CHAPTER 3 METHODOLOGY

3.1 Introduction

In this study, in order to characterize the strength and deformation behavior of air-cement treated soil, two series of tests were conducted, which were continuous monotonic loading (ML) tests and ML intervened by sustained loading (SL) and cyclic loading (CL). The small-strain stress-strain behaviors of air-cement treated soil were investigated basically to obtain the elastic properties of air-cement treated soil at different densities and cement content (i.e., E, ν).

3.2 Materials

The materials for testing consist of the following:

3.2.1 Clay

The clay utilized in this study is the typical soft Bangkok clay. The sample soil is at depth from the topsoil layer about 4-5 m. and sampling from a location at the King Mongkut's University of Technology Thonburi, Bangmod, Thongkru, Bangkok, Thailand. Its basic properties are listed in Table 3.1 and Table 3.2 property of untreated soils compare with soil study.

Table 3.1 Physical properties of untreated soil.

Properties		Characteristics Values
Water content	%	80
Liquid limit, LL	%	103
Plastic limit, PL	%	43
Plasticity index, PI	%	60
Liquidity index, LI		0.79
Shrinkage limit, SL	%	14
Total unit weight, γ_t	kN/m^3	14.1
Dry unit weight	kN/m^3	7.83
Initial void ratio		2.50
Specific gravity, G_s		2.68
Colors		Dark grey

3.2.2 Portland Cement

This study uses Portland cement type I of TPI Polene Public Company Limited. Specific Gravity (G_s) of Portland cement is 3.14.

3.2.3Foam

Foam is material made by mixing a both foaming material and air together in air foam generator. The required density is 0.05 t/m^3 (Hayashi et al., 1998). The foaming material is made by diluting the foaming agent with water, these proportional of mixture;(foaming agent : water) is 1:19 as suggested by Phoenix SDS CO., Ltd.

3.2.4 Water

Water is the water supply.

Table 3.2 Physical properties of untreated soils considered in this study.

	Kumamoto Port (Hayashi et al.,2002)	TokyoBay (Takashi etal.,2001)	Bangkok Clay at AIT (Jongpradist et al., 2011)
water content, %	68.30	-	84.30
wet density, t/m^3	1.58	-	1.49
Void ratio, %	1.85	-	2.28
Liquid limit, %	35.80	100.40	117
Plastic limit, %	28.30	38.90	39.20
Plasticity index, %	7.50	61.50	77.80
Sand, %	19.00	34.20	-
Silt, %	58.50	41.30	-
Clay, %	22.50	24.50	-
Soil classification	-	-	CH

3.3 Method of Remolding the Base Clay

The clay samples utilized in all tests were remolded to water contents ranging from the liquid limit (LL) about 1.5 to 3.0 LL, until the clay becomes to mud. The purpose of the remolding water contents is to increase the workability and flowability. The flow value is about 45 cm from flow test (Kohashi, 2005), which utilized to initial mud is required to prevent the bleeding of air-cement treated soil. Prior to the addition of cement content and foam, the natural soil were mixed with the associated addition of water. The remolding clay water content (w*) is hereinafter defined as the water content of the remolded clay prior to addition of cement content and foam. The amount of water added to a wet clay sample to obtain the desired remolding water content was calculated by the following fundamental equation:

$$\Delta W_W = \frac{W_T}{1+w_0}(w^* - w_0) \tag{3.1}$$

where ΔW_W is the additional weight of water to be added.
W_T is the total weight of prepared original untreated clay sample
w^* is the required remolding clay water content
w_0 is the natural water content of the clay sample.

The disturbed samples of the base clay with the required amount of additional water, were placed inside a portable mechanical soil mixer, allowed to mix thoroughly for a few hours. When the mixed clay is uniformly remolded, the water content is closer ±1% to the desired remolding water content, then the sample was ready for admixture mixing. The clay sample or mud was placed in humid room overnight for maintainable the water content of samples.

3.4 Method of Air-Cement Treated Soil Preparation

Prior to admixing with foam, the prepared remolded clay sample at particular remolding water content was mixed with cement inside soil mixer until the mixture becomes slurry for about 6 minutes. The constant remolding water content of 300% was used in all tests. Subsequent, air foam was added and mixed with the slurry, the desired density of air-cement treated soil is adjusted to achieve the target density within a range of ±0.03

g/cm^3, and ranging flowability value of flow test is 16 to 20 cm (Kohashi, 2005). Since the foam has water, then the overall water content of the clay-water-cement-foam just after the time of mixing was the total remolding water plus the water in the foam. From concept of soil cement, the total clay water content (C_W) was discussed by Miura et al. (2001), the total clay water content (C_W) of air-cement treated soil can be adapted by relation in Eqs. 3.2. The overall water content in the mixture is hereinafter called the mixing water content or the total clay water content (C_W). The total clay water content (C_W) was defined as follows:

$$C_w = w^* + (w/w_F)F_w \tag{3.2}$$

where C_W is the total clay water content (or mixing water content) of the clay-water-cement-foam paste (%) from the dry weight of soil only;
w^* is remolding clay water content (%) before mixing the cement and foam
w/w_F is the water-foam material ratio
F_w is the desired foam (%). Foam (F_W) is defined as the percentage ratio of the weight of foam to the dry weight of soil.

The above relation disregards the amount of foam agent and water lost in the hydration process of cement during preparation.

The overall air-cement treated soil preparation for the entire program consisted of 300% remolding water content at initial state in all mixture, and controlled unit weight of 8, 10 and 12 kN/m^3. The cement content, C, which is defined as 100, 150, and 200 kg in air foam-cement-admixed clay 1 m^3.

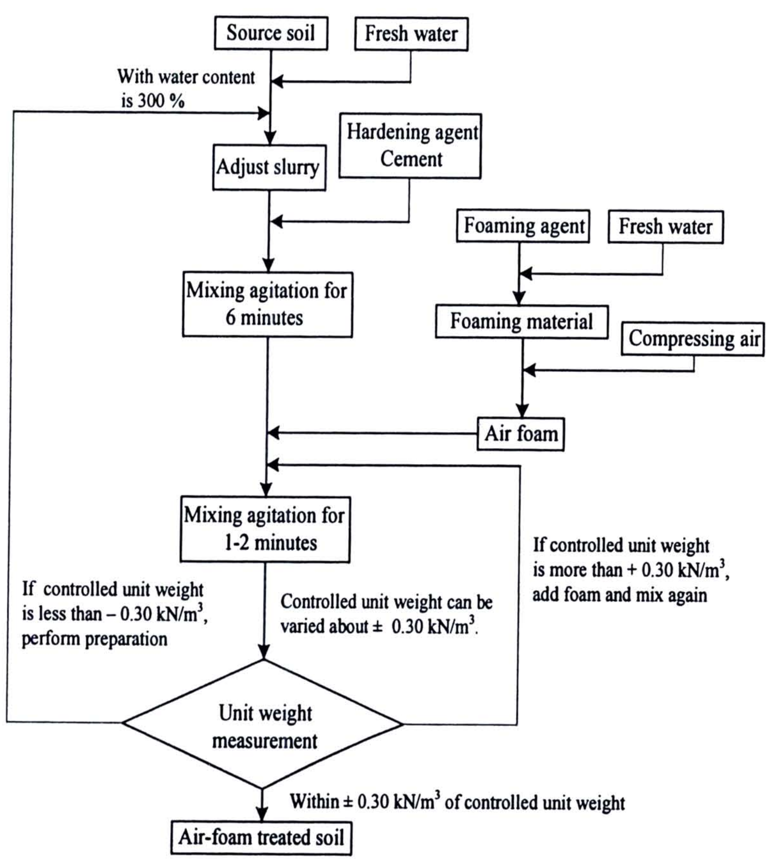


Figure 3.1 Foam mixed stabilized soil preparation flow chart

Figure 3.2 through 3.5 show preparation of mixture for this study.

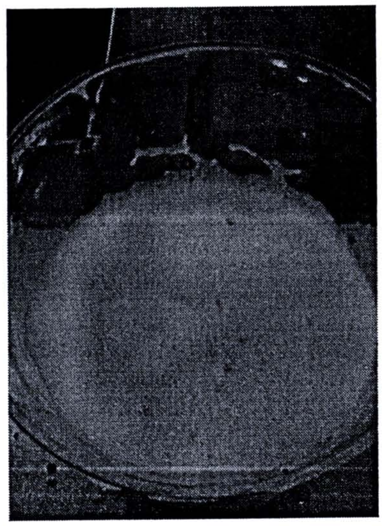


Figure 3.2 Foam

Figure 3.3 Slurry

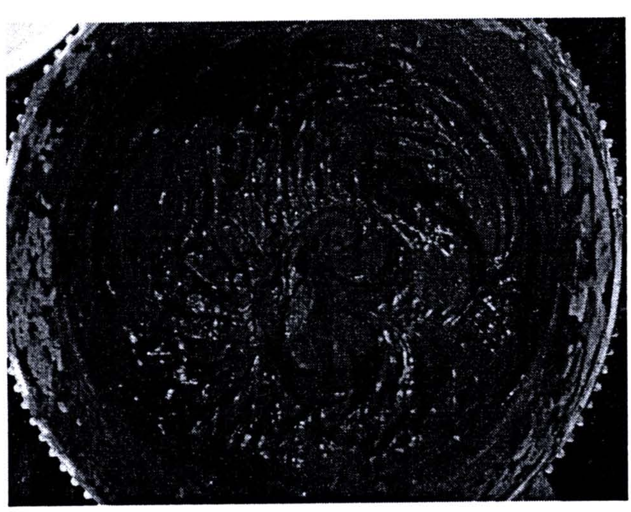


Figure 3.4 Slurry mixed by cement

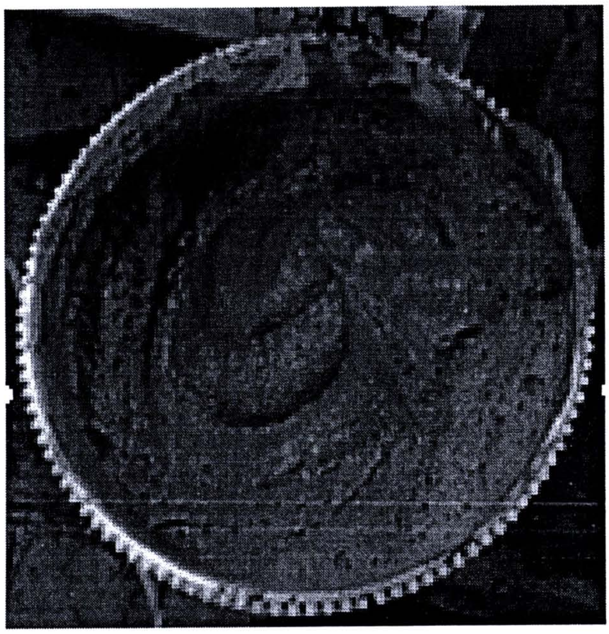


Figure 3.5 Slurry mixed by Cement and Foam

3.5 Apparatuses for mixing

The required apparatuses in this study are as the followings:

1. Molds are the iron square having the width of 7.5 cm. and the height is 15.0 cm.

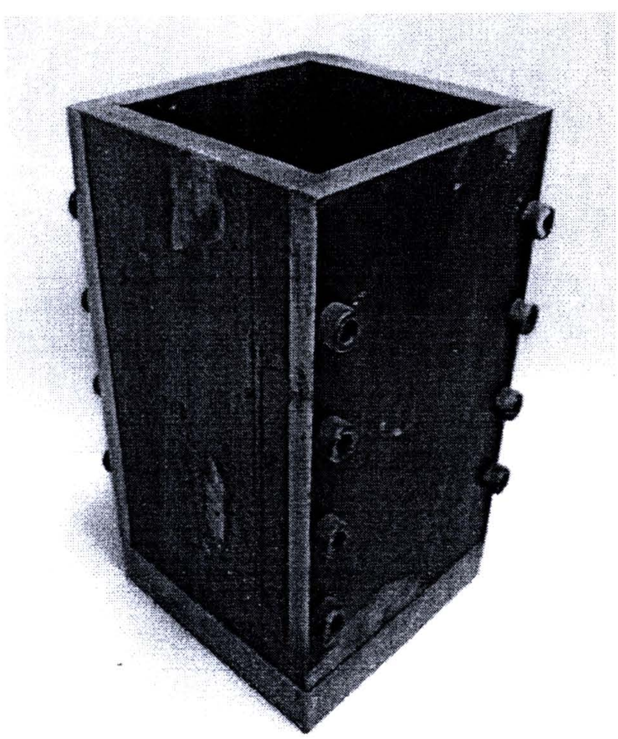


Figure 3.6 Molds

2. Mixing Machine

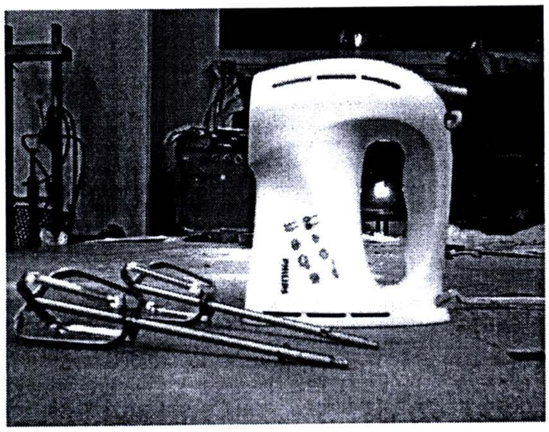


Figure 3.7 Mixing Machine

3. Oven

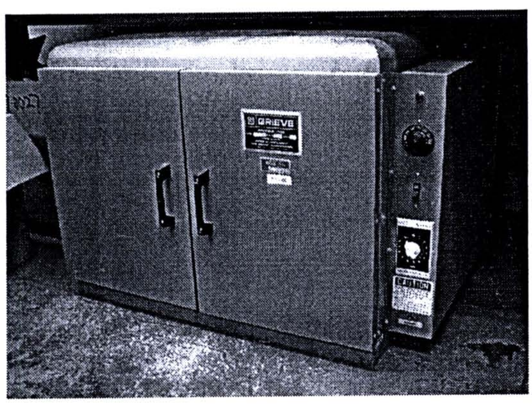


Figure 3.8 Oven

6. Air pump

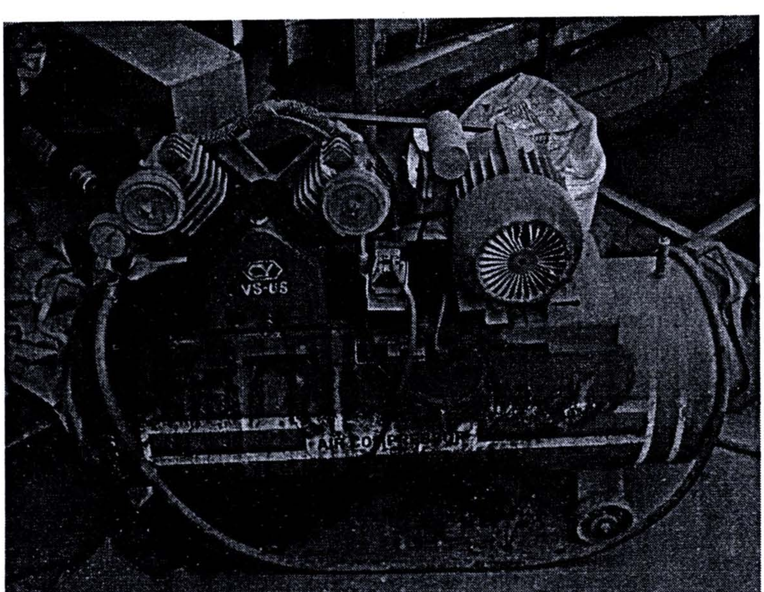


Figure 3.9 Air pump

7. Air storage tank

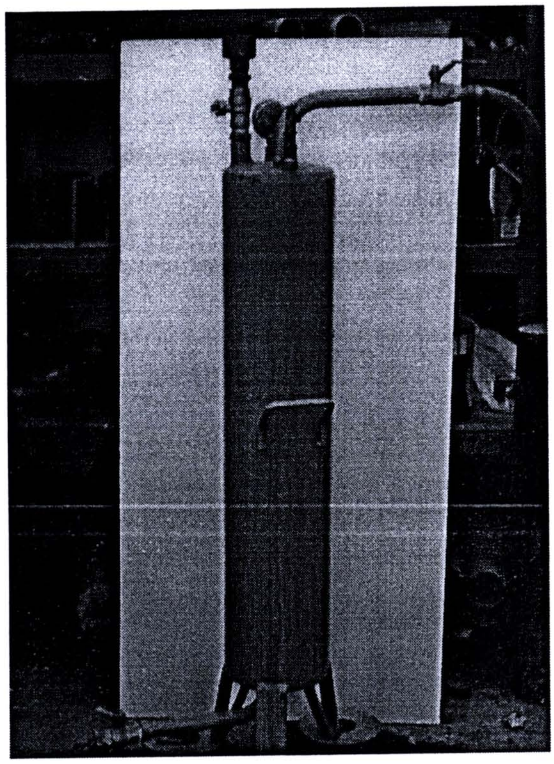
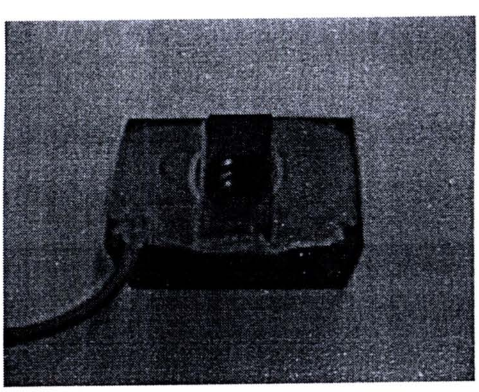


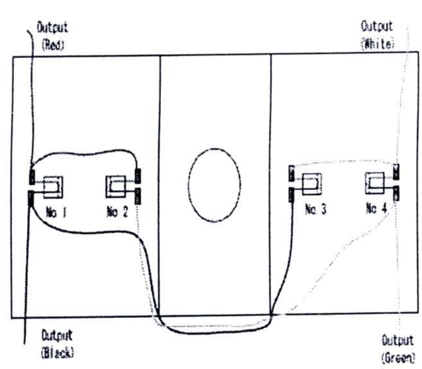
Figure 3.10 Air storage tank

3.6 Measuring devices

3.6.1 Load cell

A load cell was used for measurement of axial load (i.e., vertical load) applied to the specimen. The body of load cell was made from Phosphor Bronze (C5212P) having a shape as shown in Fig. 3.11a. Four strain gages (KFG-02-120-C1-16) manufactured by Kyowa Co. Ltd., Japan were glued on the top of the load cell's body as shown in Fig. 3.11b with adhesive (CC-33A) (Hirakawa, 2003).





(a) **(b)**

Figure 3.11 Detail of load cell: a) the body of load cell; and b) attachment of four strain gages on the top surface of load cell's body

3.6.2 Displacement transducers
The displacement transducers were used for the measurement of the vertical and horizontal strain of the specimen. There are three types of the displacement transducers used in testing in this study: 1) LVDT; 2) LDT (local deformation transducers); and 3) CG (Clip gage transducers).

3.6.2.1 Linear variable displacement transducer (LVDT)
LVDT is the most common instrument for measuring displacement in laboratory testing. The LVDT was used for the external measurement of axial (vertical) strain from the axial displacement of the loading piston as shown in Fig 3.12.

Figure 3.12 LVDT having capacity of 10 mm for global vertical displacement measurement

3.6.2.2 Local deformation transducers (LDT)
LDTs were used for the local measurement of vertical strain of the specimen as shown in Fig 3.13. The LDT reads the vertical displacement by means of gage strains mobilized on the surface of the phosphor bronze strip, which were measured by strain gages attached at the center.

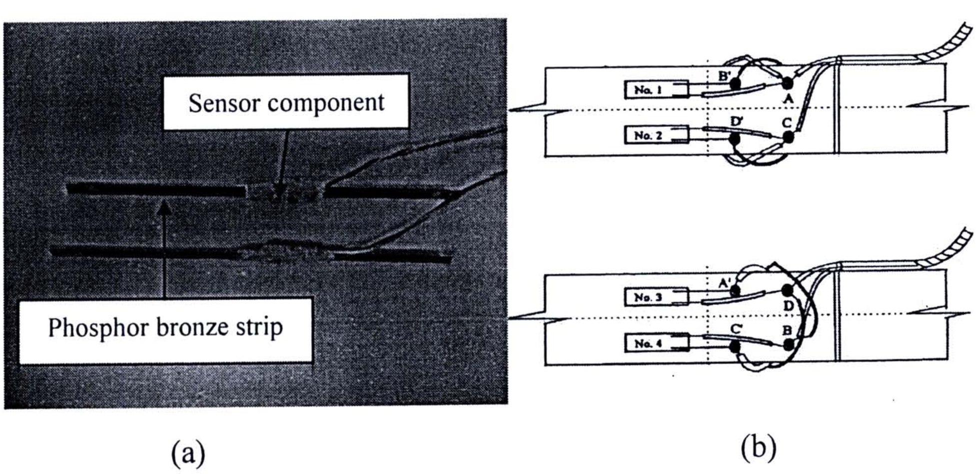


Figure 3.13 LDT having capacity of about 2.5 mm for local displacement measurement: a) the body LDT; and b) details of the internal connections

3.6.2.3 Clip gage

Clip gages were used to measure the lateral strain of the specimen as shown in Fig 3.14. A clip gage measures the displacement by means of gage strains mobilized on a surface of phosphor bronze strip, fixed with a U-shape aluminum frame, similar to those of LDT.

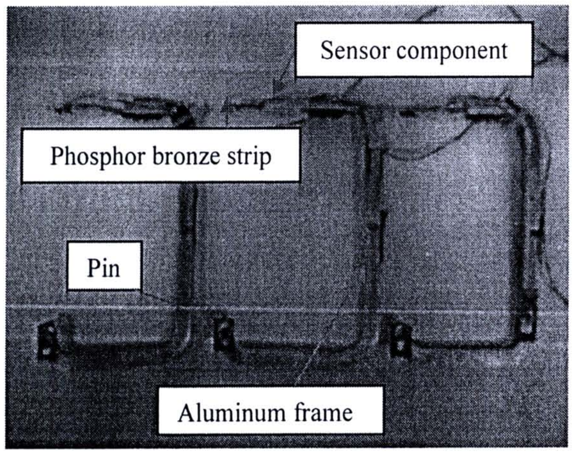


Figure 3.14 Clip gauges

Figure 3.14 Clip gage having capacity of about 1.5 mm for local displacement measurement

3.7 Test Preparations

3.7.1 Set ups of specimen

After curing 28 days, in temperature control room at 25 °C, the plastic film that has wrapped the sample for curing since demolding, was remold. Then the samples were laboratory wrapped with the new plastic file again for property the change of moisture content during testing

Then, spot was marked on plastic film for location of installation hinges. The next step was ream on plastic film and specimen. Then, gypsum was pasted on the ream to provide smooth surfaces on which LDTs and clip gage will be equipped. And, a pen was used to draw markers on gypsum surface to locate the positions for these instruments.

3.7.2 Set ups of pedestal and cap

The next step is pedestal and cap procedures. The 3M Scotch™ tape was cut to strips having equal length and attach around on the pedestal and cap. The thin layer of HIVAC-G was pasted on the surfaces of the cap and the pedestal. The thickness of grease was ensured by encircling the cap and pedestal with the 3M Scotch™ tape of 50 μm in thickness as shown in Fig. 3.15 and 3.16. The excessive HIVAC-G grease was scraped from the pedestal and cap surface. Later, the 75×75 mm. rubber sheet was pasted on the pedestal and cap surface. In this process, it must be careful not to have any air bubbles between the rubber sheet and surface of cap and pedestal. The specimen was then located between the pedestal and cap. Due to the surface of specimen is not very smooth which may result in errors in this test. In order to eliminate these errors, the thin layer of wet soft gypsum was pasted between the surfaces of specimen and the rubber sheet as shown in Fig. 3.17.

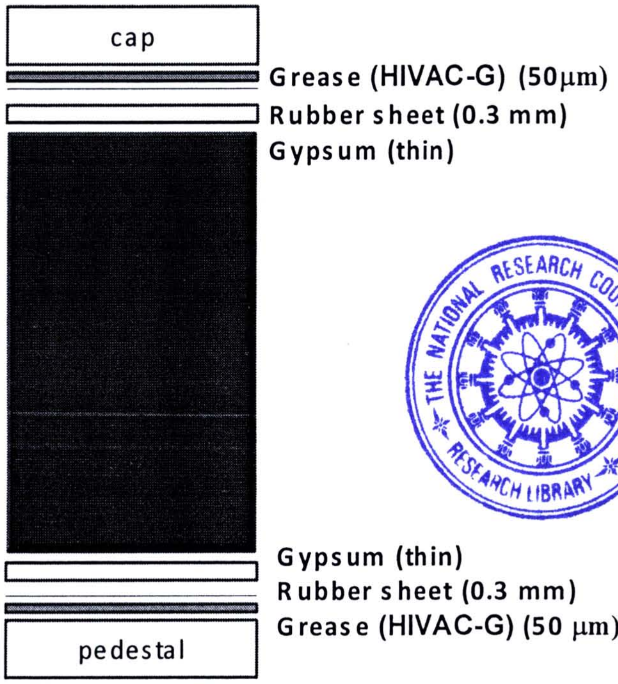


Figure 3.15 Diagram for preparing the top and bottom ends of a specimen (Kawabe, 2008)

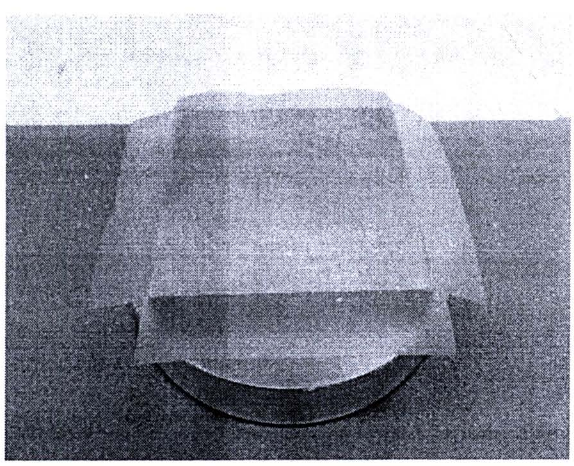


Figure 3.16 3M Scotch™ tape encircling the top cap

3.7.3 Set ups of instrument

For the vertical compaction specimen, the initial dimensions of the specimen are 150 mm in height and 75 mm in width and depth. A specimen was placed on the center of the pedestal and then adjusted to ensure that both cap and pedestal were in full-contact with top and bottom ends of specimen. Measuring devices used are a load cell, LDTs, and Clip gages. Test set up and detail of installations of measuring devices are shown in Fig. 3.17. Digital data read from the instruments are recorded by a data logger and saved to a computer. In addition to a linear variable displacement transducer (LVDT) for measuring the 'external' axial (vertical) strain from the axial displacement of the loading piston, a pair of local deformation transducers were installed on the respective opposite sides of a specimen to measure the 'local' axial (vertical) strain, ε_v, without any bedding errors associated with unexpected minute gaps at both ends of the specimen. Both ends of the LDTs were mounted onto a pair of hinges set on the lateral face of the specimen. The respective hinges were fixed to the specimen by glue. The lateral (horizontal) strain, ε_h, was measured by means of a set of three clip gauges (CG), which were positioned at the heights of 1/6, 1/2 and 5/6 of the initial total height of specimen from the bottom (Abdelrahman et al., 2008). Each of the CGs was supported by two hinges positioned diagonally on the opposite sides of the specimen, which were fixed to specimen by glue. The locally measured axial and lateral strains reported this study were those obtained by averaging the readings of a pair of LDTs and a set of three clip gages, respectively.

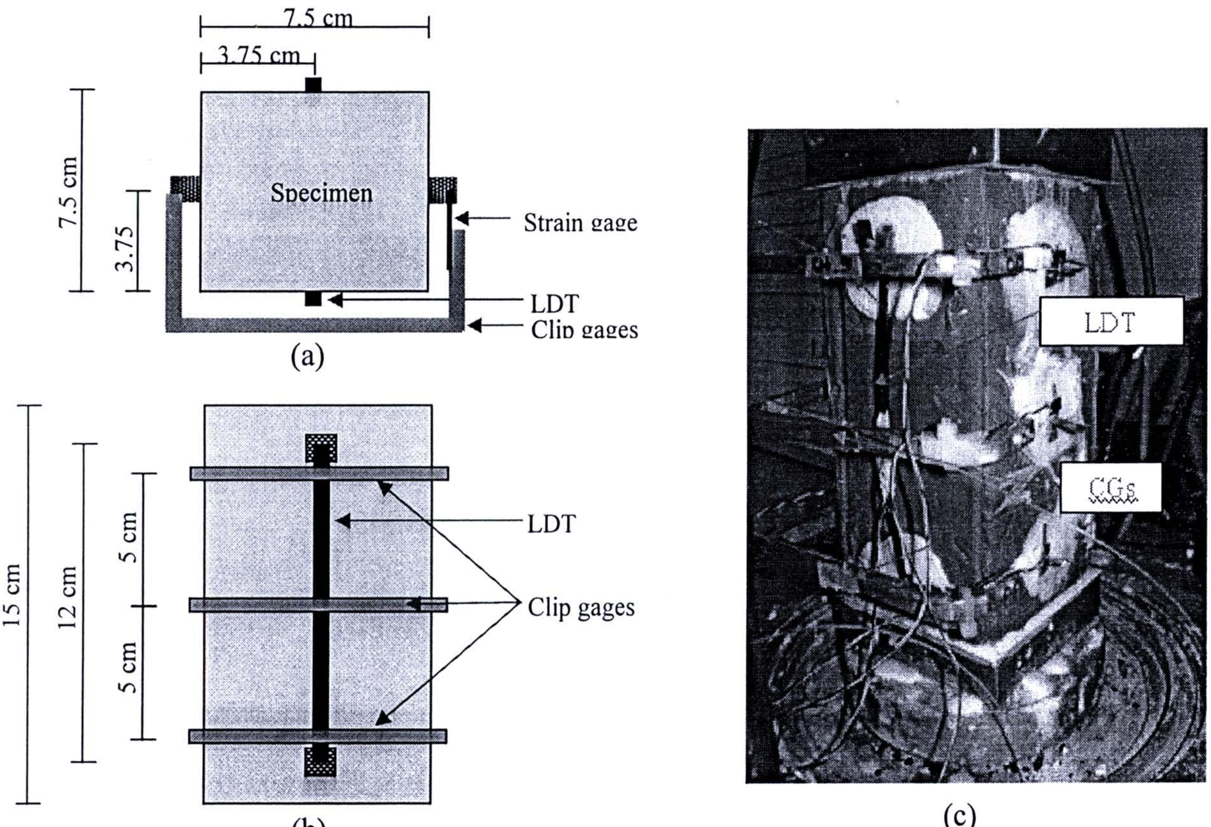
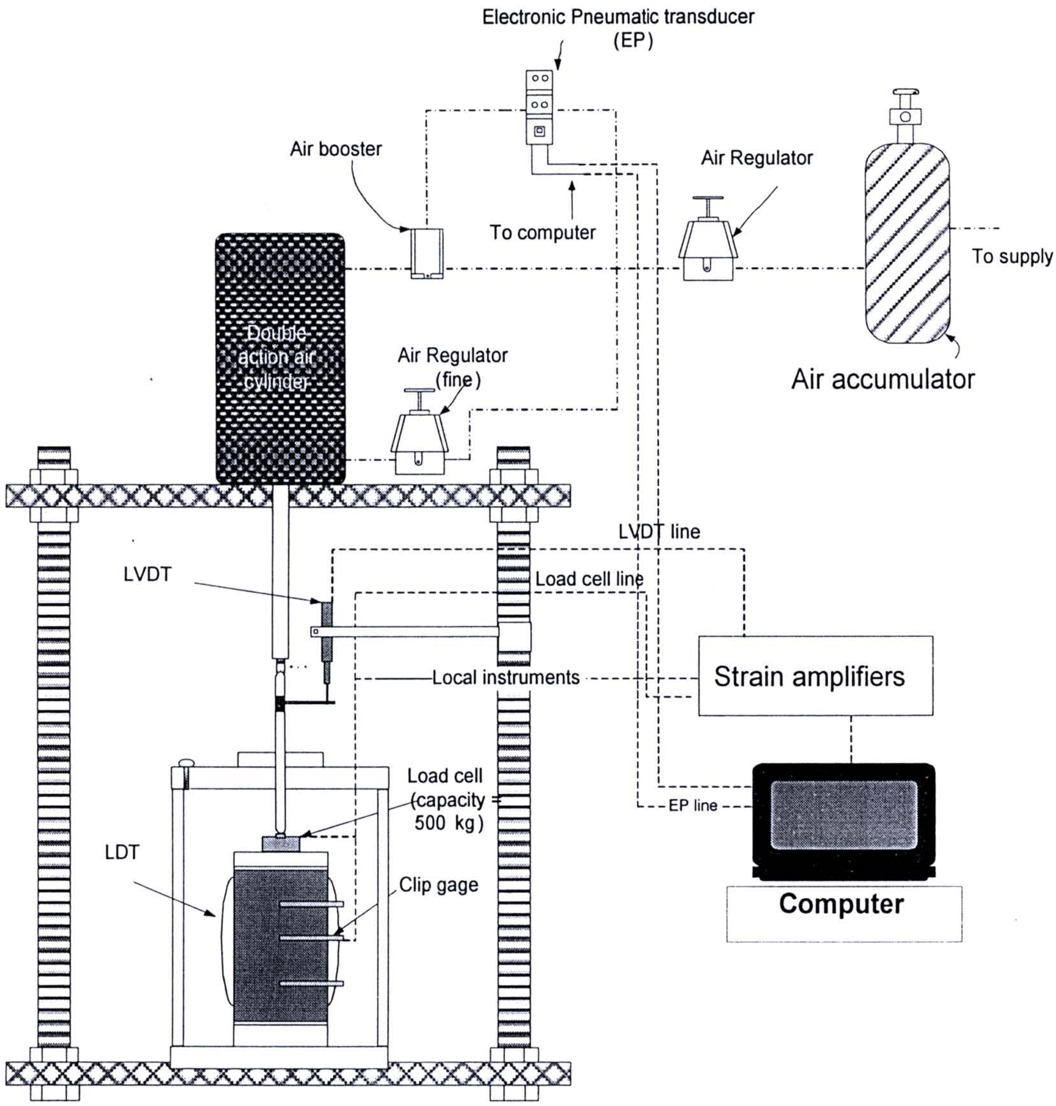


Figure 3.17 Local deformation transducers (LDTs) and clip gages (CGs) on air-cement treated soil specimen: a) plan view; b) side view; and c) installed their appearance

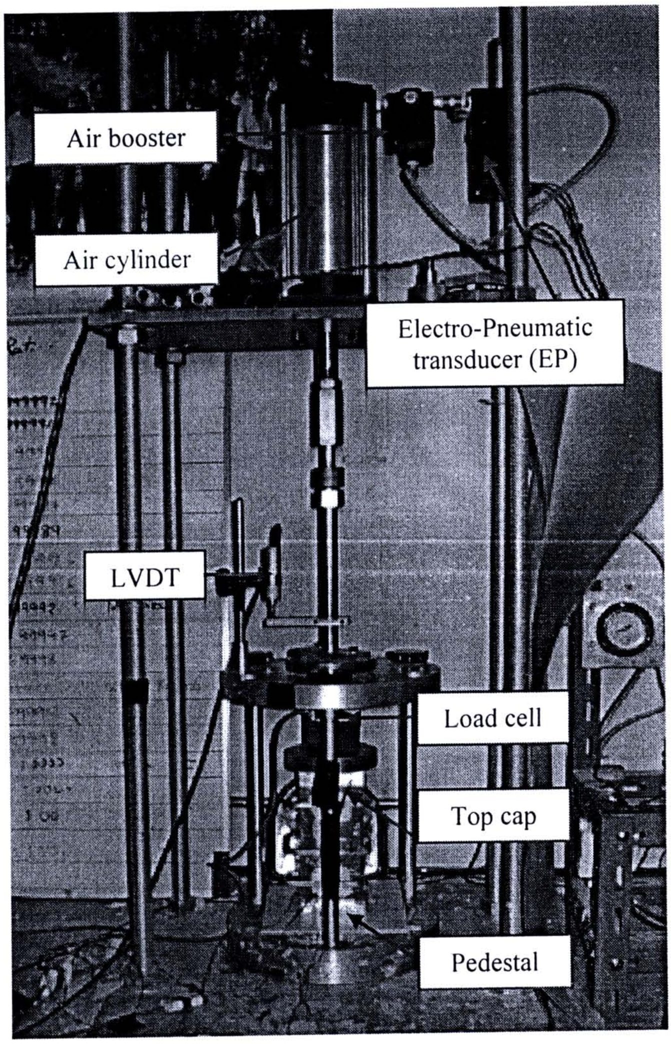
3.8 Test apparatuses

Load controlled System is load-controlled compression and extension loading type (Figs. 3.18a and 3.18b) with a capacity of about 5 kN. Compression and extension are provided by means of changes in the air pressure in the upper room of double-action air-cylinder arranged at the top of reaction frame. The air pressure in the upper room of the air-cylinder was controlled by a personal computer via an electro-pneumatic (EP) transducer while the one in the lower room by a fine regulator. To achieve as fast as possible the response during changes in the load rate and direction, the volume of air flow from the electro-pneumatic transducer was amplified by using an air booster. By using this loading apparatus, cyclic loading tests with specified load amplitude at a specified frequency were performed, without any intermission at the start of respective cyclic loading, during otherwise loading at a constant load rate.



(a)

Figure 3.18 Apparatuses used in performing unconfined compression test in this study (a) Load controlled System



(b)

Figure 3.18 (Cont.) (b) picture of Apparatus.

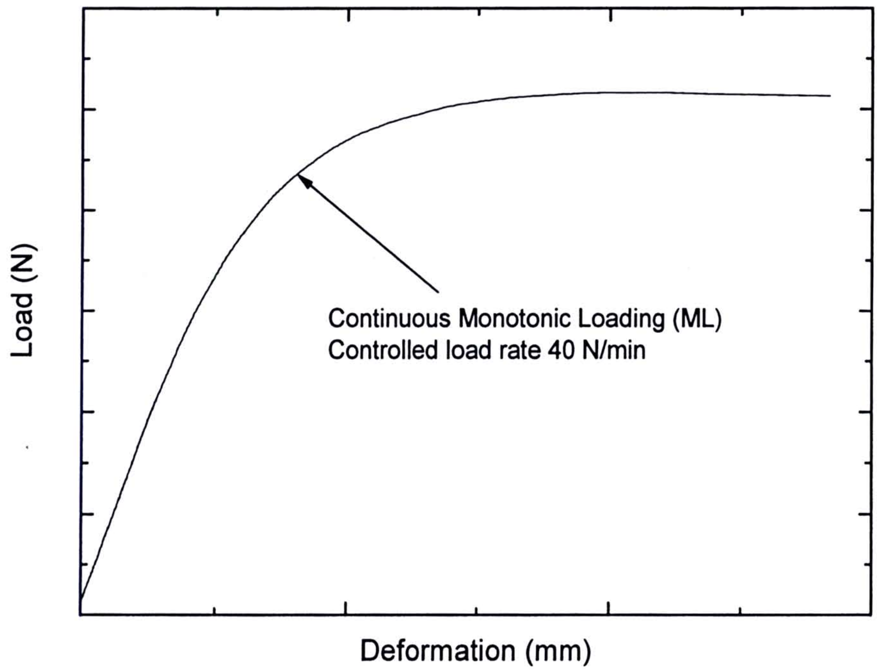
3.9 Procedures

3.9.1 Testing Procedure and Program

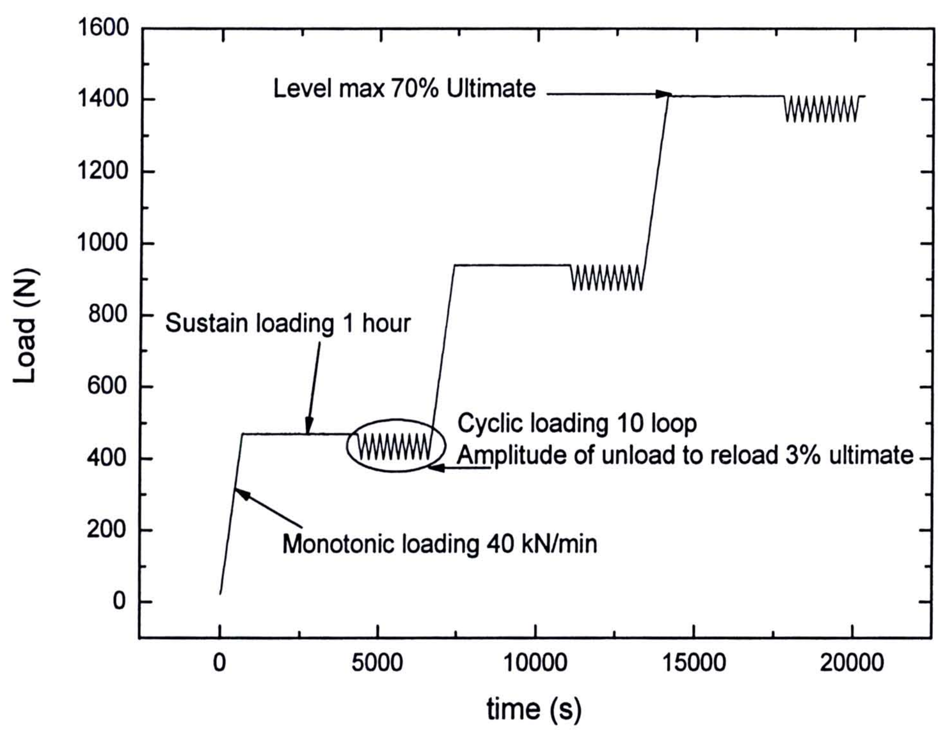
For Load controlled System, the following loading schemes were performed with load-controlled apparatus, Fig. 3.18:

1. Continuous monotonic loading (ML) at load rate 40 kN/min for mixing of ACS, figure 3.19(a).

2.Continuous ML at load rate 40 kN/min and intervened by sustained creep loading (SL) tests for 1 hour and ten cycles of unload and reload with amplitude of unload to reload 3 % of ultimate load , figure 3.19(b)



(a) Loading program for monotonic loading test



(b) Loading program for cyclic loading test

Figure 3.19 Schematic diagram showing various loading histories employed in this study: a) continuous monotonic loading (ML) at a load rate and b) continuous monotonic loading (ML) at a constant load rate, sustained creep loading (SL), and cyclic loading at constant load rate. Two series of test are by apparatus of Monotonic loading and Cyclic Loading System.

Note: Sustained creep loading (SL) tests for 1 hour is illustrated by figure(i) a though figure c. When is beginning SL, there is change of vertical strain increment more than vertical strain increment near 1 hour. Thus, SL 1 hour is adequate for testing.

3.9.2 Test program for studying behaviour of monotonic loading and small strain properties

Table 3.3 though 3.4 summarizes the test program for studying the behaviour of monotonic and small strain properties by load controlled System.

Table 3.3 Summary of the program for studying behaviour of monotonic loading.

Controlled unit weight (γ_t) (kN/m^3)	Cement content (A_w) (kg/m^3)	Remolding water content (w^*) (%)	Foaming material Agent : Water	Curing time (Days)
8	100,150,200	300	1 : 19	28
10	100,150,200	300	1 : 19	28
12	100,150,200	300	1 : 19	28

Remark: The number of specimens for testing is 18 pieces.

Table 3.4 Summarizes of the program for studying small strain properties.

Controlled unit weight (γ_t) (kN/m^3)	Cement content (A_w) (kg/m^3)	Remolding water content (w^*) (%)	Foaming material Agent : Water	Curing time (Days)
8	100,150,200	300	1 : 19	28
10	100,150,200	300	1 : 19	28
12	100,150,200	300	1 : 19	28

Remark: The number of specimens for testing is 18 pieces

3.9.3 Fit cure

From stress-strain and horizontal strain-vertical strain cure of monotonic loading test, they could not differential for tangent modulus. For this reason, a segmental initial linear fitting method and a segmental non-linear fitting were used by three-degree polynomial.

For equivalent Modulus and equivalent Poisson's ratio, value of them investigated from past unland that can see to appendix N.