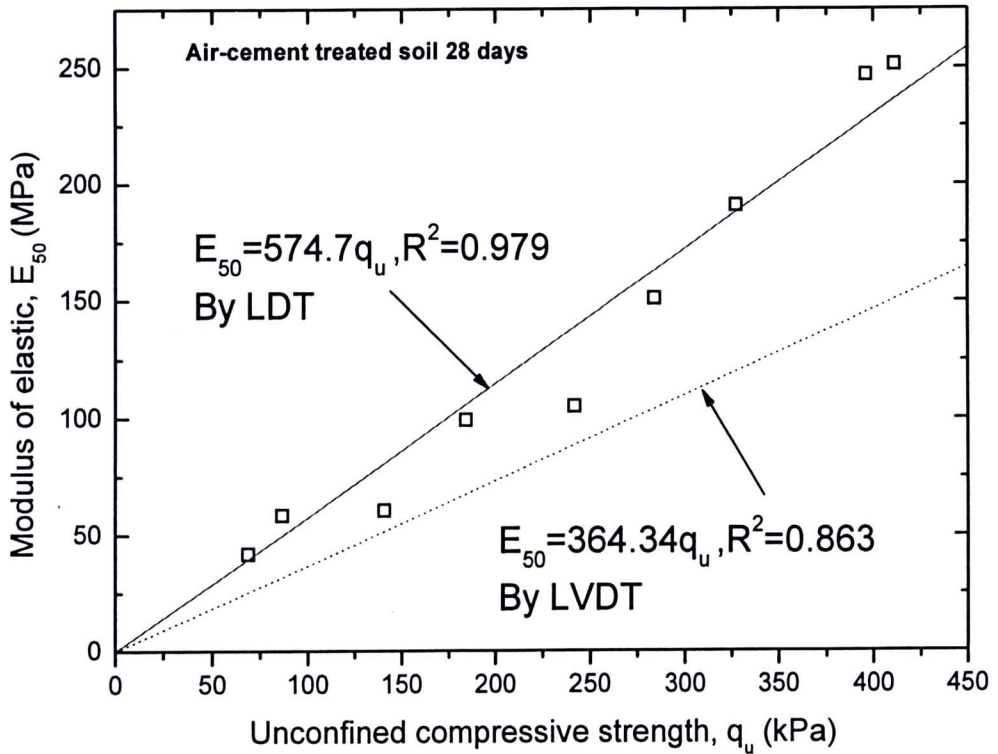
#### 4.4.2 Modulus of Elasticity

This section, Modulus of elasticity can be represented as the secant of modulus at 50% of  $q_u$ , ( $E_{50}$ ). According to the observation, the result for air-cement treated soil can be approximately estimated as  $366.31q_u$  by LVDT as shown in Figure 4.6 and  $574.7q_u$  by LDT as shown in Figure 4.7.

However,  $E_{50}$  was by LVDT, there was effect by bedding error.



**Figure 4.6** Modulus of elasticity ( $E_{50}$ ) unconfined compressive strength relationships of air-cement treated soil.



**Figure 4.7** Modulus of elasticity ( $E_{50}$ ) unconfined compressive strength relationships of air-cement treated soil.

**Table 4.2** Summary of vertical stress and  $E_{50}$  measured by LVDT and LDT stress of Air-cement treated soil and  $e_{st}$ .

Mix	$q_u$ (kPa)	strain rate (%/s)	$E_{50}$		$e_{st}$
			LVDT(Mpa)	LDT(Mpa)	
8-100	68.8	0.00639	33.9	41.87	9.881
8-150	184.3	0.00581	72.99	99.27	7.183
8-200	411.2	0.00378	183.07	251.27	5.604
10-100	86.6	0.01089	37.97	58.63	9.05
10-150	283.8	0.01048	94.25	151.2	6.93
10-200	396	0.00513	110.9	246.69	5.667
12-100	140.8	0.026	49.04	60.75	8.603
12-150	241.7	0.0126	91.38	105.06	7.022
12-200	327.4	0.00477	119.24	191.03	5.725

Form table 4.2 show compare between strength  $E_{50}$  (LVDT and LDT)

Note: In testing sample was stress controlled but ultimate stress is not constant strain rate at ultimate stress.

#### 4.5 Characterization of Strength

Jongpradict et al., (2011) demonstrated that the factor  $e_{st}$ , combines the effects of the water content, void ratio, cement content, and curing time on the  $q_u$  of air-cement treated clay and cement-treated clay prepared from the same type of clay. The parameter namely “effective void ratio,  $e_{st}$ ” is here proposed as Eq 4.1

$$e_{st} = C_w \times \ln \left( \frac{e_{of}}{A_w} \right) \tag{4.1}$$

And Consoli, N. et al. (2007) presented relationship between unconfined compression strength and function of voids/cement and porosity are here proposed as Eq 4.2

$$q_u = f \left( \frac{V_v}{V_{ci}}, \eta \right) \tag{4.2}$$

Thus, this study uses two concepts for relationship of unconfined compressive strength in mixing of ACS.

As the relation of  $e_{st}$ ,  $e_{st}/A_w$ ,  $(V_v/V_{ci}^*)$  and  $(\eta/C_{iv}^*)$  form above. This show that this parameter has effects to Air-cement treaded soil behavior this study provide for strength prediction including discussion in capability and limitation and range of applicability by using the experiment. The obtained results were shown in Figure 4.8-4.16.

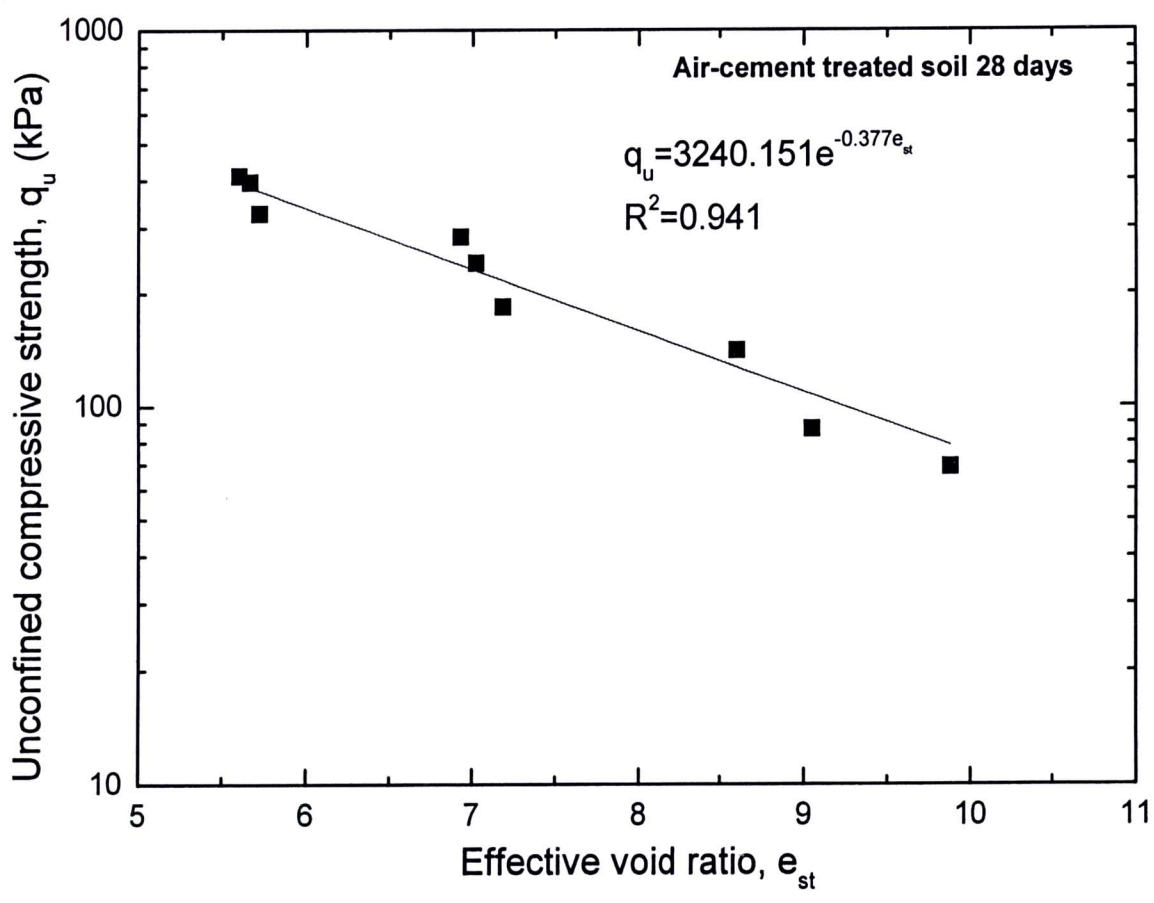
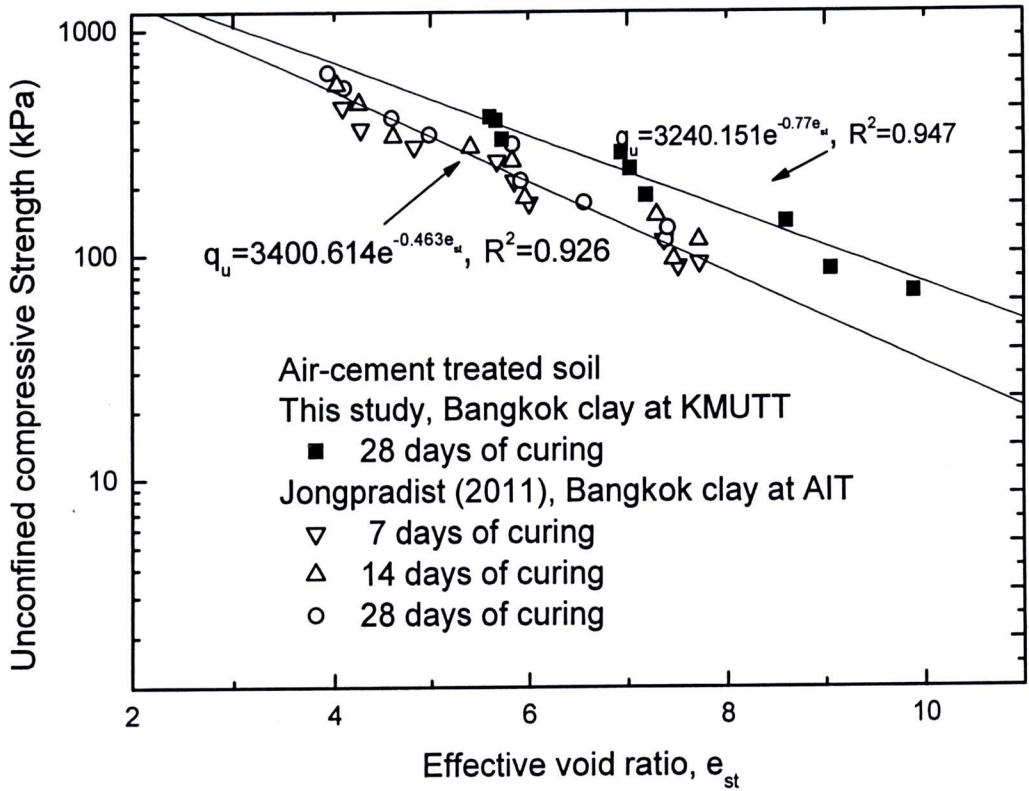
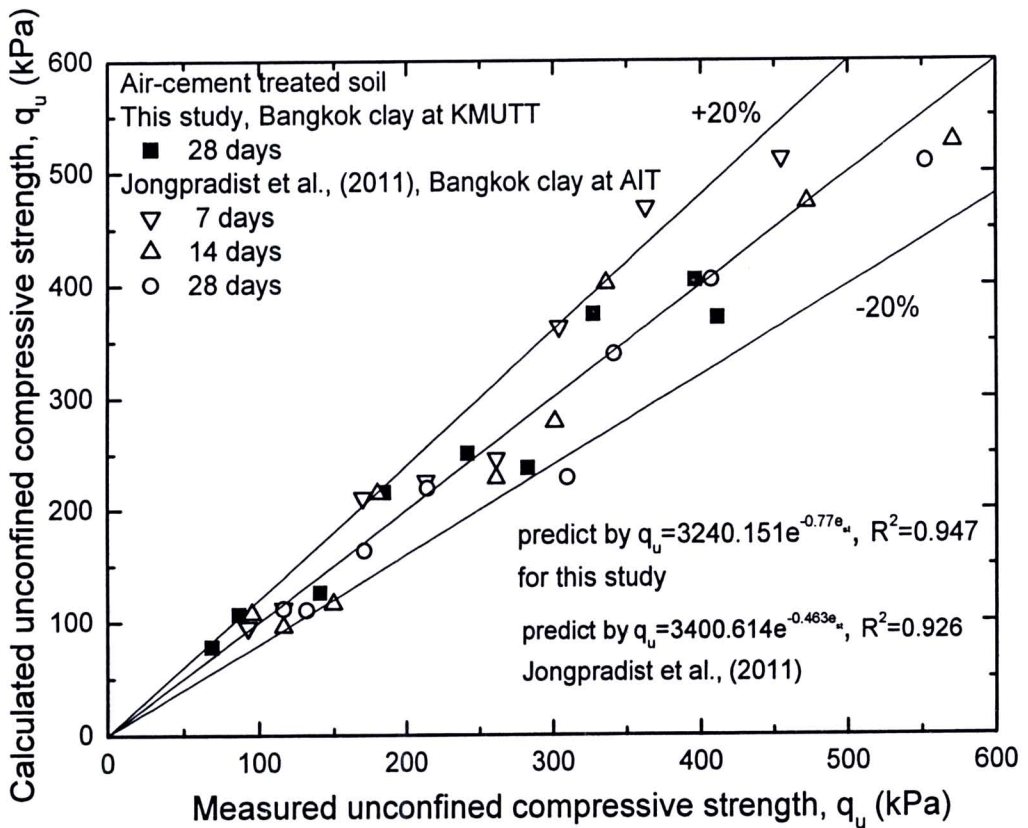


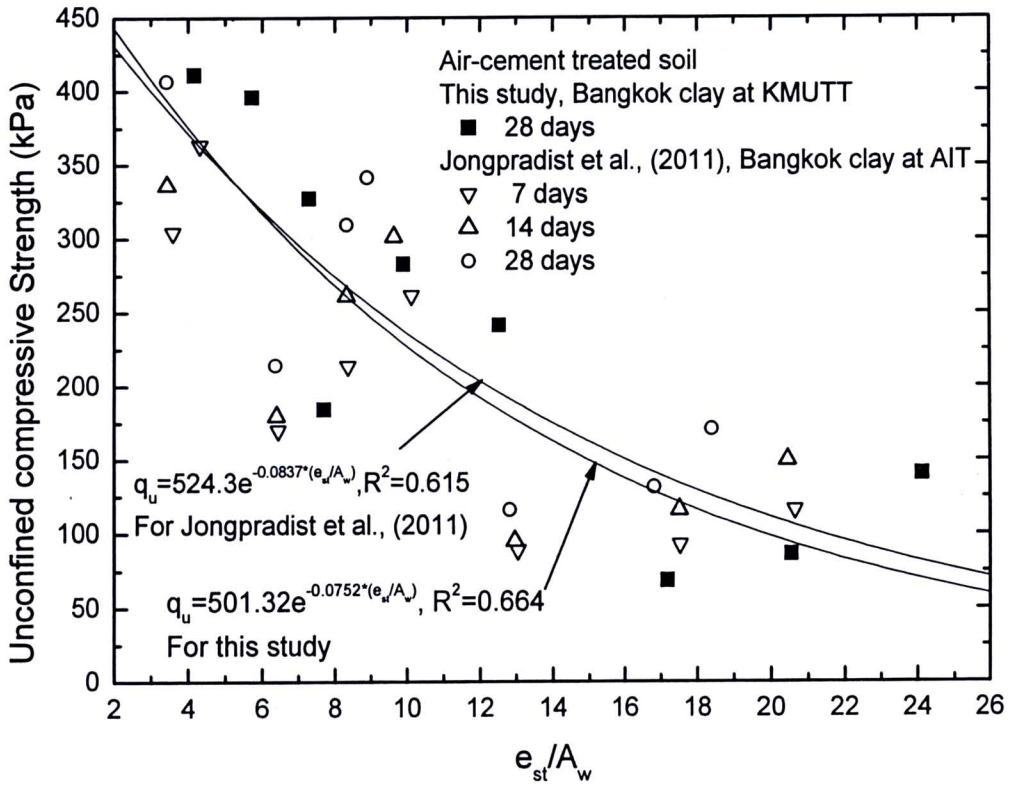
Figure 4.8 Unconfined compressive strength versus effective void ratio  $e_{st}$



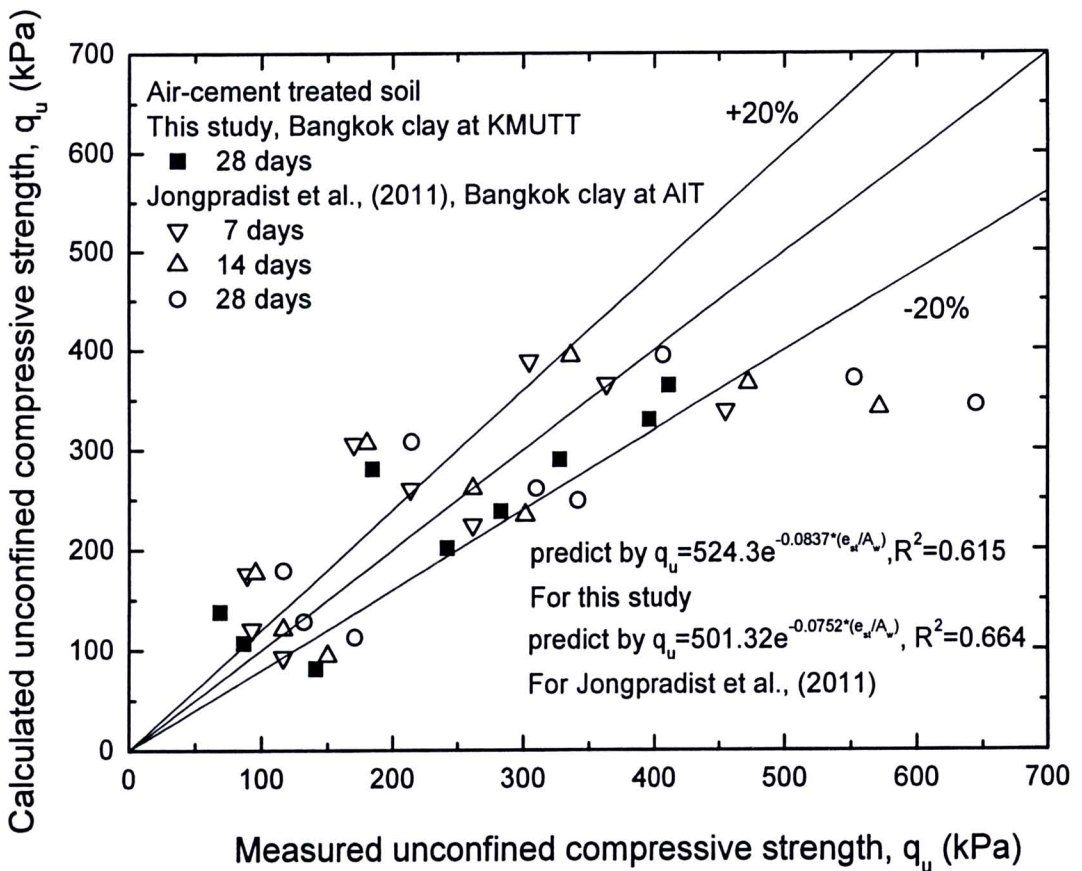
**Figure 4.9** Unconfined compressive strength-effective void ratio  $e_{st}$  relationships of air-cement treated soil.



**Figure 4.10** Calculated versus measured unconfined compressive strength by concept effective void ratio,  $e_{st}$ .



**Figure 4.11** Unconfined compressive strength-effective void ratio to cement content  $e_{st}/A_w$  relationships of air-cement treated soil.



**Figure 4.12** Calculated versus measured unconfined compressive strength by  $e_{st}/A_w$  concept.

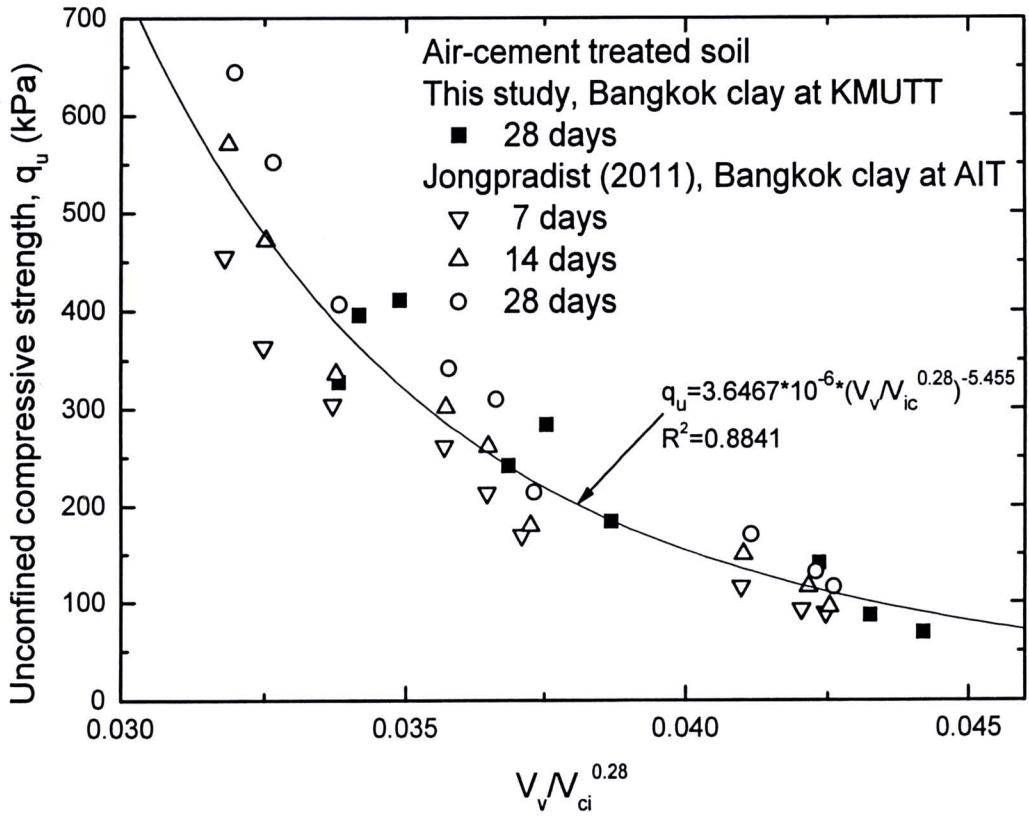


Figure 4.13 Unconfined compressive strength versus  $V_v/V_{ci}^{0.28}$  relationships of air-cement treated soil.

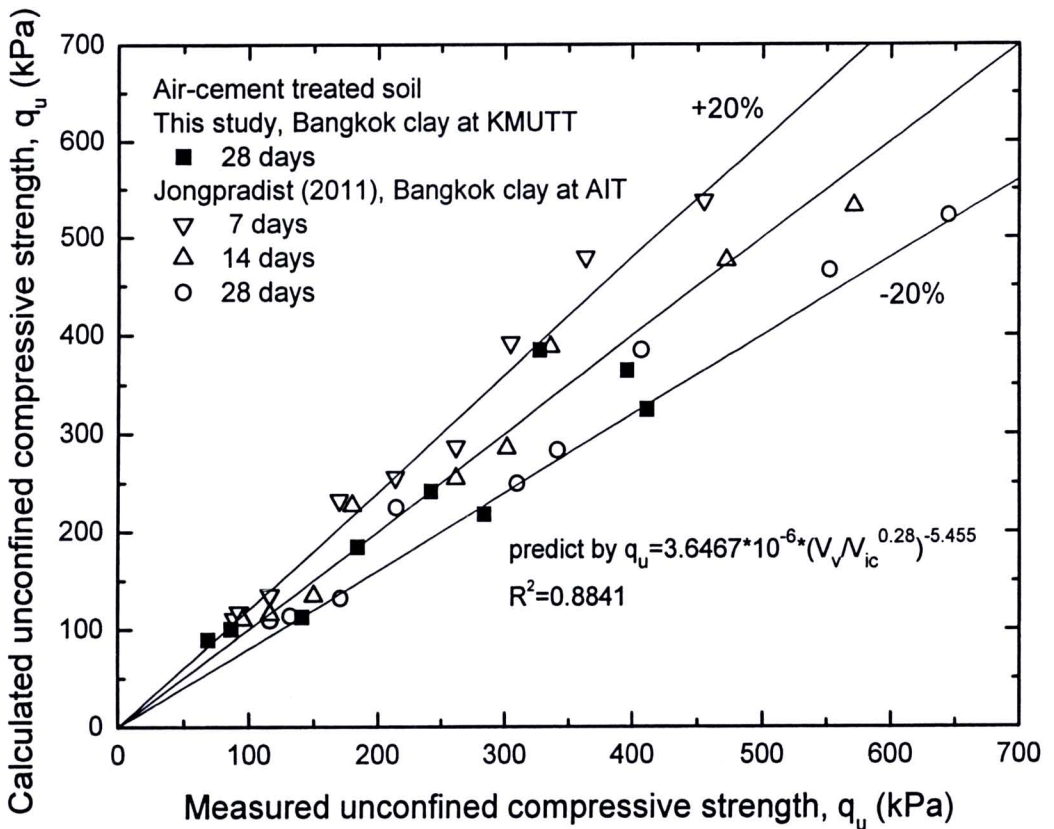
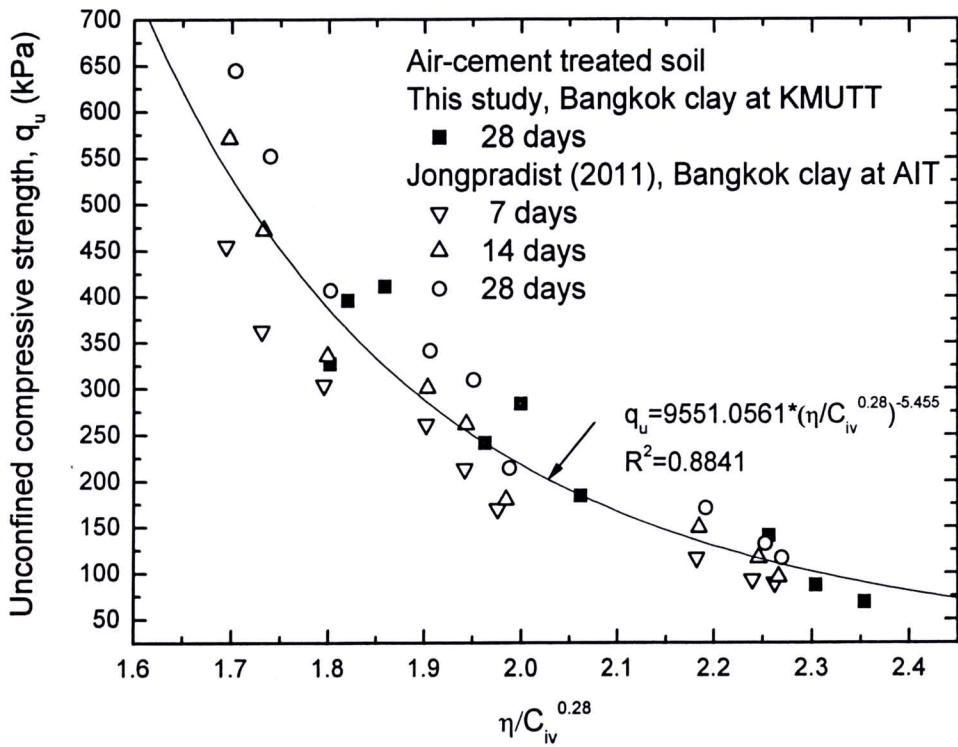
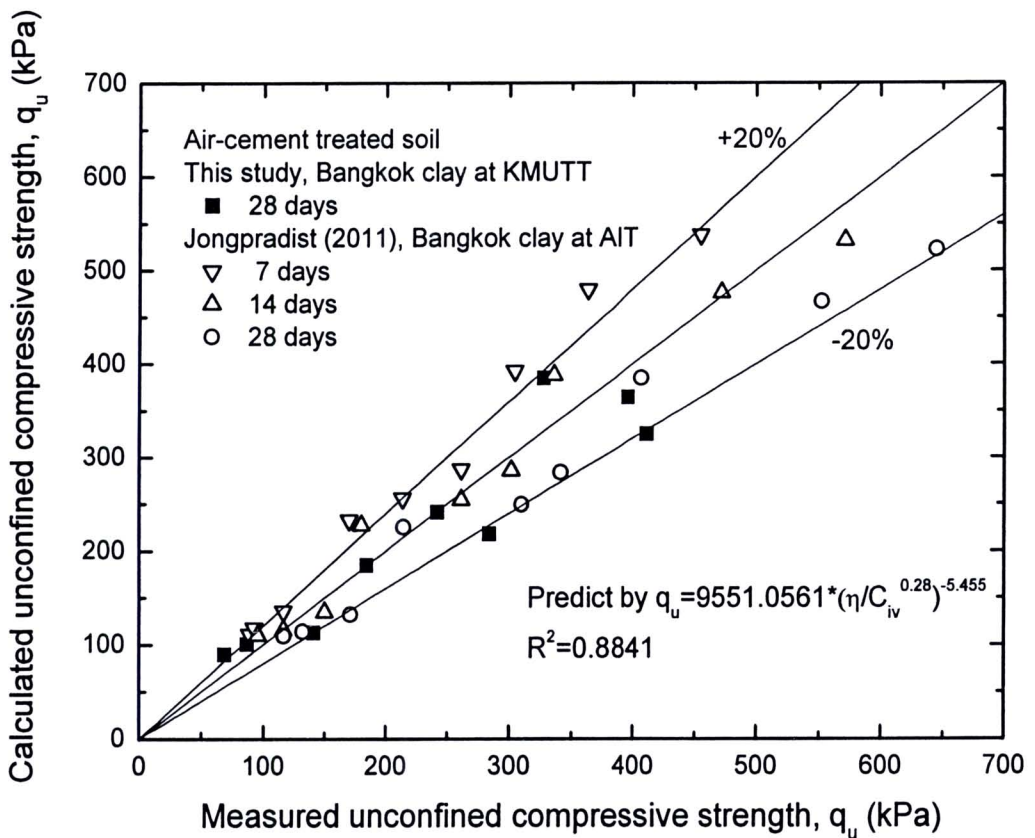


Figure 4.14 Calculated versus measured unconfined compressive strength by  $V_v/V_{ci}^{0.28}$  concept.



**Figure 4.15** Unconfined compressive strength versus  $\eta/C_{iv}^{0.28}$  relationships of air-cement treated soil.



**Figure 4.16** Calculated versus measured unconfined compressive strength by  $\eta/C_{iv}^{0.28}$  concept.

## 4.6 Modulus and Poisson's ratio

From literature review of Soil stiffness at small strain,(2.6.3). Stiffness at small strain was value more than stiffness at large strain because there is effect of plastic and viscous. Thus, this study to compare small strain stress strain property to large strain property (ML)

In the present study, a combination of the tangent modulus for major principal strain increments talking place in vertical direction,  $E_v$ , and the Poisson's ratio for major and minor principal strain increments talking place in the vertical and horizontal directions,  $\nu_{vh}$ , defined as follow were evaluated,

$$E_v = \left[ \frac{\Delta\sigma_v}{\Delta\varepsilon_v} \right]_{(\sigma_h=0)} \quad \nu_{vh} = \left[ \frac{\Delta\varepsilon_h}{\Delta\varepsilon_v} \right]_{(\sigma_h=0)} \quad (4.3)$$

Where  $\Delta\varepsilon_v$  and  $\Delta\varepsilon_h$  are the vertical and horizontal strain increment taking place when the vertical stress changes by an amount of  $\Delta\sigma_v$  at zero horizontal stress,  $\sigma_h$ . Furthermore, as the stress-strain behaviour of ACS is generally non-linear, a set Young's modulus,  $E_0$ ,  $E_{tan}$  and  $E_{eq}$ , and a set of Poisson's ratio,  $\nu_0$ ,  $\nu_{tan}$  and  $\nu_{eq}$ .

### 4.6.1 Monotonic loading test

#### 4.6.1.1 Initial modulus and Poisson's ratio

Initial modulus and Poisson's ratio defined as the slope of the apparently linear portion of initial  $\sigma_v - \varepsilon_v$  and  $\varepsilon_h - \varepsilon_v$  relation as shown in Figs 4.15(a) and 4.15(b), respectively. From the initial portions of  $\sigma_v - \varepsilon_v$  and  $\varepsilon_h - \varepsilon_v$  relations, the initial modulus,  $E_0$ , and Poisson's ratio,  $\nu_0$ , are determined as shown in Figs. 4.16(a) through 4.16(c) and 4.17(a) through 4.17(c), respectively. Note that these  $E_0$  and  $\nu_0$  values were determined from  $\varepsilon_v$  values measured by LDTs and also obtained from the respective relations from the start of loading until vertical strains less than about 0.001% ( $10^{-5}$ ).

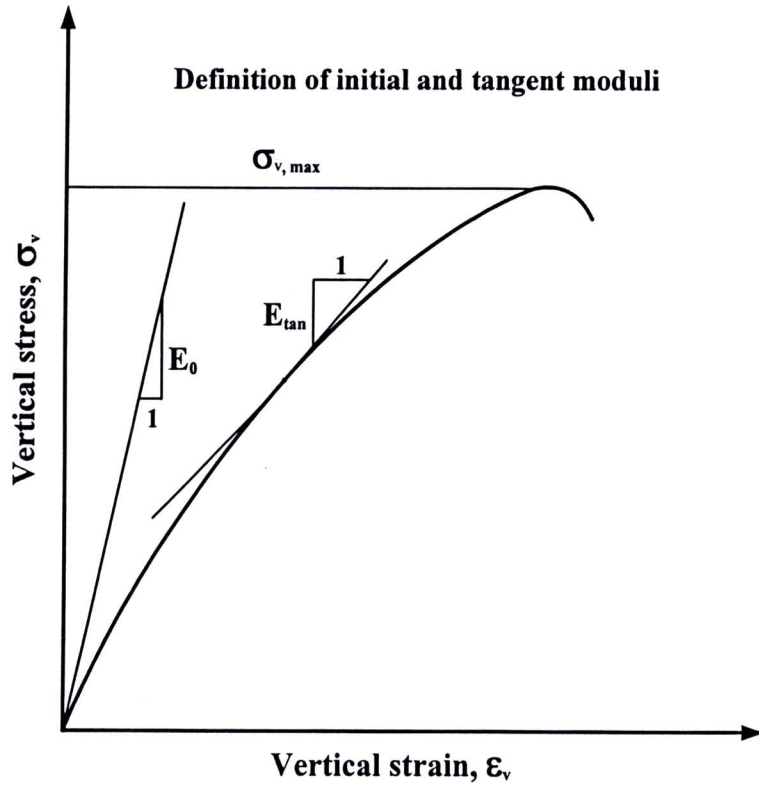
#### 4.6.1.2 Tangent modulus and Poisson's ratio

Tangent modulus and Poisson's ratio were value of large strain. Thus, this section, there was time and plastic effect.

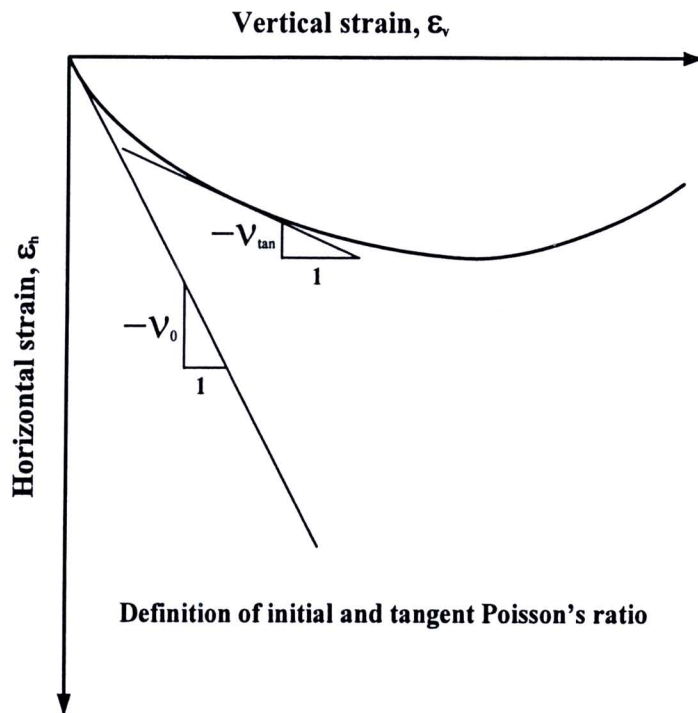
Tangent modulus and Poisson's ratio were defined as the tangential slopes of respectively  $\sigma_v - \varepsilon_v$  and  $\varepsilon_h - \varepsilon_v$  curves as shown in Figs 4.17(a) and 4.17(b). From Figs. 4.19(a) through 4.19(c) and 4.20(a) through 4.20(c), the tangent modulus,  $E_{tan}$ , and Poisson's ratio,  $\nu_{tan}$ , of Air-cement treaded soil specimens at different unit weight equal to 8, 10, 12 kN/m<sup>3</sup> and cement content 100, 150, 200 kg/m<sup>3</sup> were determined based on the  $\varepsilon_v$  measured by LDTs and  $\varepsilon_h$  measured by CGs and then plotted against  $\sigma_v$ .

The following trends of behavior may be seen from Figs. 4.18 to 4.20:

- 1) The trend of  $E_0$  increased with a decrease effective void ratio,  $e_{st}$  (Fig4.18)
- 2) The values of  $E_{tan}$  decreased with a increase stress vertical.
- 3) Trend of  $E_{tan}$  increased with a decreased  $e_{st}$ .
- 4) The  $\nu_{tan}$  - value increased noticeably with an increase in vertical stress,  $\sigma_v$ .
- 5) The value of  $E_0$  and  $\nu_0$  was close to  $E_{tan}$  and  $\nu_{tan}$  respectively..



(a)



(b)

**Figure 4.17** (a) Definition of initial and tangent moduli (b) Definition of initial and tangent Poisson's ratio

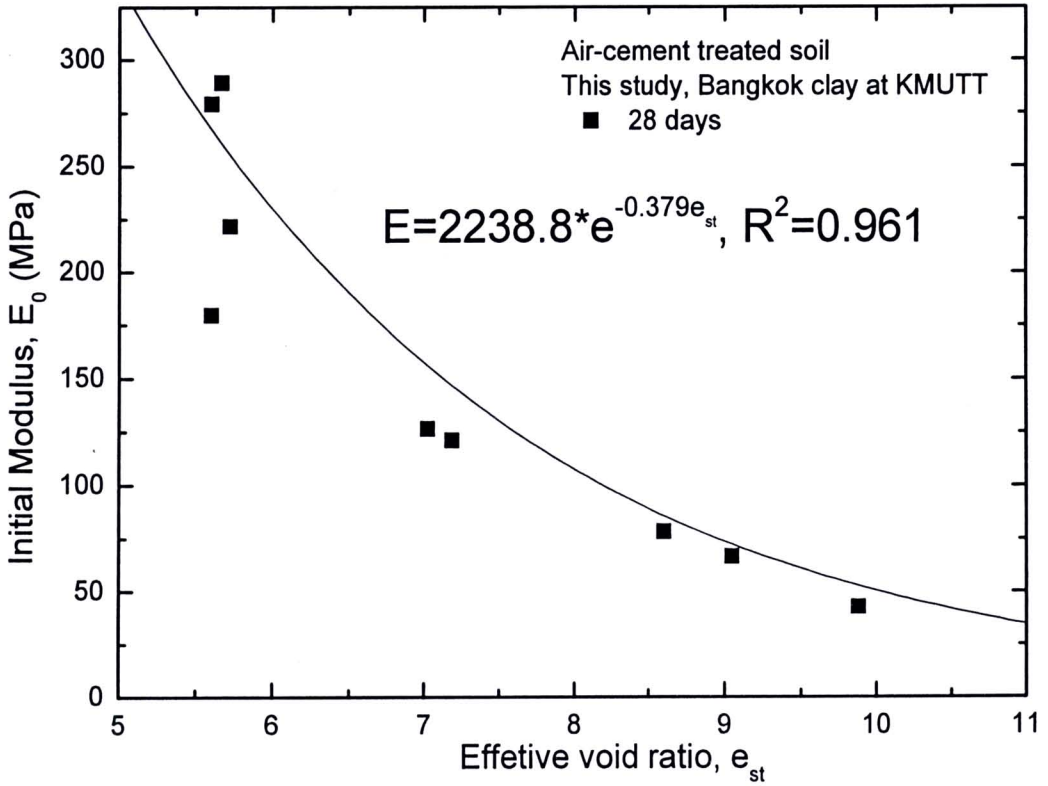
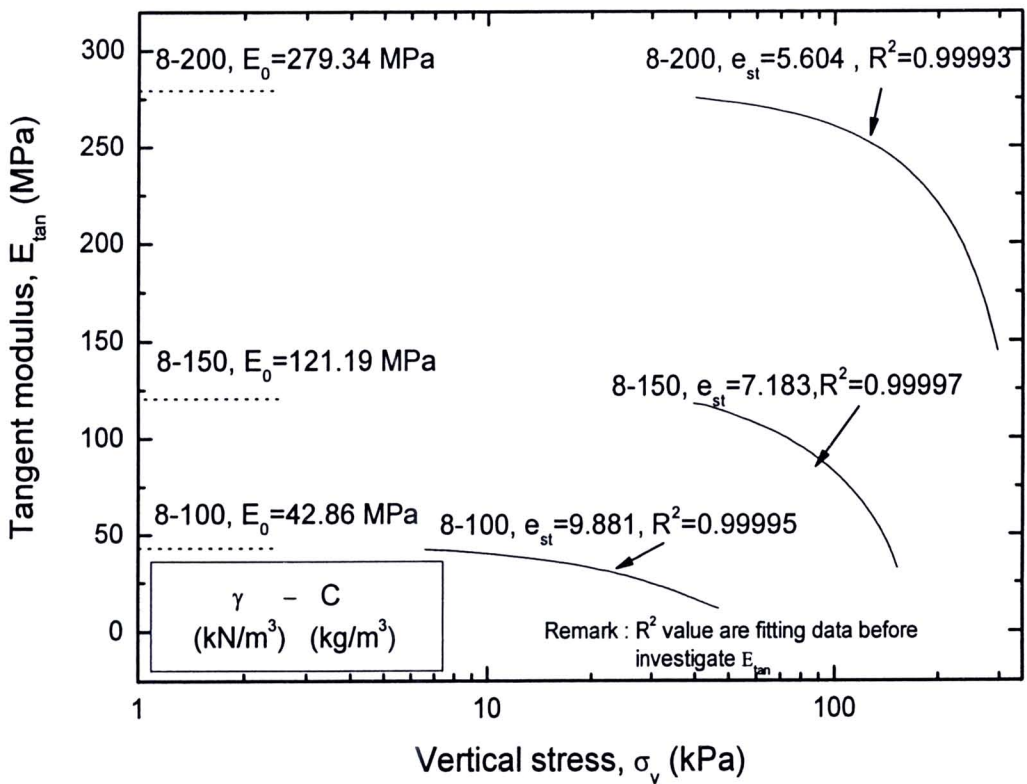
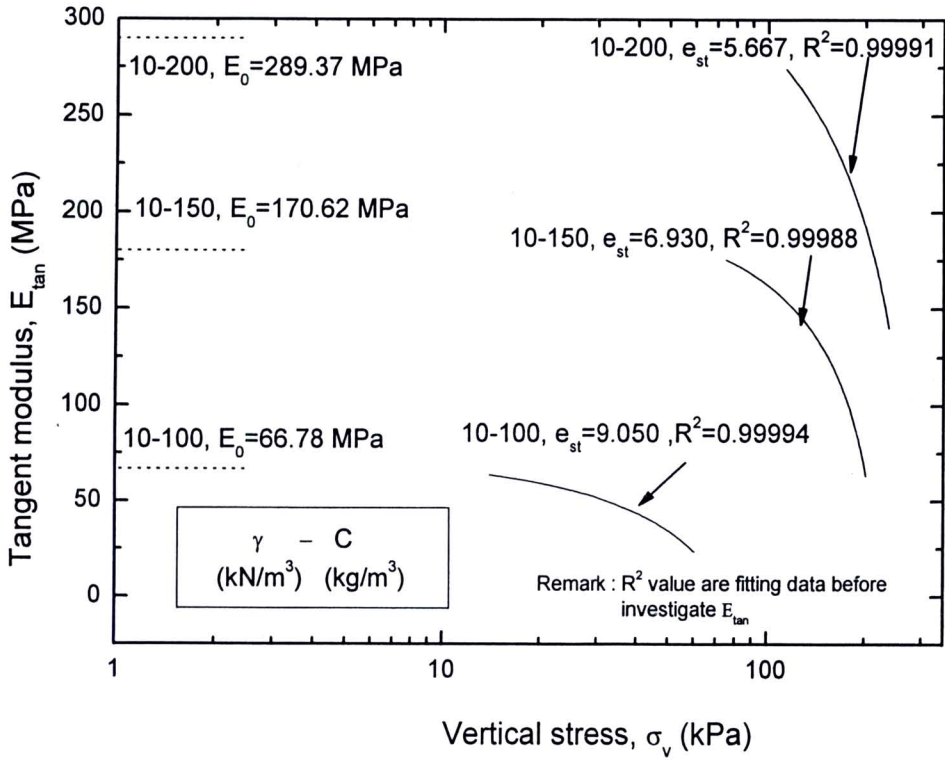


Figure 4.18 Relationship between initial modulus and effective void ratio,  $e_{st}$

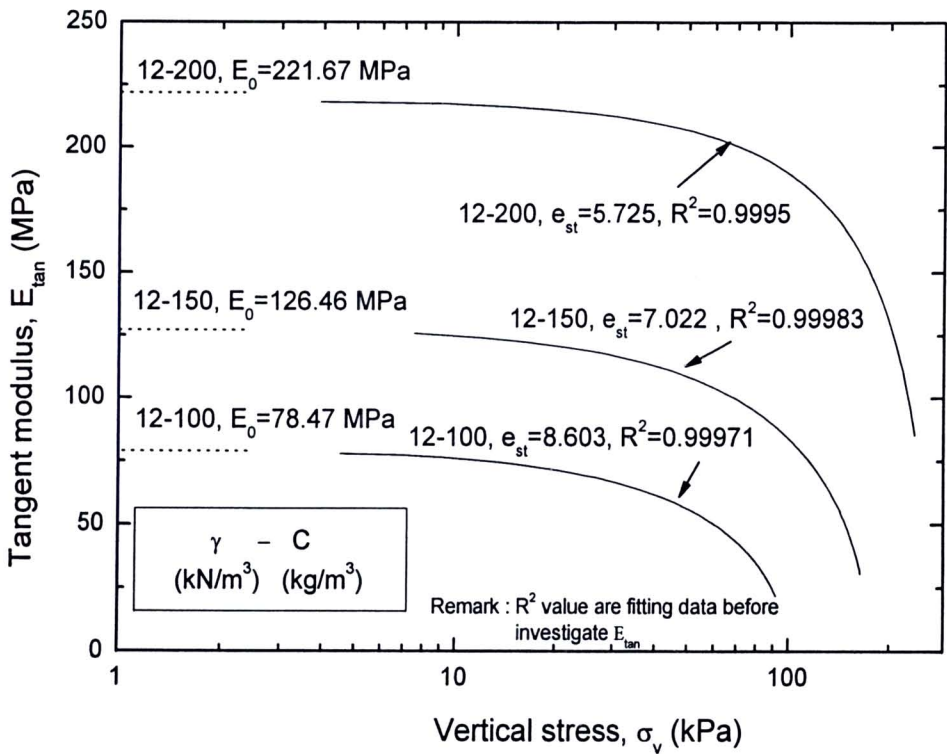


(a)

Figure 4.19 Relationship between Tangent modulus and vertical stress  
(a) Unit weight  $8\text{kN/m}^3$  and cement content 100, 150, 200  $\text{kg/m}^3$

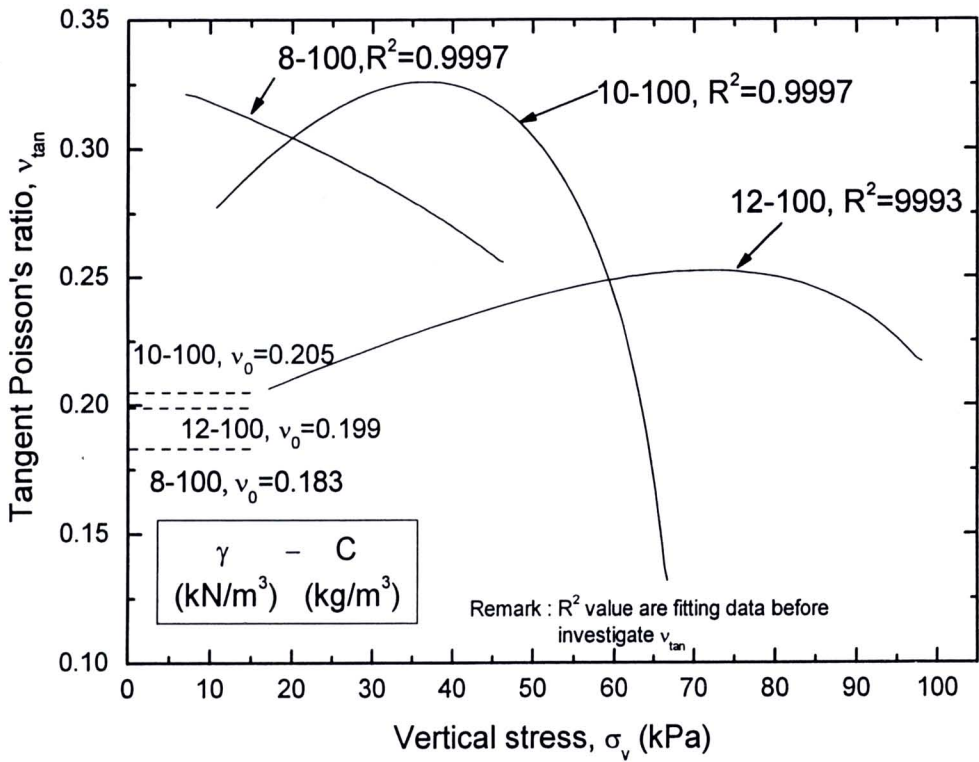


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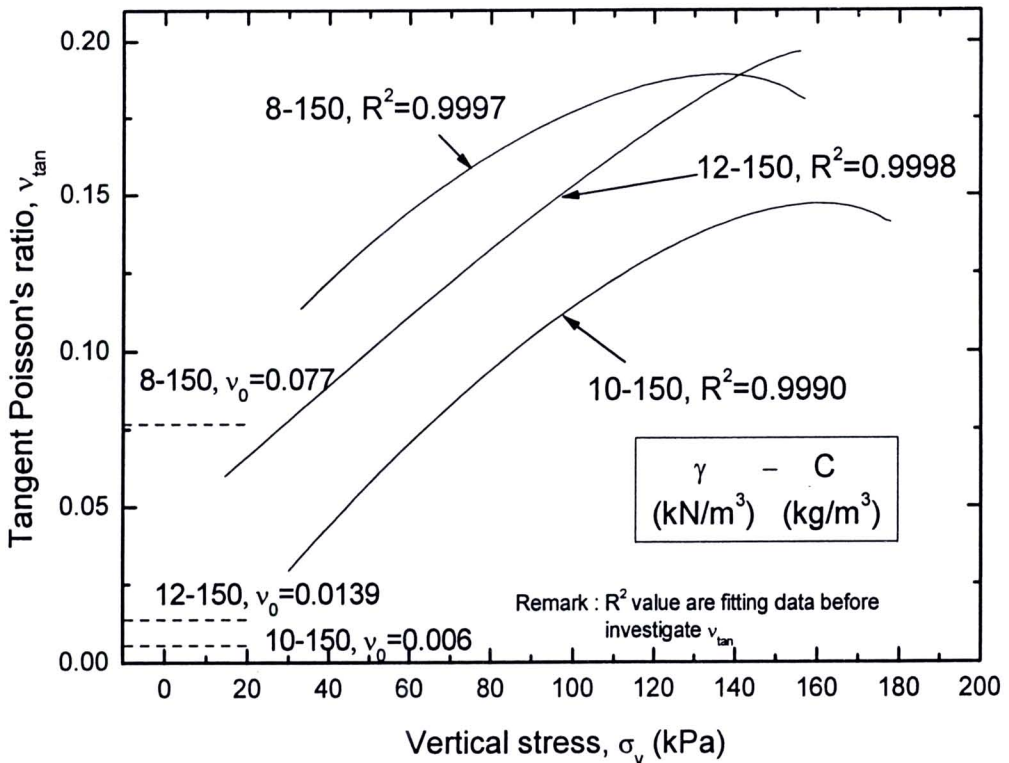


(c)

Figure 4.19 (Cont.) (b) Unit weight 10kN/m<sup>3</sup> and cement content 100, 150, 200kg/m<sup>3</sup>  
 (c) Unit weight 12kN/m<sup>3</sup> and cement content 100, 150, 200kg/m<sup>3</sup>

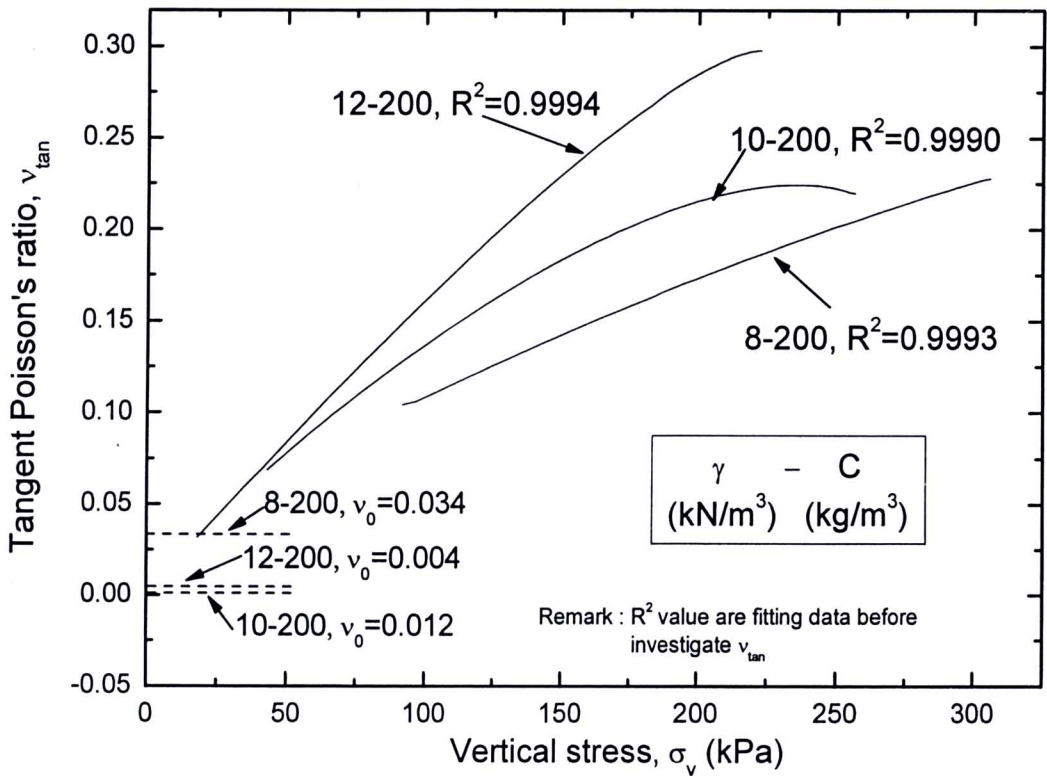


(a)



(b)

**Figure 4.20** Relationship between Tangent Poisson's ratio and vertical stress  
 (a) Cement content 100 kg/m<sup>3</sup> and unit weight 8, 10, 12kN/m<sup>3</sup>  
 (b) Cement content 150 kg/m<sup>3</sup> and unit weight 8, 10, 12kN/m<sup>3</sup>



**Figure 4.20 (Cont.)** (c) Cement content  $200 \text{ kg/m}^3$  and unit weight 8, 10,  $12 \text{ kN/m}^3$

## 4.6.2 Stress-strain and Small strain properties test

### 4.6.2.1 Stress-Strain Relation

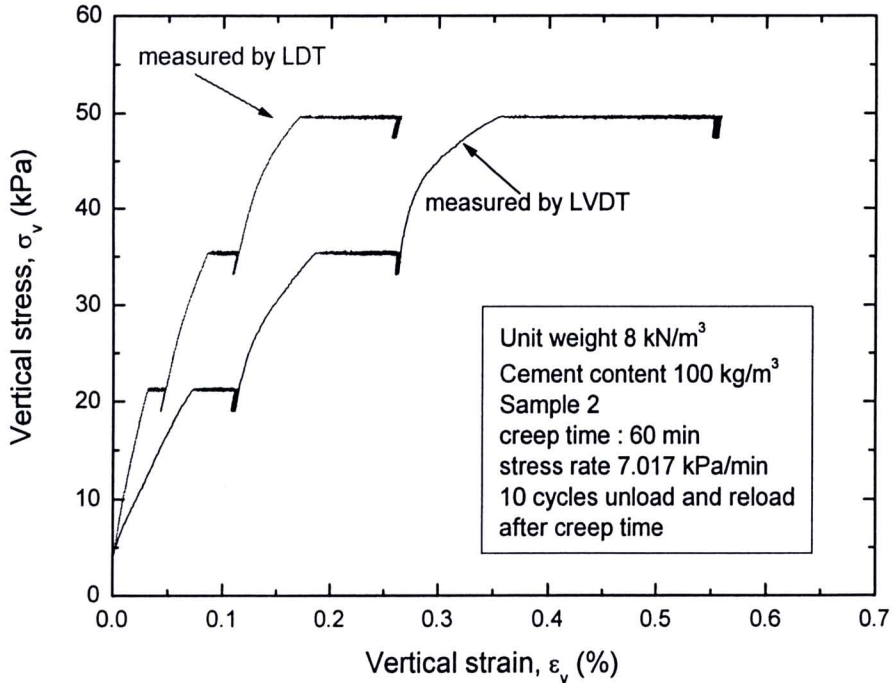
Presentation and discussion in this section were operation of results in minute-amplitude cyclic loading histories. Figures 4.21(a) through 4.21(c) show the stress-strain behaviour from continuous monotonic loading tests inserted by sustained loading after which minute-amplitude unload/reload cycles were perform at constant vertical stress rate of  $7.017 \text{ kPa/min}$ . by using load-controlled compression and extension loading system on Air-cement tread soil samples. Only Air-cement tread soil samples with unit weight  $8 \text{ kN/m}^3$  and cement content of 100, 150,  $200 \text{ kg/m}^3$  were selected to show their stress-strain behaviour for as example of all samples. The 70% of ultimate strength was used for test samples. Figures 4.22(a) though 4.22(c) show the relation of horizontal strain and vertical strain for Air-cement tread soil samples with unit weight  $8 \text{ kN/m}^3$  and cement content 100, 150,  $200 \text{ kg/m}^3$ , respectively. Moreover, Figures 4.23(a) through 4.23(c) and Figures 4.24(a) through 4.24(c) show the zoomed up of Figures 4.21 and 4.22, respectively. The following trends of behavior may be seen from this figure.

1) For the same vertical stress the value of vertical strain measured by LVDT is always greater than that measured by a pair of LDTs, which is due to the measuring errors consisting of system compliances and bedding errors.

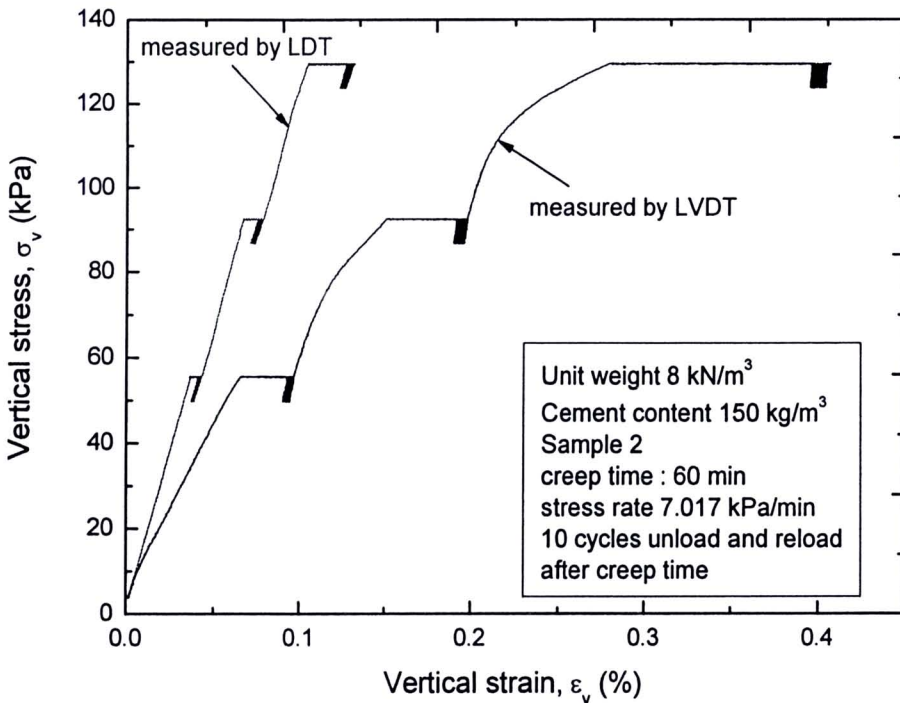
2) The vertical strains measured by using a pair of LDTs are found to give a sound basis for vertical strain measurements at small strains.

3) Creep strains and residual strains caused by minute-amplitude cycles performed after creep are noticeable. Therefore, the rate effect on the development of residual strain is not negligible.

4) From Figures 4.24(a) through 4.24(c), Lateral expansion always occurs during the Vertical compression, lateral compression and sustained load always occur during the vertical expansion.



(a)



(b)

**Figure 4.21** Relationship between vertical stress and vertical strain obtained from cyclic loading test on Air-cement treated soil.

(a) Unit weight  $8 \text{ kN/m}^3$  and cement content  $100 \text{ kg/m}^3$   
(b) Unit weight  $8 \text{ kN/m}^3$  and cement content  $150 \text{ kg/m}^3$

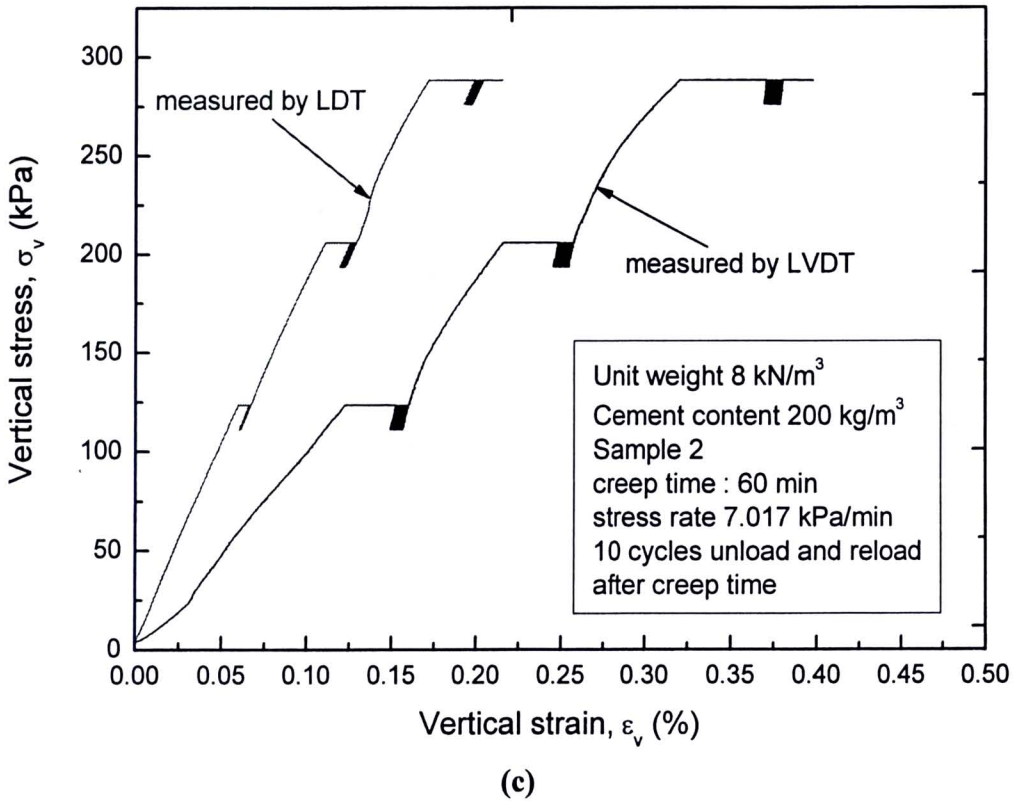


Figure 4.21 (Cont.) (c) Unit weight 8 kN/m<sup>3</sup> and cement content 200 kg/m<sup>3</sup>

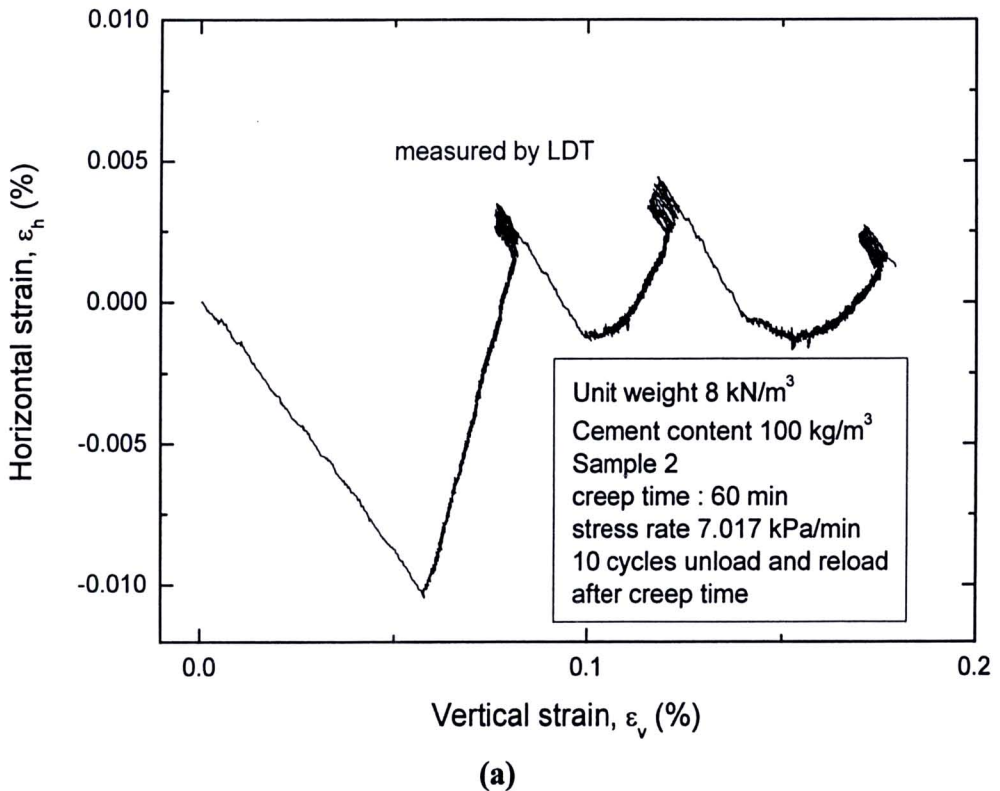
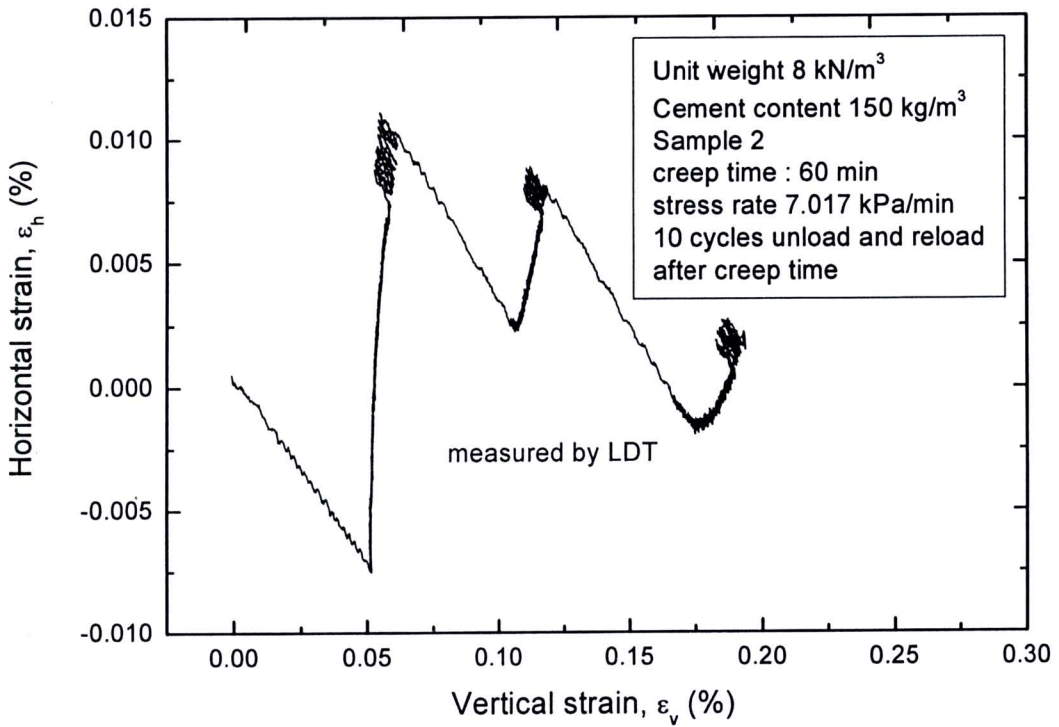
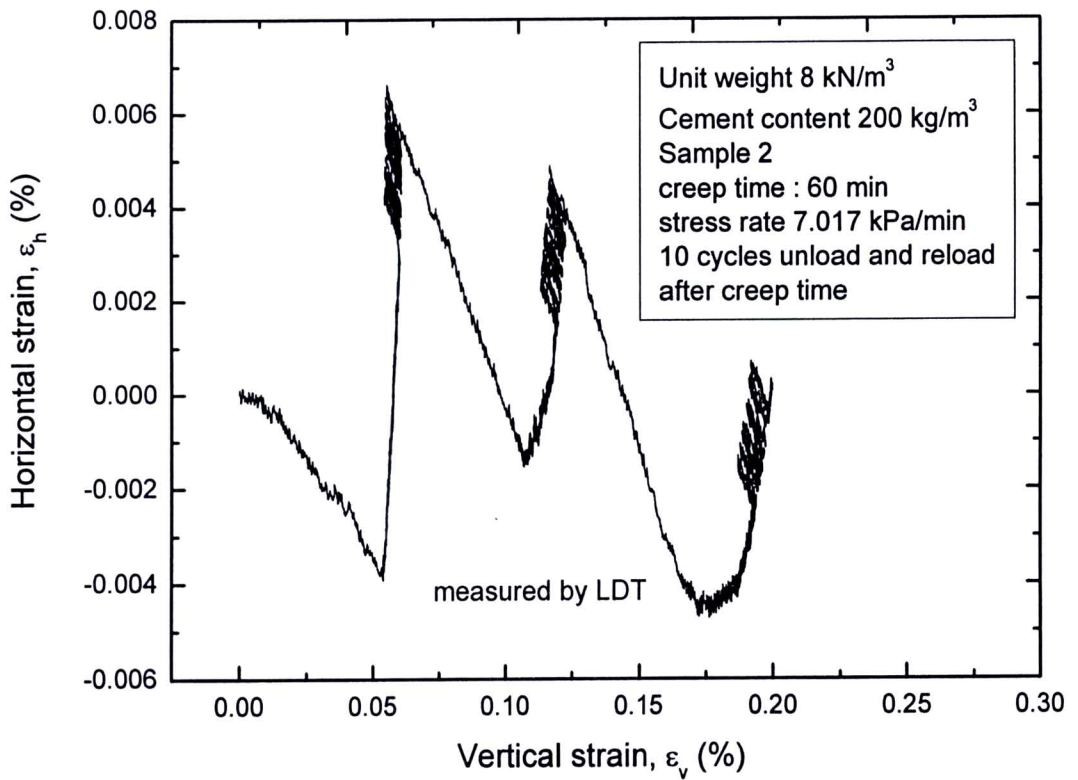


Figure 4.22 Relationship between horizontal strain and vertical strain obtained from cyclic loading test on Air-cement treated soil.  
 (a) Unit weight 8 kN/m<sup>3</sup> and cement content 150 kg/m<sup>3</sup>

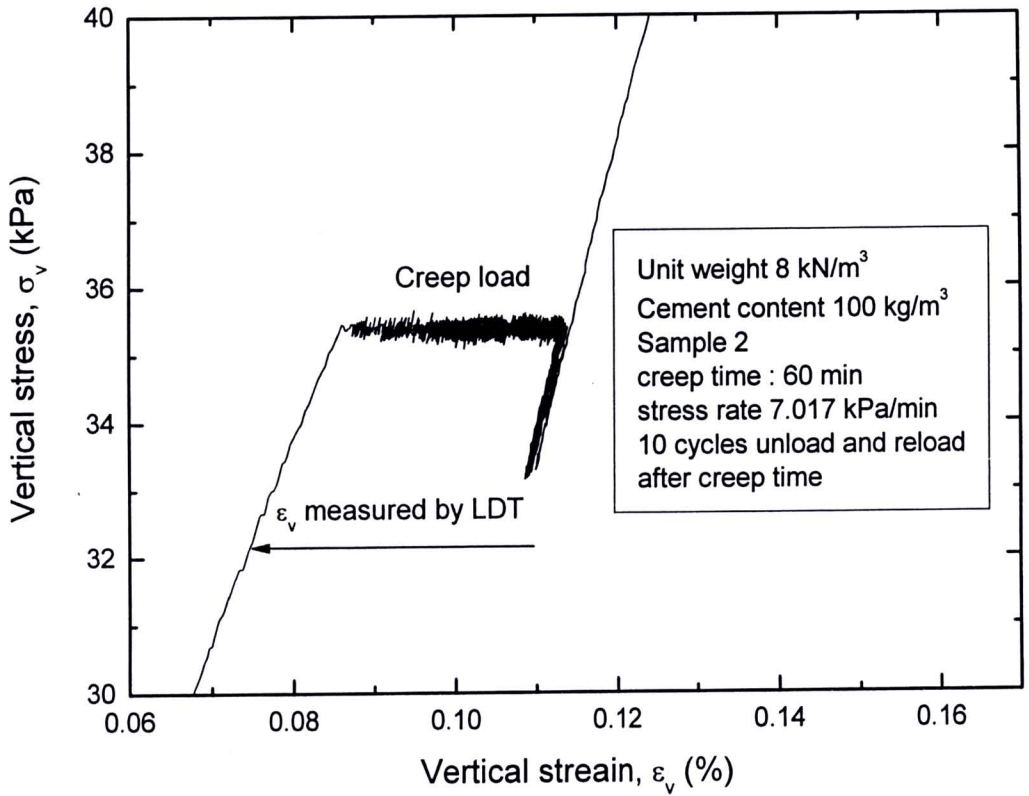


(b)

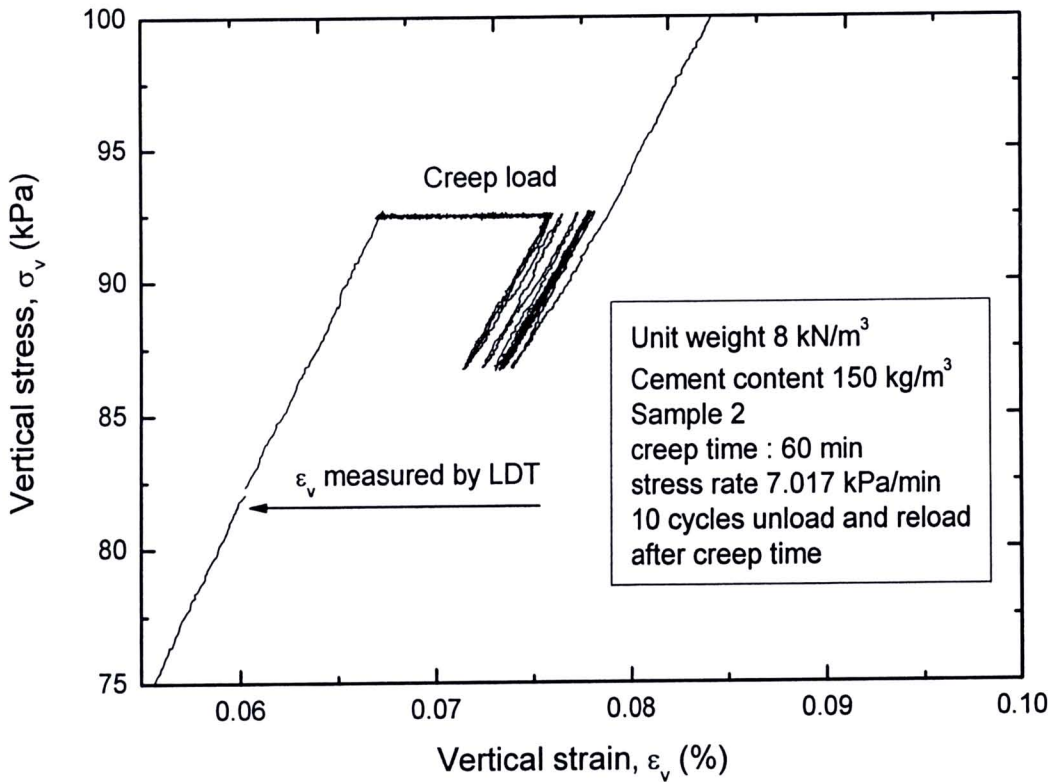


(c)

**Figure 4.22 (Cont.)** (b) Unit weight  $8 \text{ kN/m}^3$  and cement content  $150 \text{ kg/m}^3$   
 (c) Unit weight  $8 \text{ kN/m}^3$  and cement content  $200 \text{ kg/m}^3$



(a)

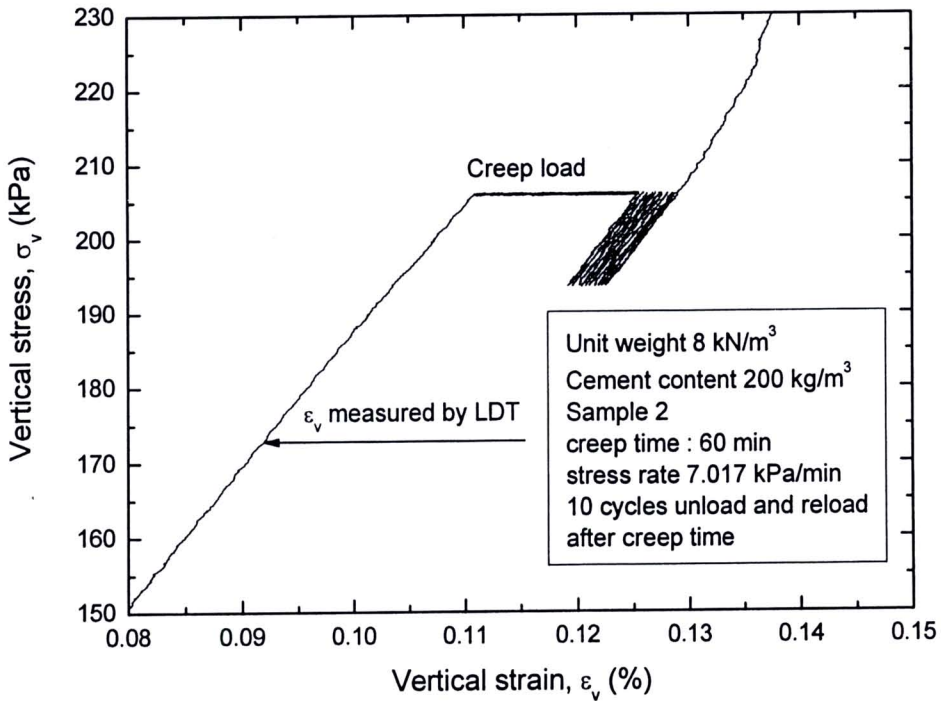


(b)

**Figure 4.23** Close-up of vertical stress and vertical strain obtained from cyclic loading test on air-cement tread soil

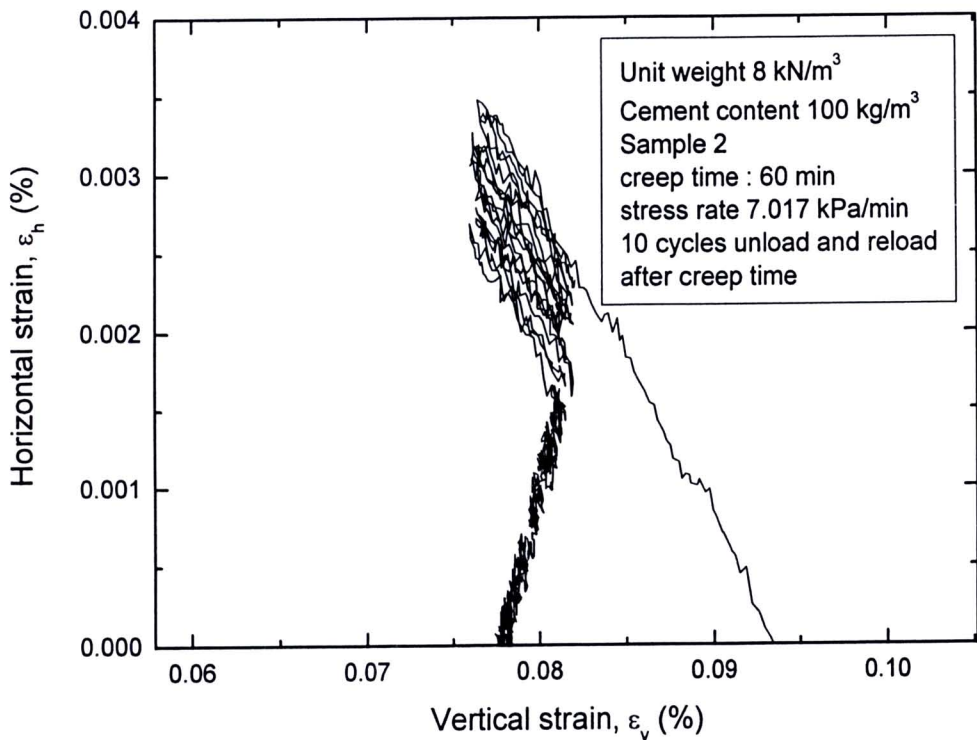
(a) Unit weight  $8 \text{ kN/m}^3$  and cement content  $100 \text{ kg/m}^3$

(b) Unit weight  $8 \text{ kN/m}^3$  and cement content  $150 \text{ kg/m}^3$



(c)

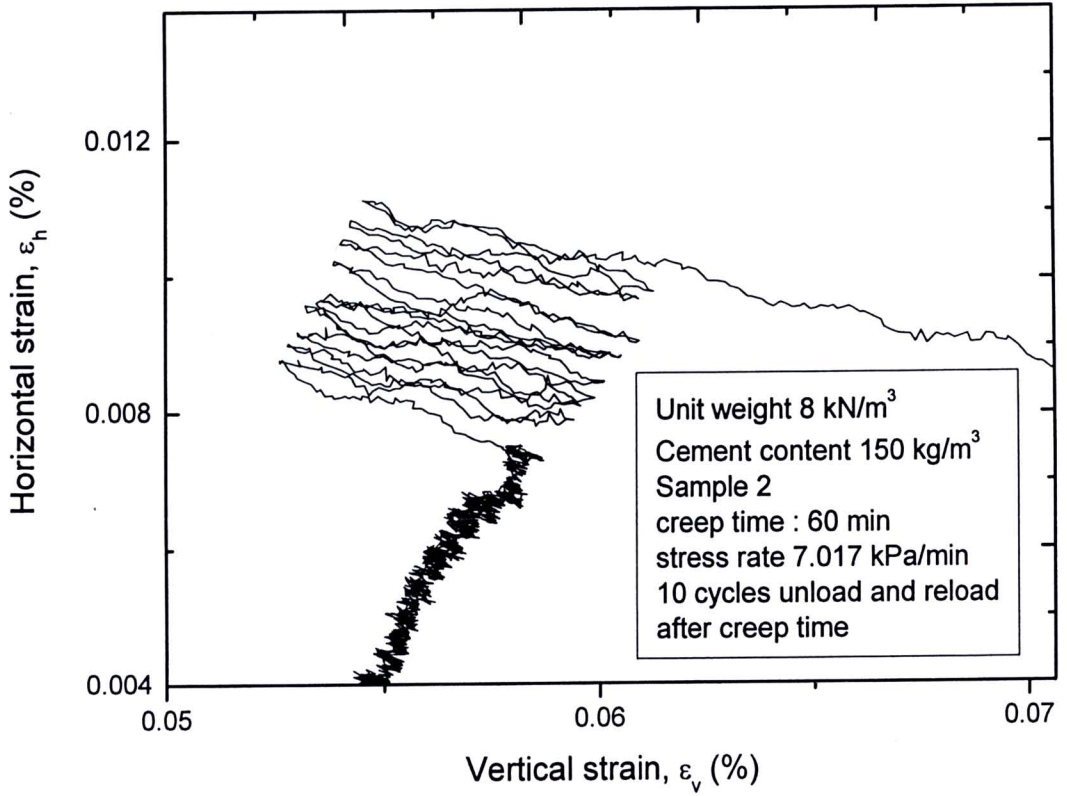
Figure 4.23 (Cont.) (c) Unit weight  $8 \text{ kN/m}^3$  and cement content  $200 \text{ kg/m}^3$



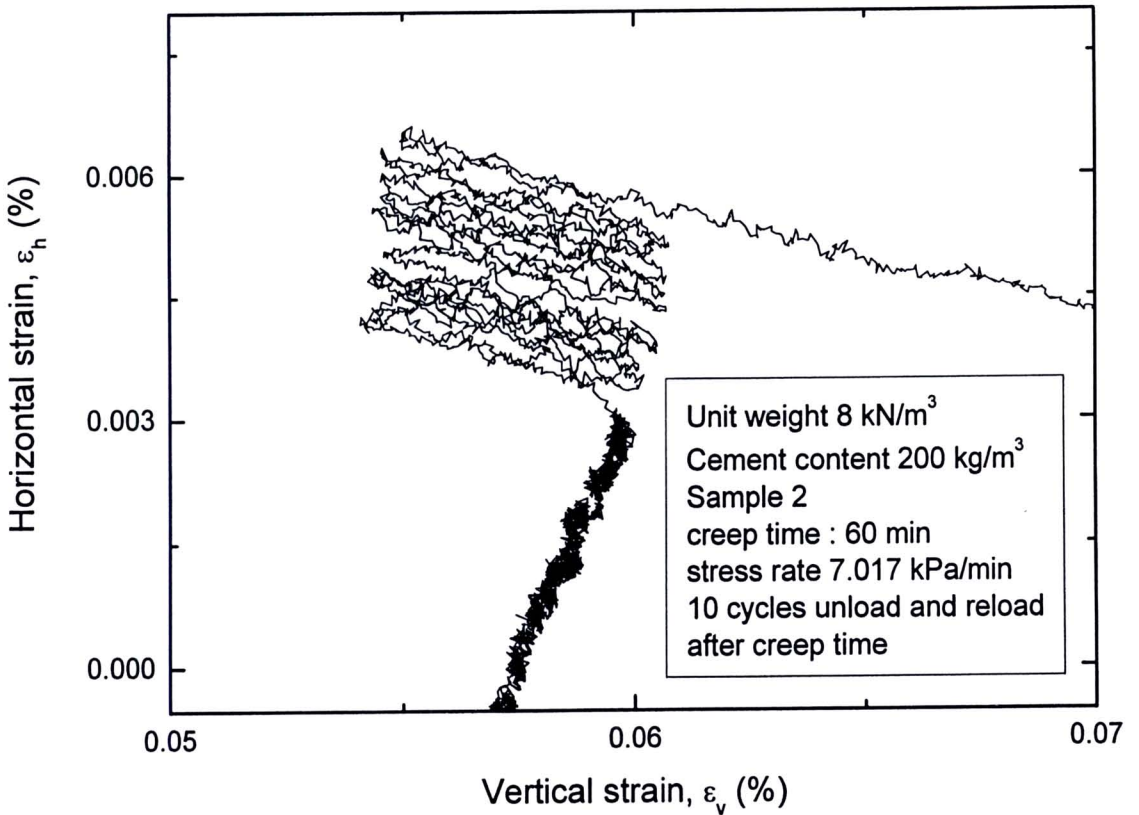
(a)

Figure 4.24 Close-up of horizontal strain and vertical strain obtained from cyclic loading test on air-cement tread soil.

(a) Unit weight  $8 \text{ kN/m}^3$  and cement content  $100 \text{ kg/m}^3$



(b)



(c)

**Figure 4.24 (Cont.)** (b) Unit weight  $8 \text{ kN/m}^3$  and cement content  $150 \text{ kg/m}^3$   
 (c) Unit weight  $8 \text{ kN/m}^3$  and cement content  $200 \text{ kg/m}^3$

#### 4.6.2.2 Equivalent Modulus and Poisson's ratio

Equivalent modulus and Poisson's ratio are value of small strain. The stiffness of small strain is near to elastic property. Thus, they can be show behaviour of small deformation.

Equivalent modulus and Poisson's ratio are defined as the slope of the apparently linear portion from an unload cycle on vertical stress-vertical strain and horizontal strain-vertical strain curve as shown in Figure 4.25(a) and Figure 4.25(b), respectively. It is known that the unload and reload cycles of vertical stress give stiffness value greater than those at initial virgin loading with many materials including soils. It is also known that the equivalent modulus ( $E_{eq}$ ) acting in the vertical direction defined by vertical stress divided vertical strain for unbound granular materials (i.e., sands and gravels) increases with an increase in the vertical stress (e.g., Hoque and Tatsuoka, 1988; Tatsuoka et al., 1999a and 1999b). Therefore, it is of interest to evaluate the equivalent modulus ( $E_{eq}$ ) and Poisson ratio ( $\nu_{eq}$ ) value of the Air-cement treading soil sample that mixed with cement for road construction against the respective values of vertical stress at which these equivalent modulus ( $E_{eq}$ ) and Poisson ratio ( $\nu_{eq}$ ) values were measured.

The equivalent modulus ( $E_{eq}$ ) and Poisson ratio ( $\nu_{eq}$ ) value were evaluated from vertical stress-vertical strain and horizontal strain-vertical strain relation of which the horizontal strain and vertical strain values were obtained by CGs and LDTs, during ten minute-amplitude unload/reload cycles performed after sustained load. The equivalent modulus ( $E_{eq}$ ) and Poisson ratio ( $\nu_{eq}$ ) were obtained from the average of the ones obtained from the unloading paths of the sixth to the tenth loops ( 5 loops in total). The following trends of behaviour may be seen from this Figure Appendix N:

1) From observation it is implied that, at small strain level near the origin, the stress-strain behaviors are significantly elastic for all specimens prepared at different mixes. Then, the equivalent modulus ( $E_{eq}$ ) and equivalent Poisson's ratio ( $\nu_{eq}$ ) for Air-cement treading soil decreases with an increase in the vertical stress, as show in Figure 4.27(a) through 4.27(c) and Figure 4.30(a) through 4.30(c), respectively.

2) At the same vertical stress and equivalent modulus ( $E_{eq}$ ) evaluated from vertical strain measured by a pair of LDT were greater than measured by LVDT. It is known that the vertical strains measured externally are utterly unreliable, which is due mostly to significant effects of bedding error at the top and bottom ends of specimen partly to the deformation of the loading piston and specimen cap (i.e., the system compliance), as shown in Figure 4.26 (e.g., Tatsuoka, 2000). Therefore, the measurements with a local gauge (i.e. LDTs) were extremely importance.

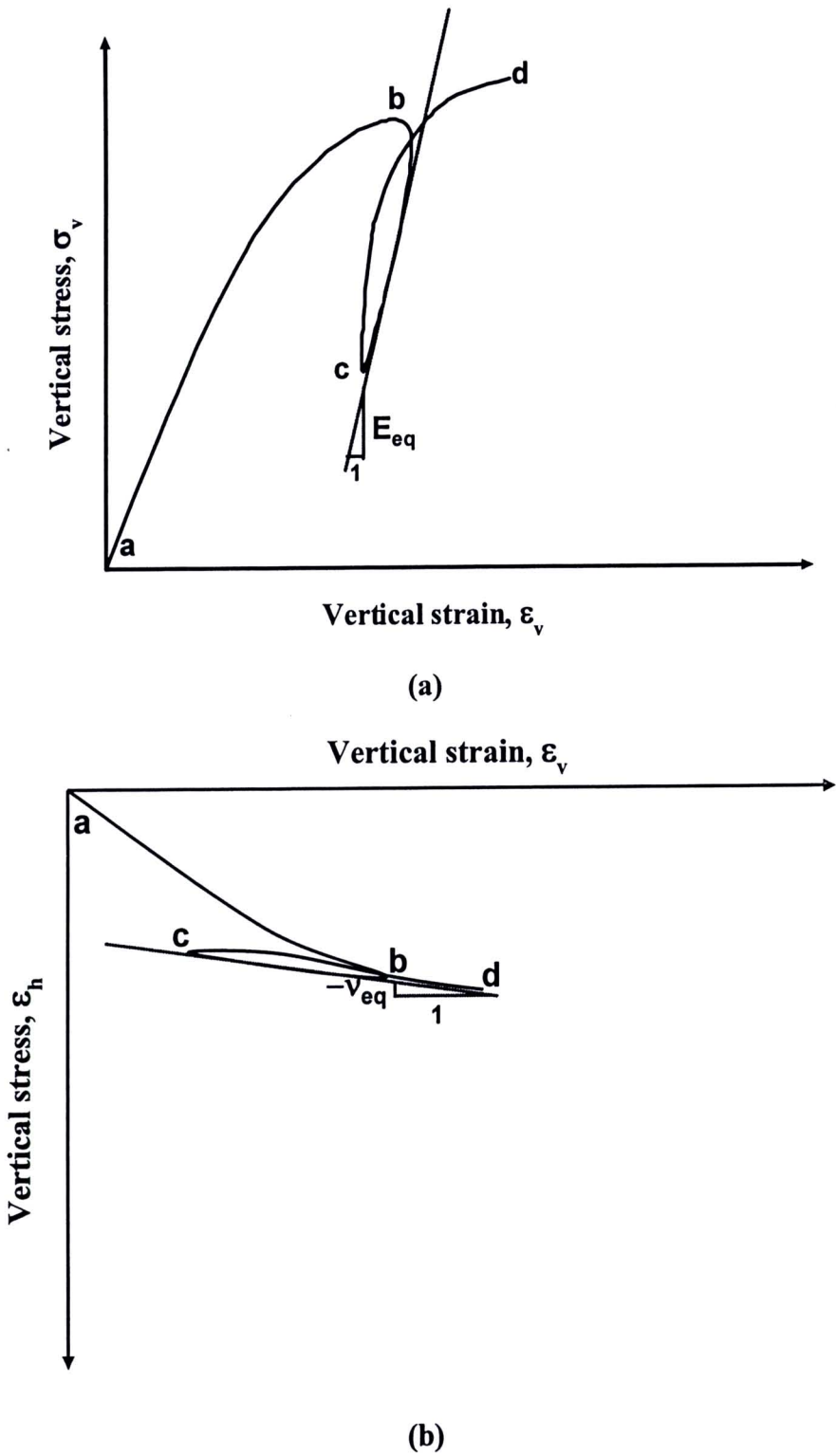
3) For all  $E_{eq}$  trend of Air-cement treading soil was not harmonized with the trend of unbound materials (i.e., sands and gravels) that increases with an increase in the vertical stress (e.g., Hoque and Tatsuoka, 1988; Tatsuoka et al., 1999a and 1999b) but there was trend with Expanded polystyrene (EPS) geofoam (G.E. Abdelrahman et al., 2008).

4) Trend of  $E_{eq}$  varied effective void ratio,  $e_{st}$ .

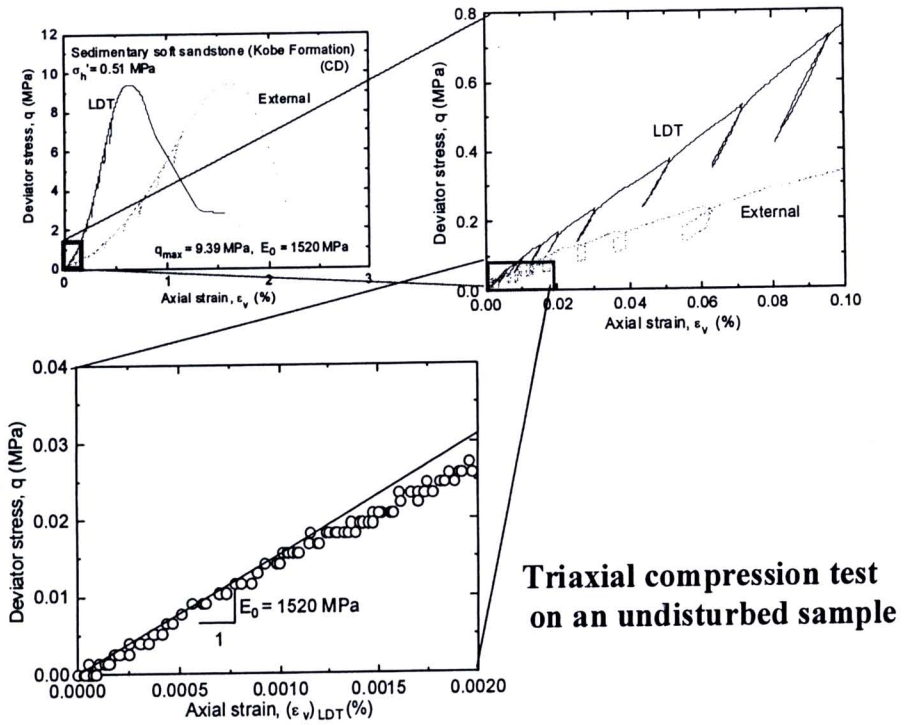
5) Trend of  $E_{eq}$  increased with a decreased  $e_{st}$ .

6) The value of  $E_0$  was close to the  $E_{eq}$  at first level of vertical stress. But the value of  $\nu_0$  and  $\nu_{eq}$  were difference.

7) When constant Cement content (C) trend of  $\nu_{eq}$  decreased with decrease unit weight.

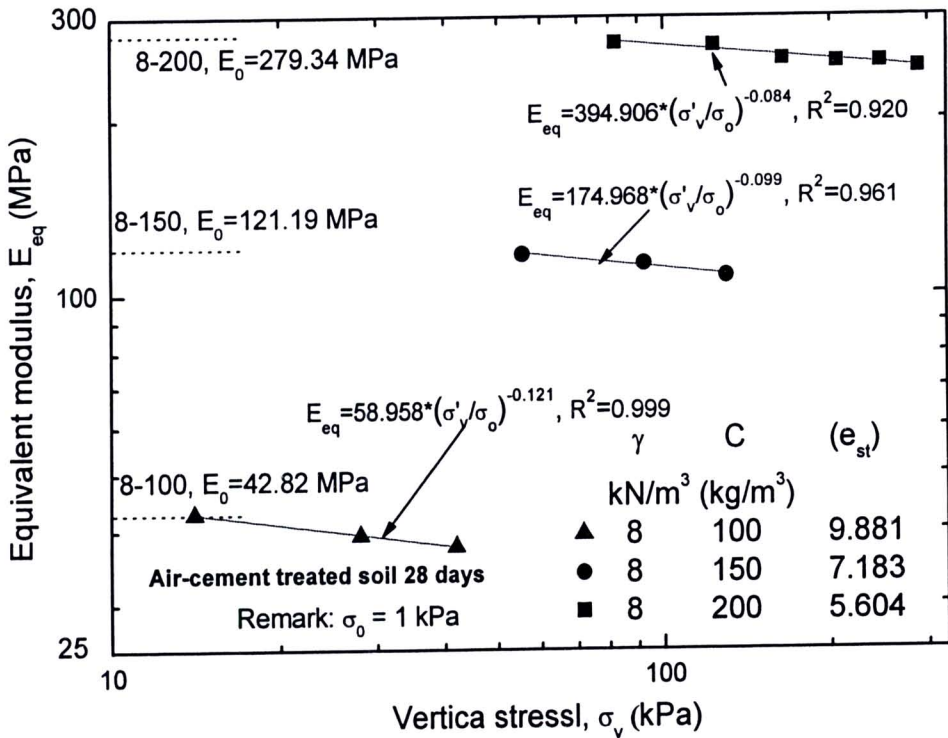


**Figure 4.25** Definition of equivalent elastic modulus and equivalent Poisson ratio  
 (a) Definition of equivalent elastic modulus  
 (b) Definition of equivalent Poisson ratio



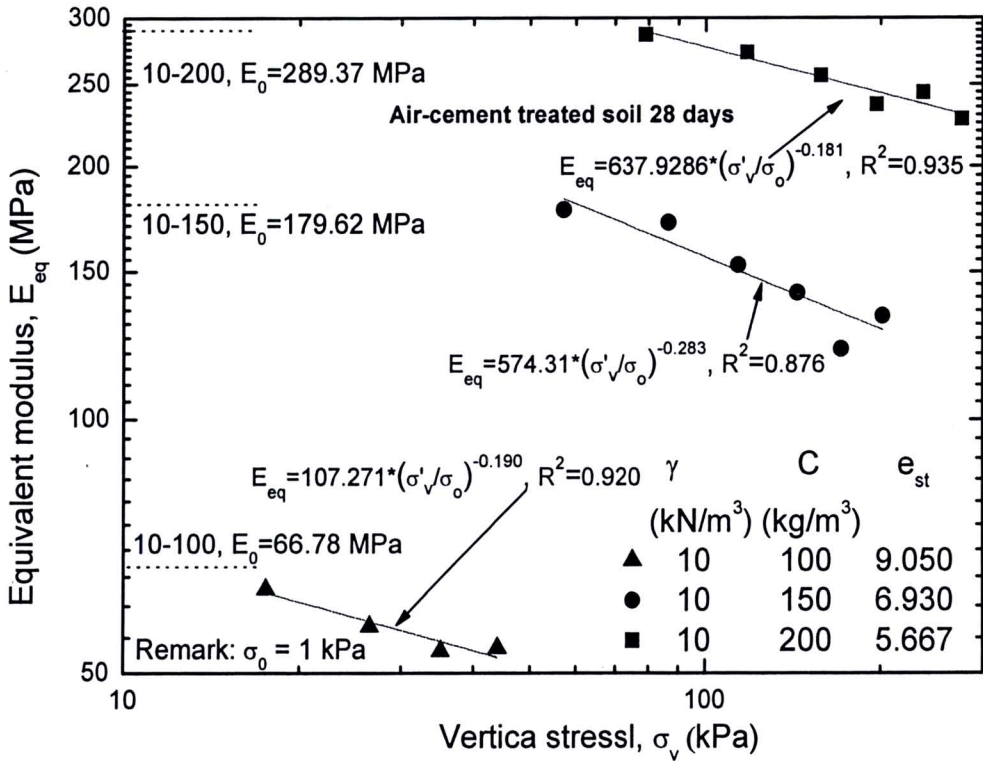
**Triaxial compression test on an undisturbed sample**

**Figure 4.26** Typical relationships between deviator stress and the axial strain from a CD TC test on a specimen obtained by block sampling at the bottom of excavation for Anchor A1, Akachi Kaikyo Bridge (Tatsuoka and Kohata, 1995)

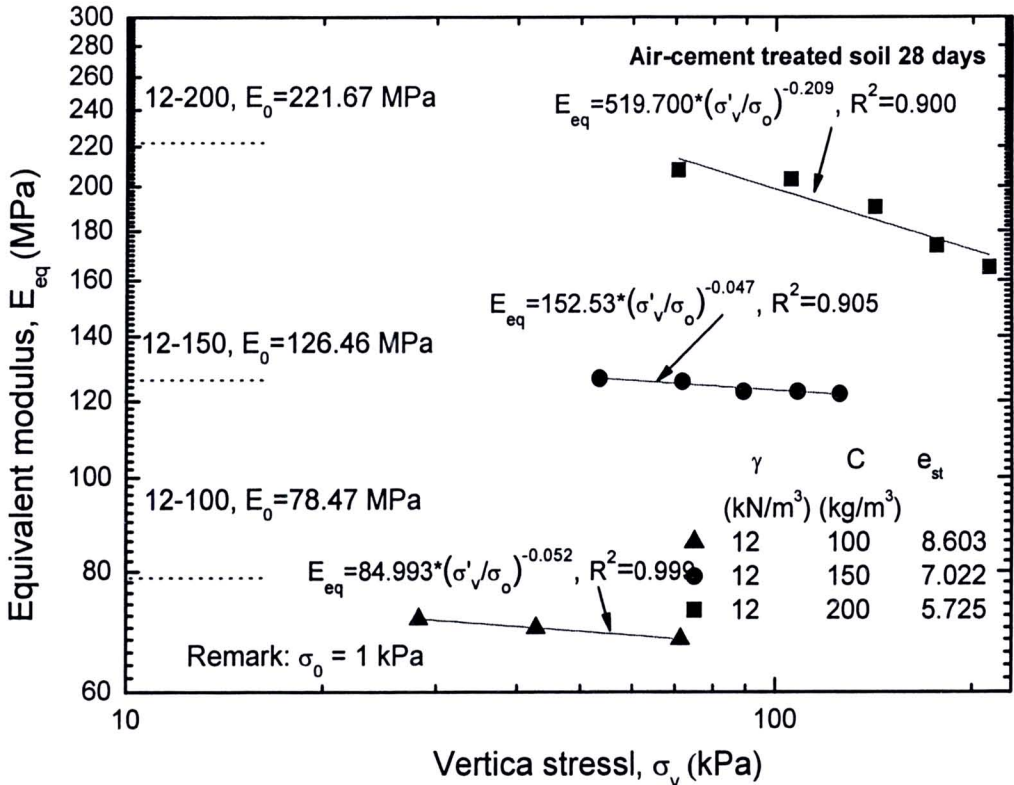


(a)

**Figure 4.27** Comparisons of equivalent stiffness as a function of vertical stress  
 (a) Unit weight 8 kN/m<sup>3</sup> vary cement content 100, 150, 200 kg/m<sup>3</sup>



(b)



(c)

**Figure 4.27 (Cont.)** (b) Unit weight 10 kN/m<sup>3</sup> vary cement content 100, 150, 200 kg/m<sup>3</sup>  
 (c) Unit weight 12 kN/m<sup>3</sup> vary cement content 100, 150, 200 kg/m<sup>3</sup>

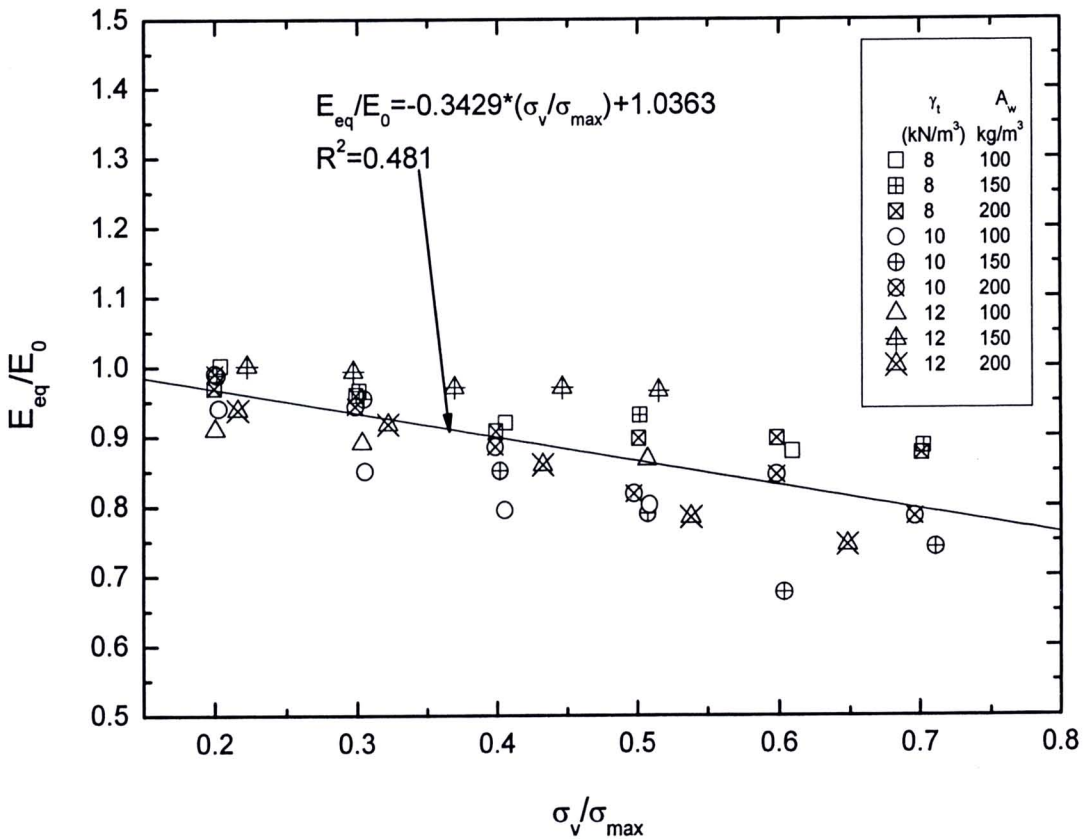
However, Effective void ratio has been relation with initial modulus ( $E_0$ ), as shown in Eq (4.4).

$$E_0 = 2238.8e^{-0.379e_{st}} \tag{4.4}$$

From Figure 4.28, shown normalizing the equivalent modulus value by  $E_0$  has been relation with stress level, as shown in Eq (4.6).

$$\frac{E_{eq}}{E_0} = -0.3429\left(\frac{\sigma_v}{\sigma_{max}}\right) + 1.0363 \tag{4.5}$$

From Eq(4.4) and Eq(4.5), remarkable relation of equation have been connection by parameter  $e_{st}$  and  $E_0$  that they have used prediction  $E_{eq}$ . With in used the idea mention above calculate equivalent modulus, as shown in Figure 4.29 which was relationship between calculate equivalent modulus to measured equivalent modulus.



**Figure 4.28** Relationships between normalized equivalent stiffness and level of vertical stress for air-cement treated soil.

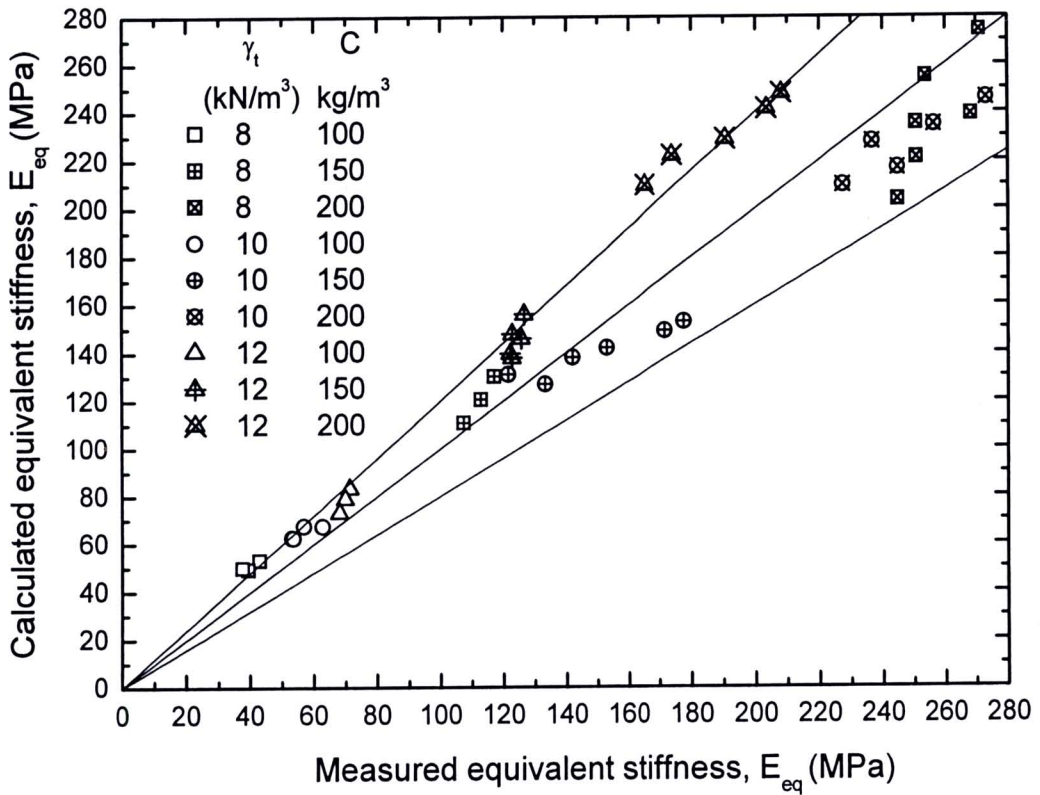
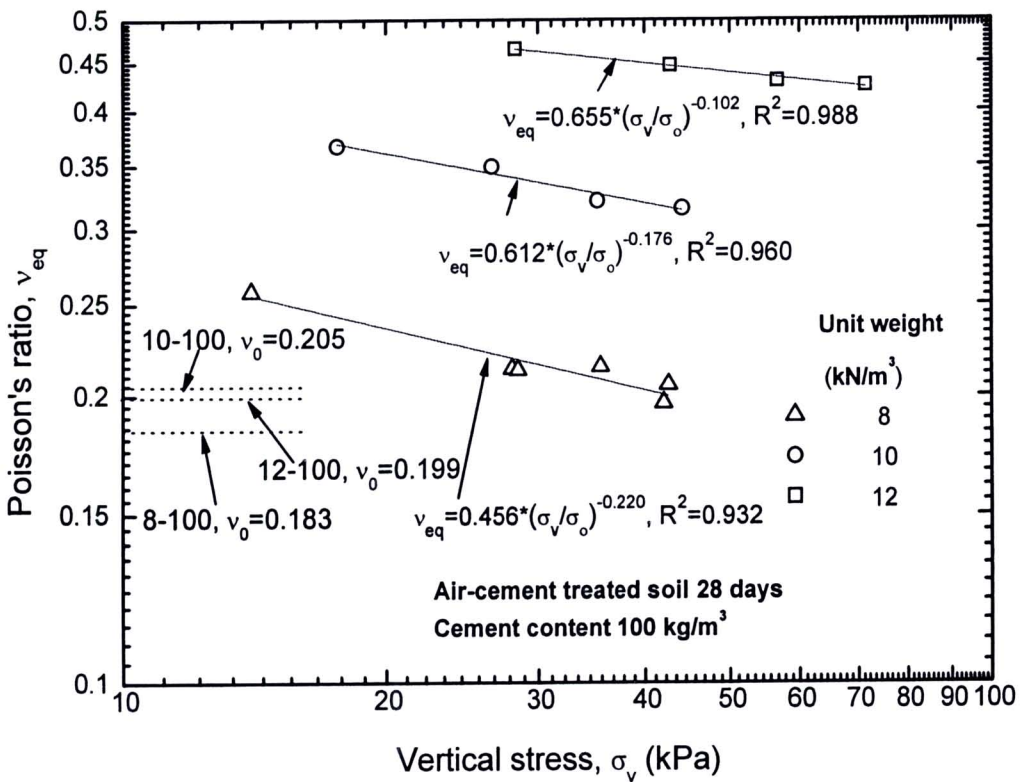
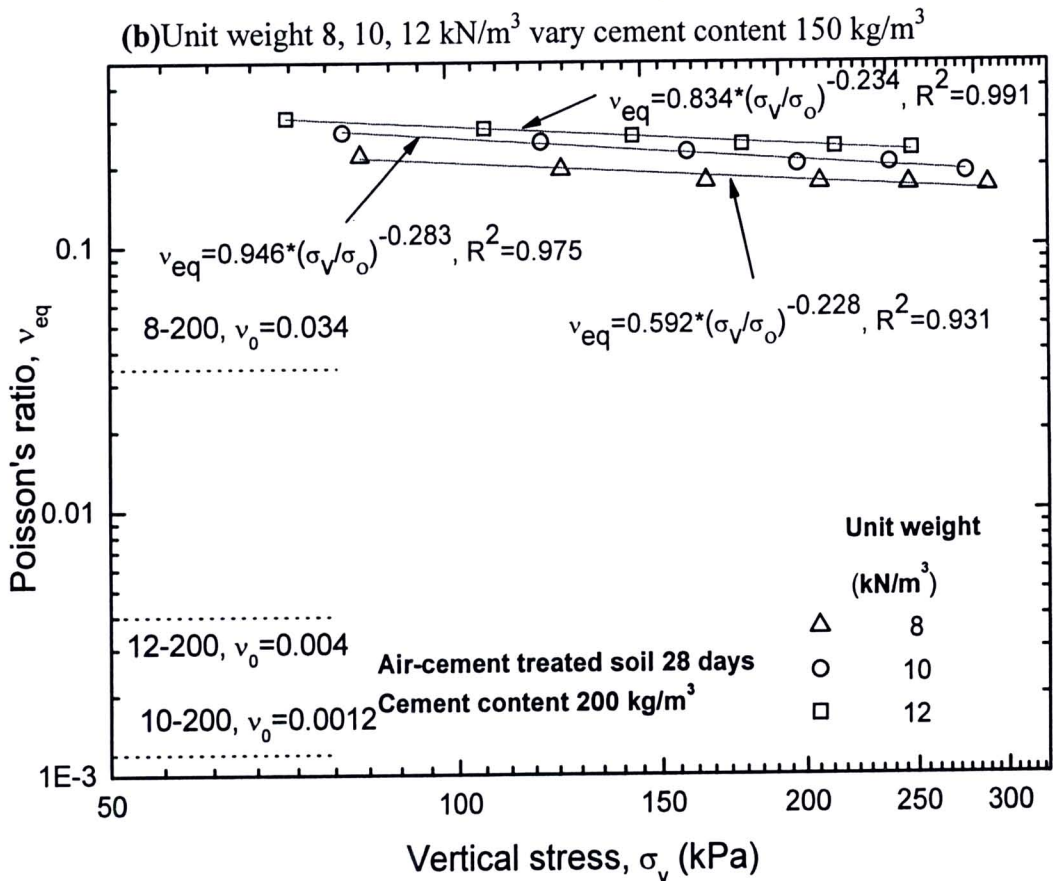
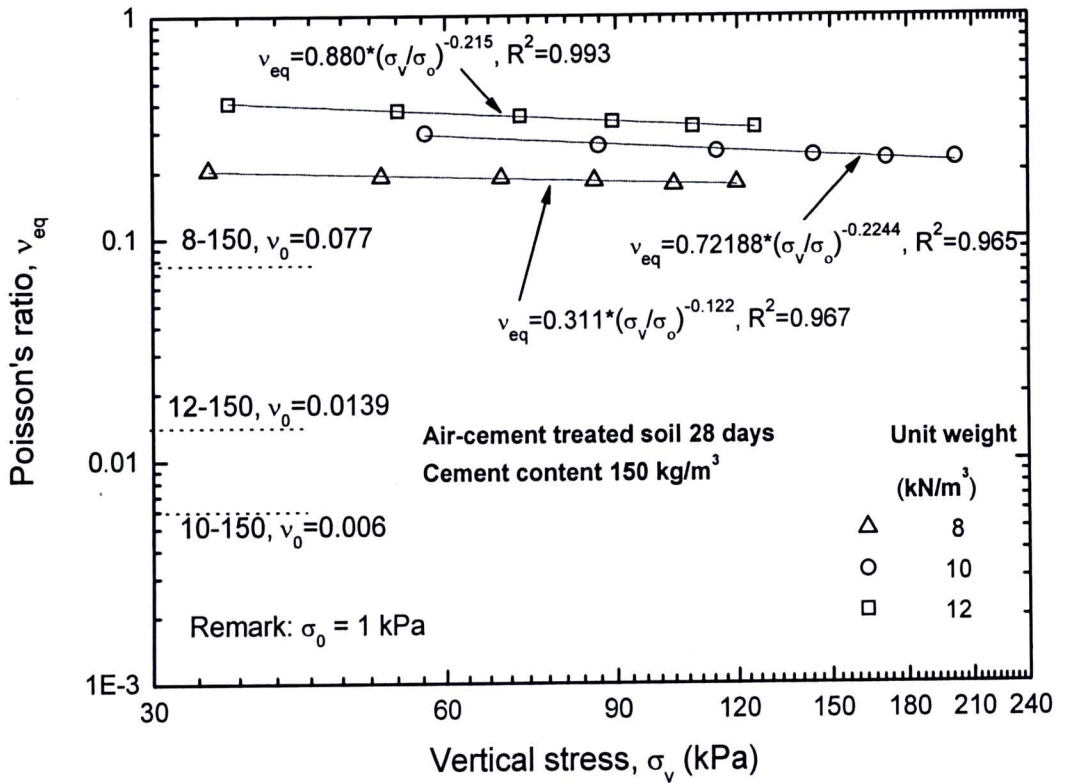


Figure 4.29 Relationship between calculated and measured equivalent stiffness



(a)

Figure 4.30 Comparisons of equivalent stiffness as a function of vertical stress  
 (a) Unit weight 8, 10, 12  $kN/m^3$  vary cement content 100  $kg/m^3$



(c)

**Figure 4.30 (Cont.)** (b) Unit weight 8, 10, 12 kN/m<sup>3</sup> vary cement content 150 kg/m<sup>3</sup>  
 (c) Unit weight 8, 10, 12 kN/m<sup>3</sup> vary cement content 200 kg/m<sup>3</sup>

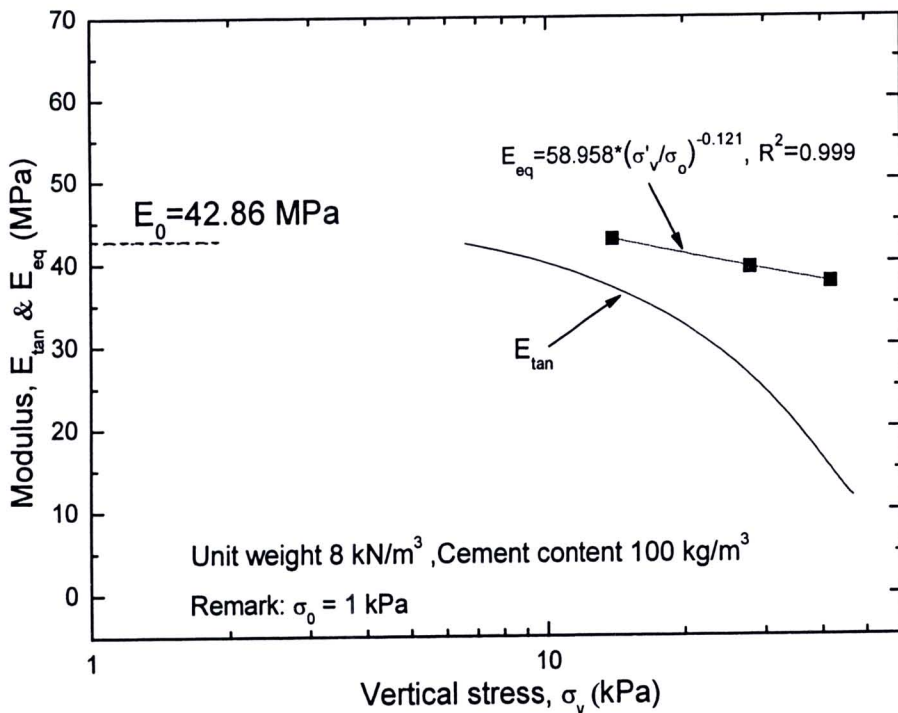
From Negussey (2007), EPS, there was structure of EPS and gas in cell for Load. Structure of EPS is polystyrene. Thus cell of EPS can be confine atmosphere in its. But ACS is slurry mixing to cement. Void of ACS can not confine atmosphere in the void. Thus ACS can be damage by structure only.

From Abdelrahman et al. (2008), EPS ,  $E_{eq}$  and  $\nu_{eq}$  value decreased with an increase in  $\sigma_v$ . Which is similar this study.  $\sigma_v$

#### 4.7 Comparison between the tangent modulus and the equivalent modulus

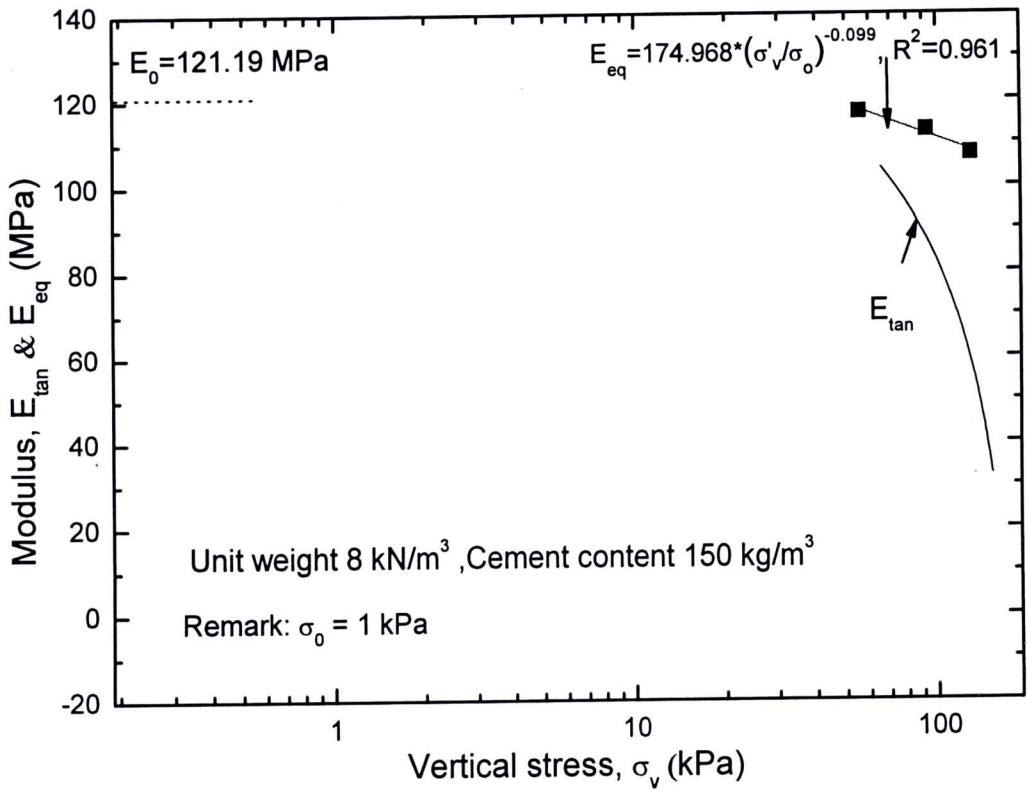
Figures 4.31(a) through 4.31(i) compared the  $E_{tan}$ -values with the  $E_{eq}$ -values while Figs 4.32(a) through 4.32(i) compared the  $\nu_{tan}$ -values with the  $\nu_{eq}$ -values of air-cement treated soil specimens at different Unit weight and cement content. The following trends of behavior may be seen from these figures:

- 1) Initial modulus,  $E_0$  was more than  $E_{tan}$  and  $E_{eq}$ .
- 2) The  $E_{eq}$  - values decreased with an increase in  $\sigma_v$  in a manner similar to the  $E_{tan}$  - values.
- 3) Equivalent modulus,  $E_{eq}$ , evaluated from minute-amplitude unload and reload cycles applied after sustained loading is noticeably greater than the value of  $E_{tan}$  when compared at the same level vertical stress,  $\sigma_v$  because there was rate effect and plastic effect for  $E_{tan}$ .
- 4) Initial Poisson ratio,  $\nu_0$  was less than  $\nu_{tan}$  and  $\nu_{eq}$ .
- 5) The  $\nu_{eq}$ -values decreased with an increase in  $\sigma_v$  a different way to the  $\nu_{tan}$  - value.

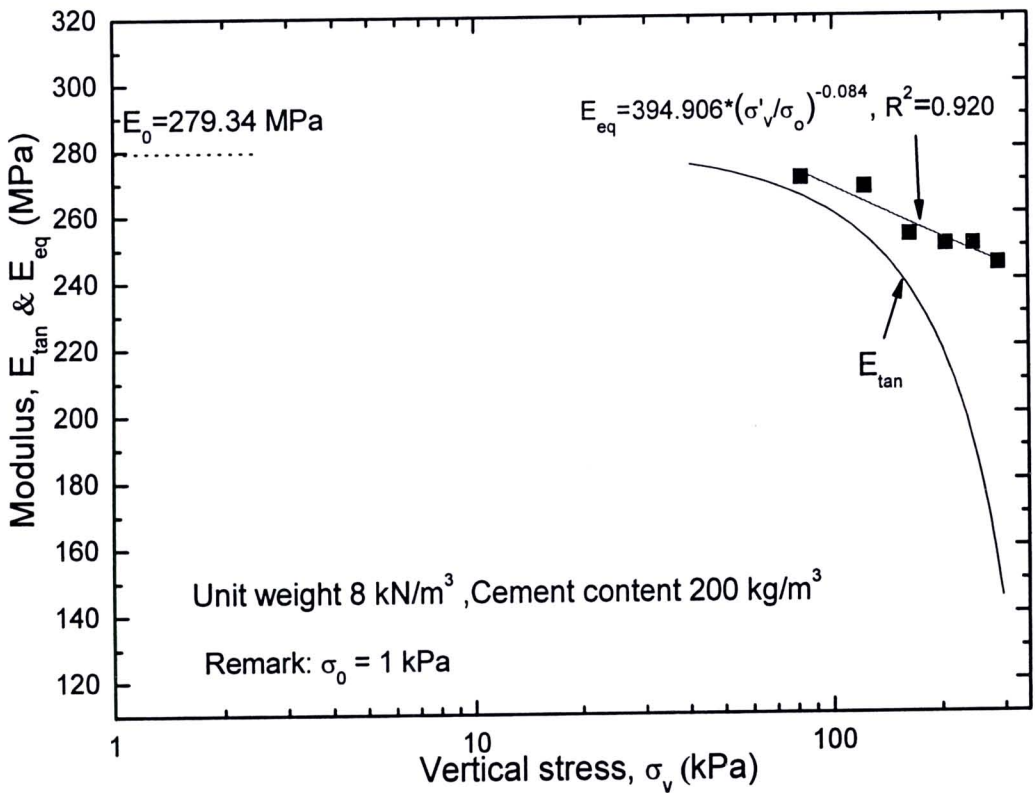


(a)

**Figure 4.31** Comparison between tangent modulus and equivalent modulus  
(a) Unit weight  $8 \text{ kN/m}^3$  Cement content  $100 \text{ kg/m}^3$

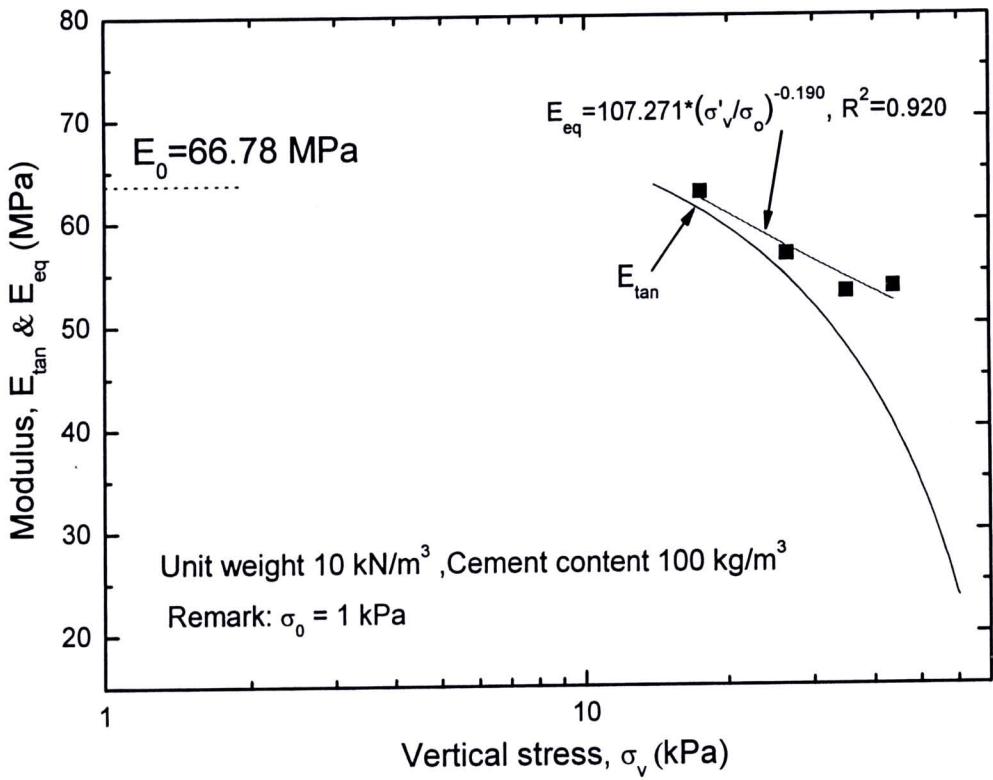


(b)

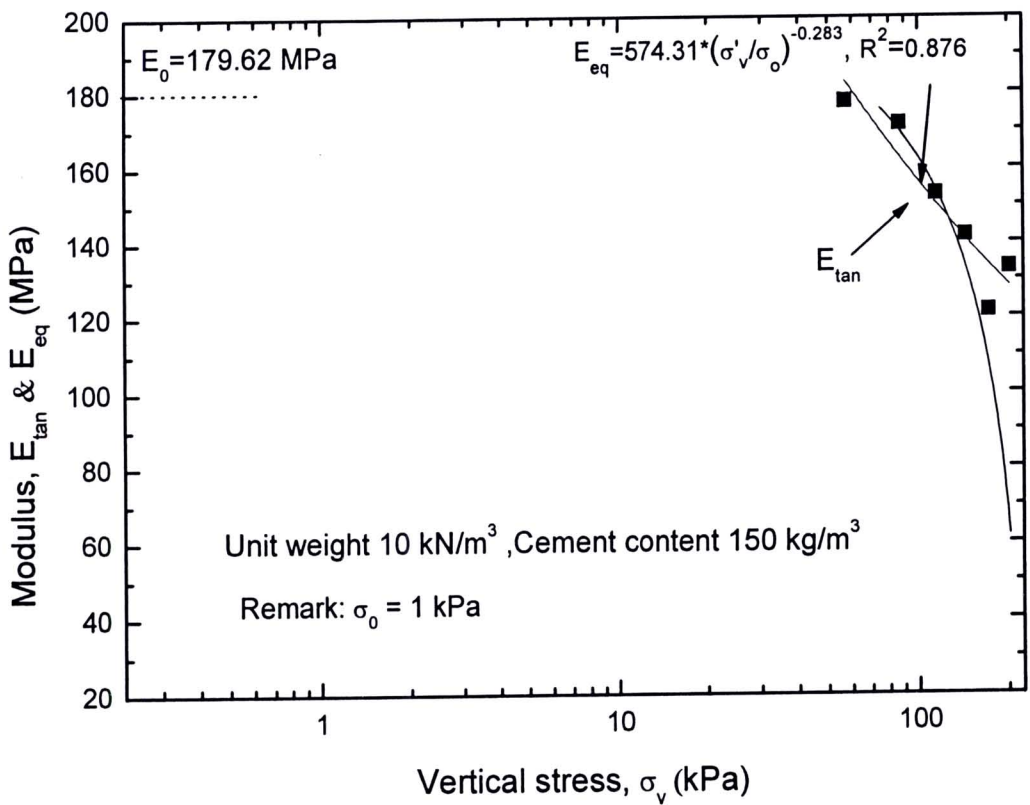


(c)

**Figure 4.31 (Cont.)** (b) Unit weight  $8 \text{ kN/m}^3$  Cement content  $150 \text{ kg/m}^3$   
 (c) Unit weight  $8 \text{ kN/m}^3$  Cement content  $200 \text{ kg/m}^3$

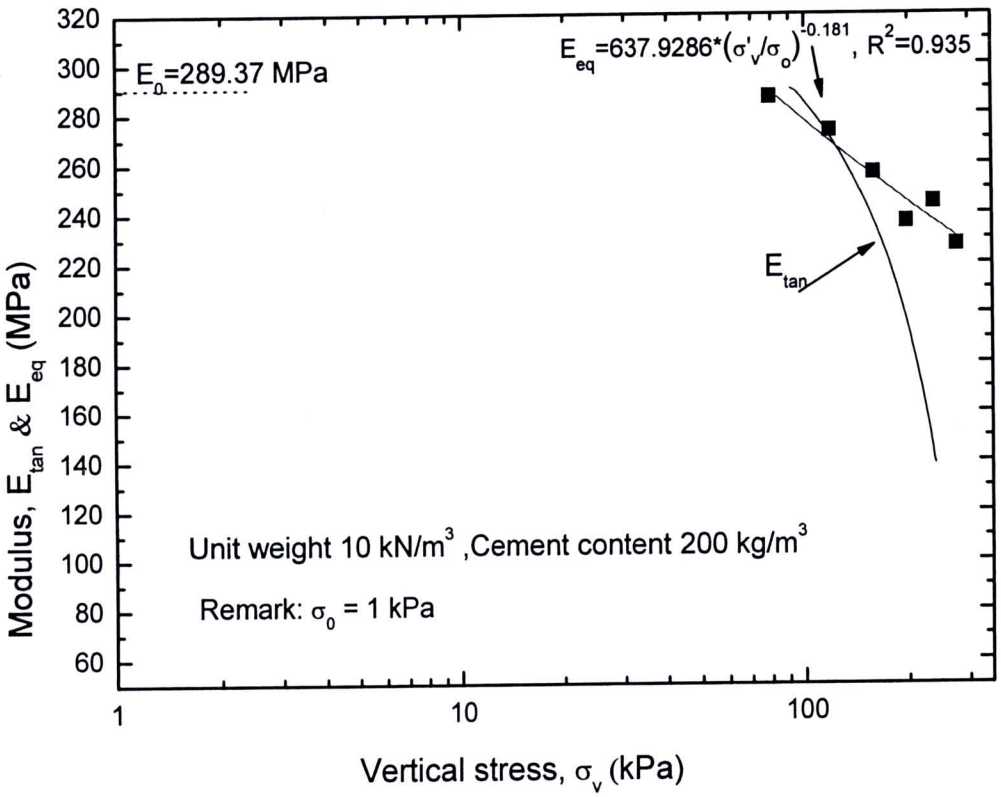


(d)

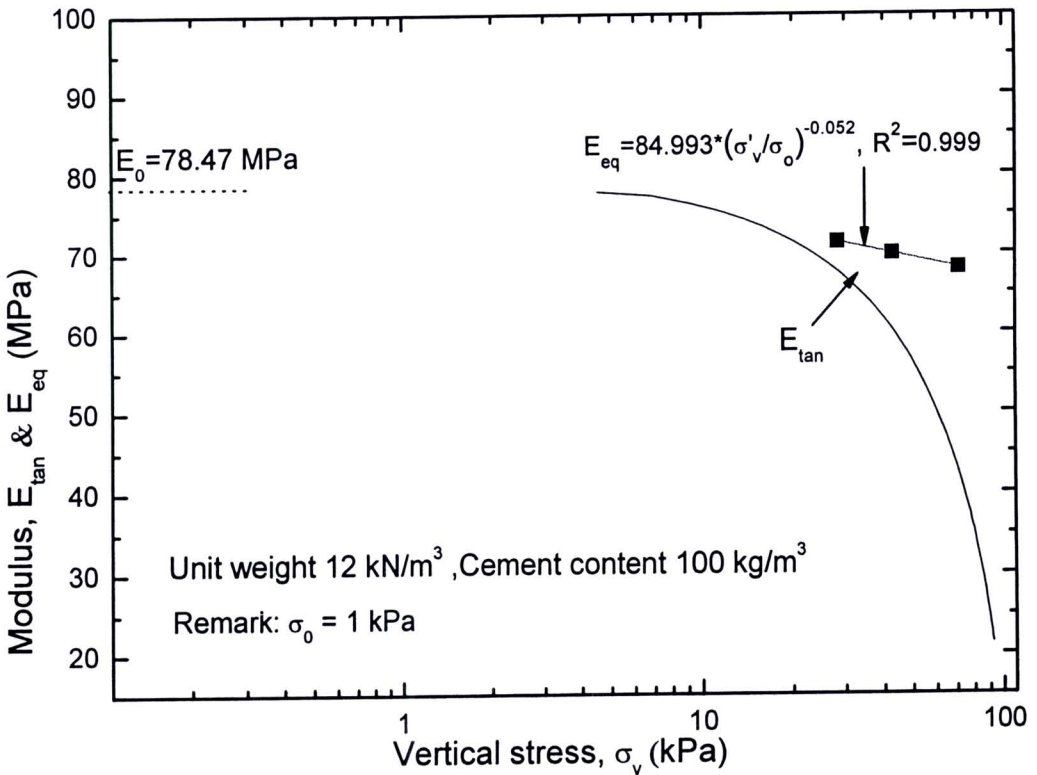


(e)

**Figure 4.31 (Cont.)** (d) Unit weight  $10 \text{ kN/m}^3$  Cement content  $100 \text{ kg/m}^3$   
 (e) Unit weight  $10 \text{ kN/m}^3$  Cement content  $150 \text{ kg/m}^3$

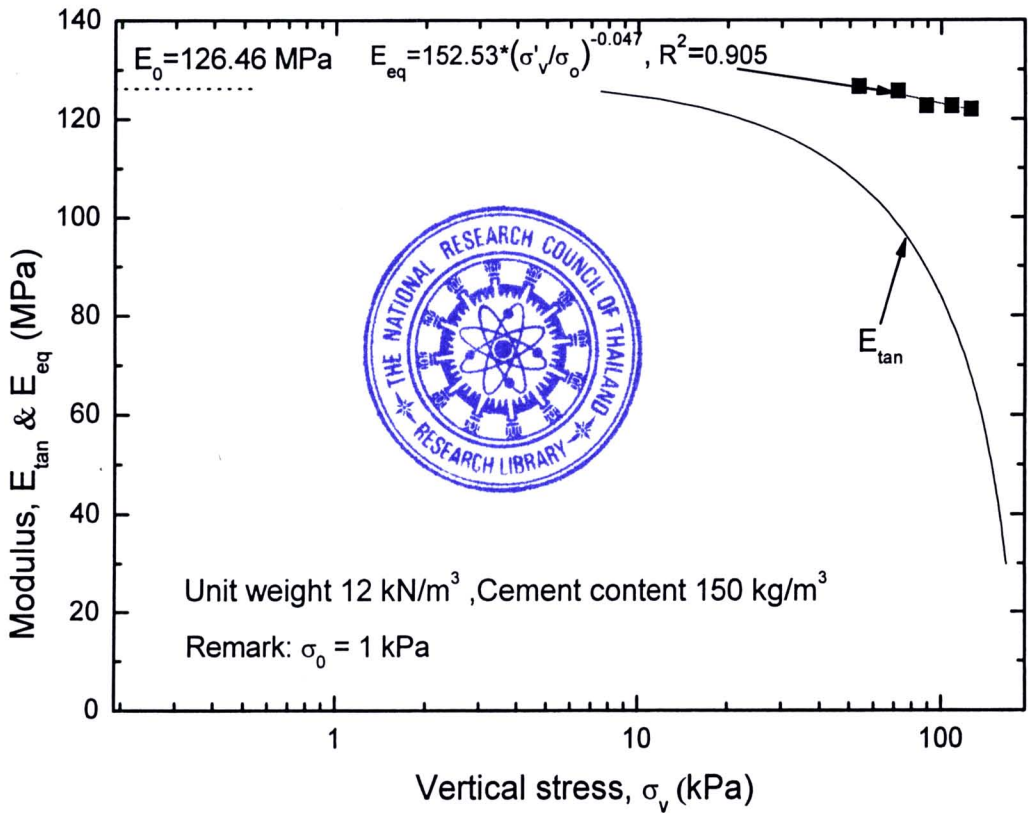


(f)

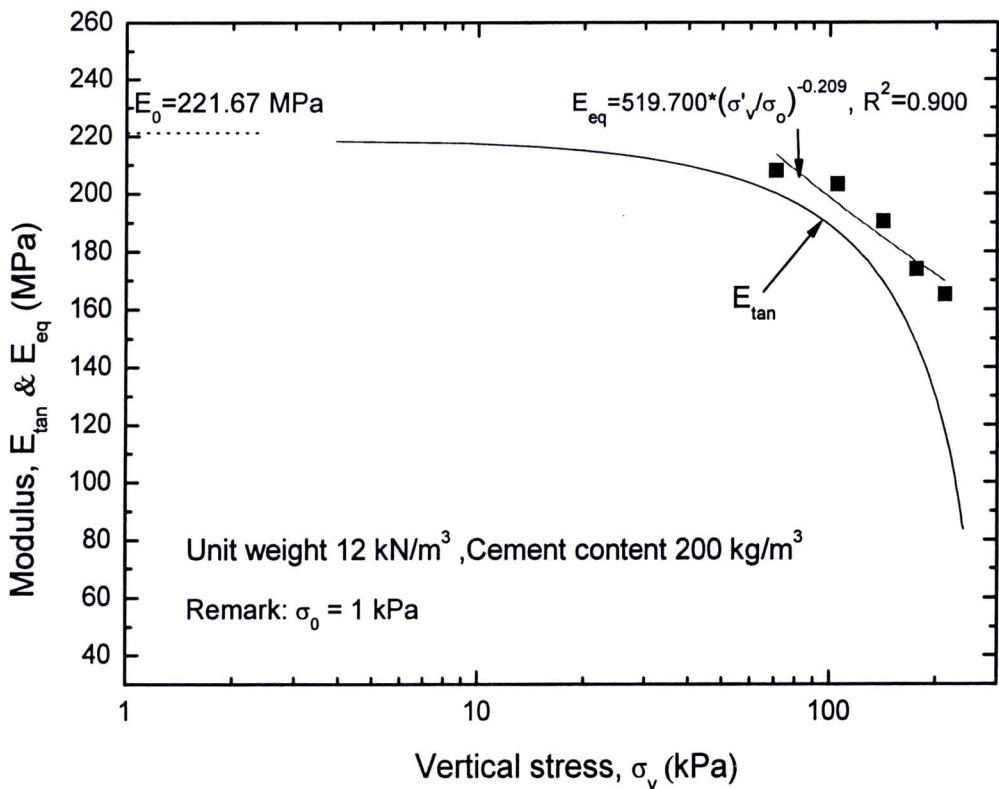


(g)

**Figure 4.31 (Cont.)** (f) Unit weight  $10 \text{ kN/m}^3$  Cement content  $200 \text{ kg/m}^3$   
 (g) Unit weight  $12 \text{ kN/m}^3$  Cement content  $100 \text{ kg/m}^3$

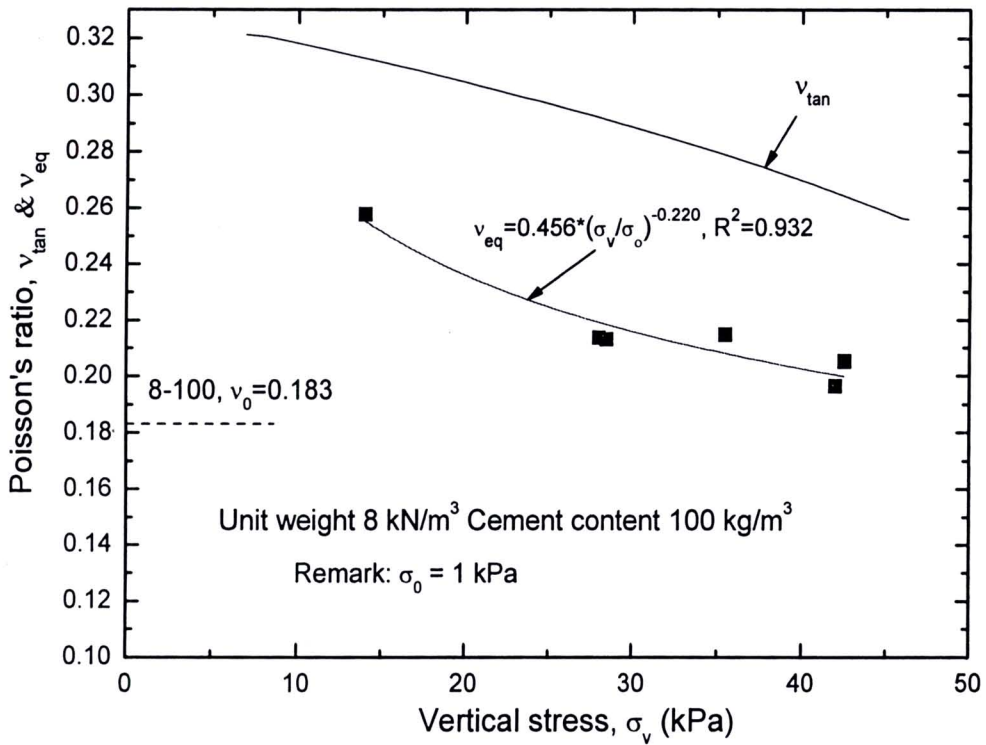


(h)

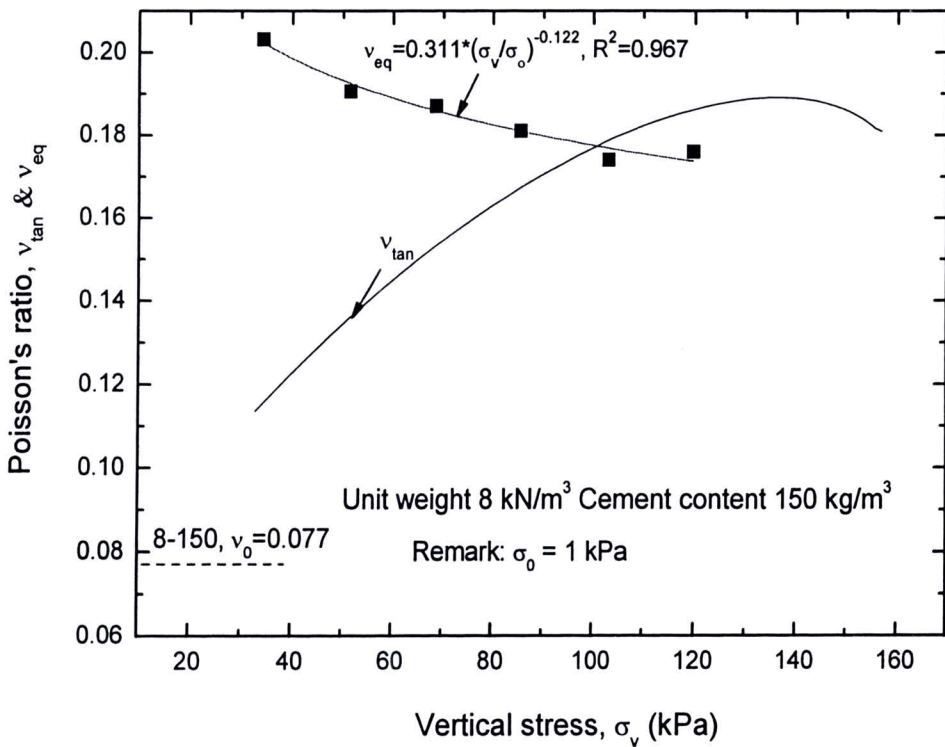


(i)

**Figure 4.31 (Cont.)** (h) Unit weight  $12 \text{ kN/m}^3$  Cement content  $150 \text{ kg/m}^3$   
 (i) Unit weight  $12 \text{ kN/m}^3$  Cement content  $200 \text{ kg/m}^3$

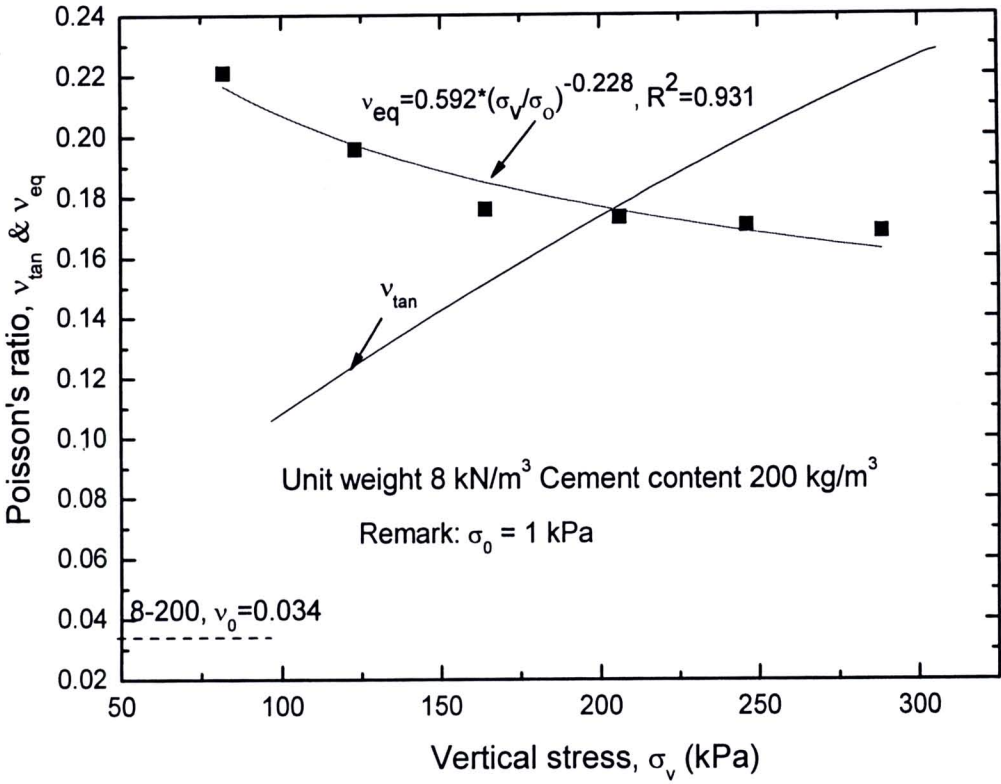


(a)

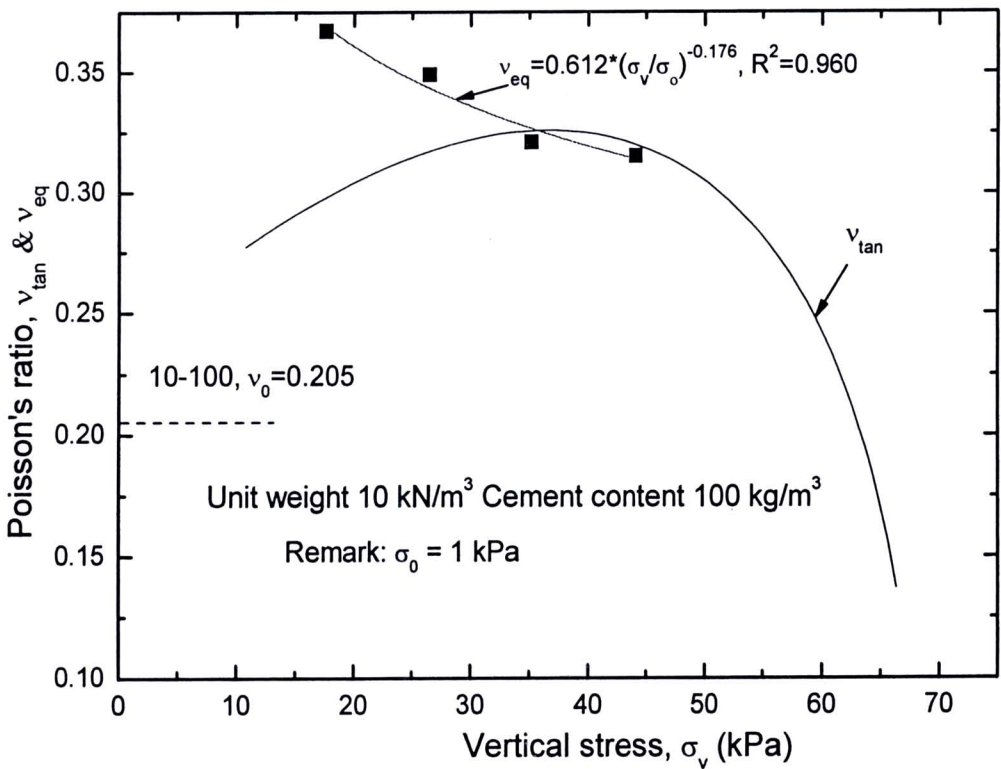


(b)

**Figure 4.32** Comparison between tangent Poisson's ratio and equivalent Poisson's ratio  
 (a) Unit weight 8 kN/m<sup>3</sup> Cement content 100 kg/m<sup>3</sup>  
 (b) Unit weight 8 kN/m<sup>3</sup> Cement content 150 kg/m<sup>3</sup>

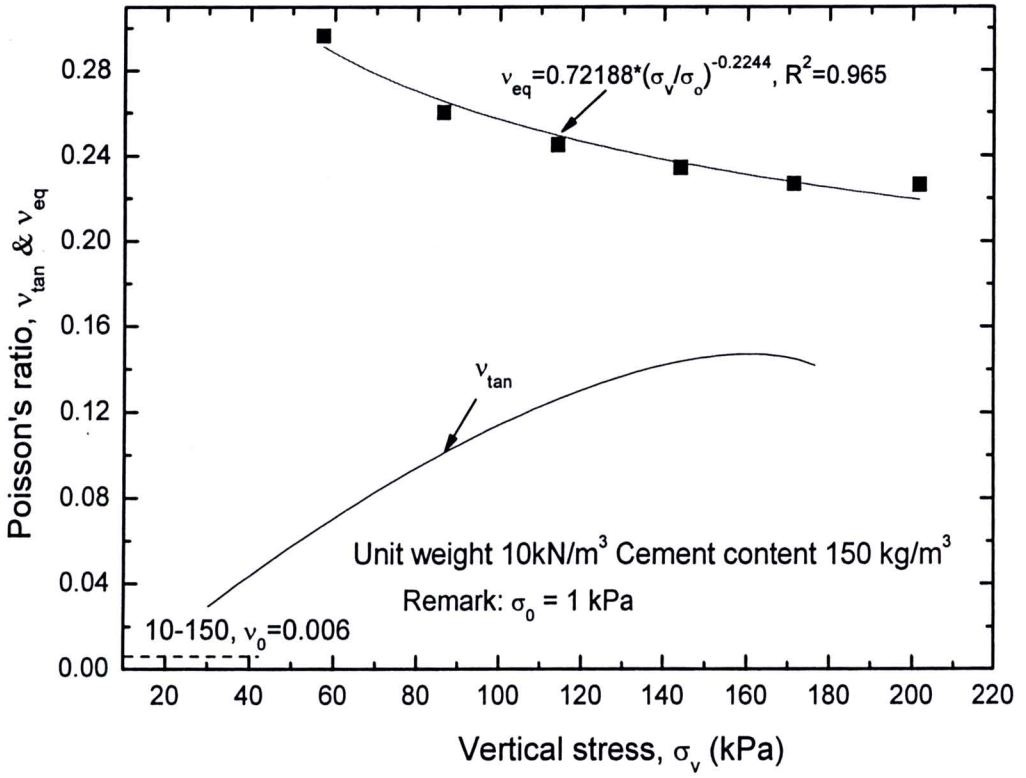


(c)

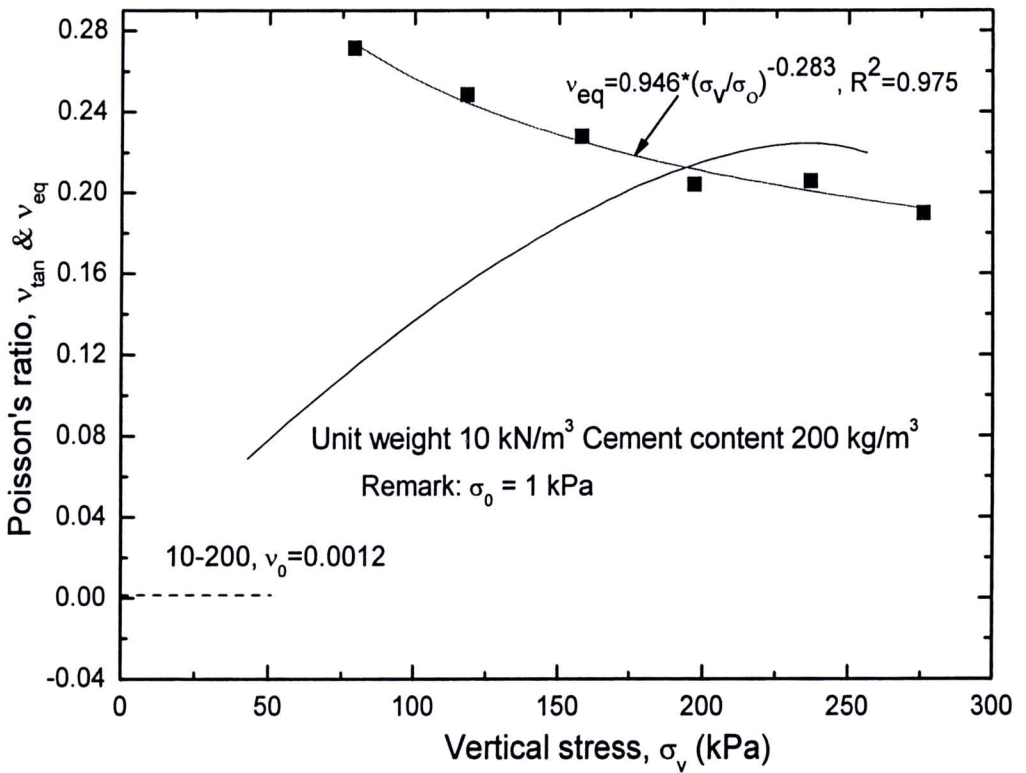


(d)

**Figure 4.32 (Cont.)** (c) Unit weight  $8 \text{ kN/m}^3$  Cement content  $200 \text{ kg/m}^3$   
 (d) Unit weight  $10 \text{ kN/m}^3$  Cement content  $100 \text{ kg/m}^3$

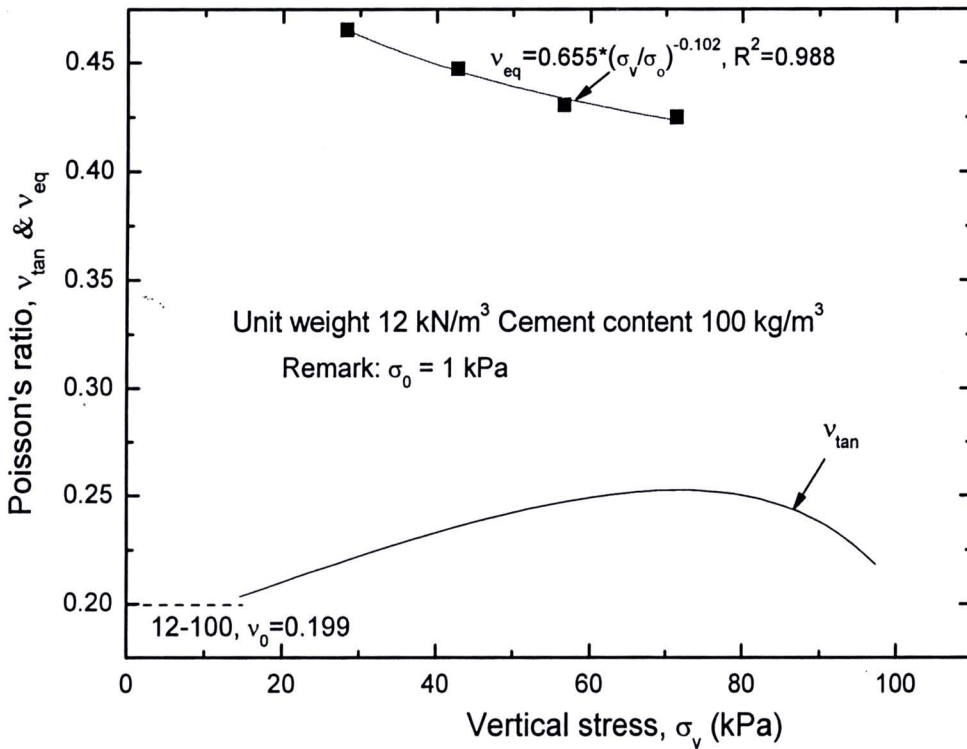


(e)

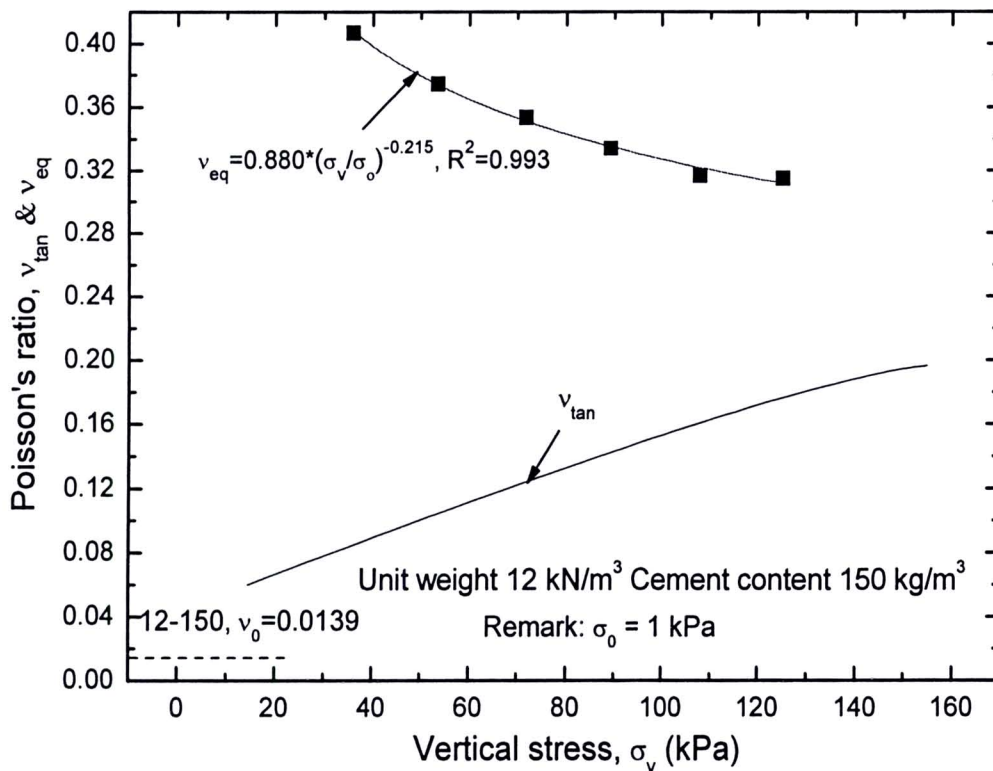


(f)

**Figure 4.32 (Cont.)** (e) Unit weight 10 kN/m<sup>3</sup> Cement content 150 kg/m<sup>3</sup>  
 (f) Unit weight 10 kN/m<sup>3</sup> Cement content 200 kg/m<sup>3</sup>



(g)



(h)

**Figure 4.32 (Cont.)** (g) Unit weight  $12 \text{ kN/m}^3$  Cement content  $100 \text{ kg/m}^3$   
 (h) Unit weight  $12 \text{ kN/m}^3$  Cement content  $150 \text{ kg/m}^3$

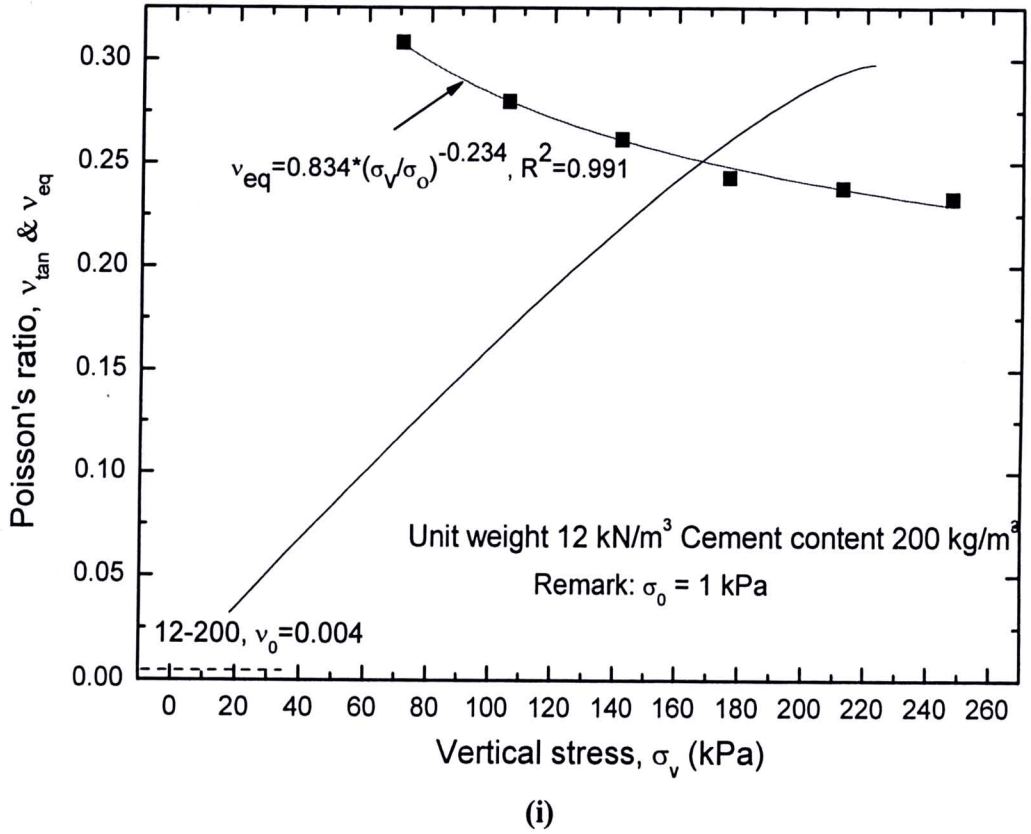


Figure 4.32 (Cont.) (i) Unit weight  $12 \text{ kN/m}^3$  Cement content  $200 \text{ kg/m}^3$