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Stress History during Sample Preparation for Triaxial Test I

——Discussions on Test Procedures——

三軸試験用の供試体作成中の応力径路 I

——試験方法の検討——

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1. Introduction

In order to know the stress and strain histories during preparation of triaxial sand samples and their effects on the stress-strain behaviours during triaxial tests under a low confining pressure, several preliminary tests were performed at Delft Soil Mechanics Laboratory. So far no or hardly any measurements of the stress and strain conditions during sample preparation have been reported in literature. However, in order to obtain accurate stress-strain relationships of sand in triaxial compression tests under low confining pressures, it is essential to know the differences in the stress and strain histories among different methods of sample preparation and their effects on later sand behaviours.

It was found that the stress histories during sample preparations considerably depend on the detail of sample preparation method employed. It was also found that at some moments during sample preparation the effective principal stress ratio σ_1'/σ_3' at the bottom or at the top of sample can be very large, almost near failure, in the triaxial compression or extension stress conditions.

2. Test Material and Apparatus

The sand used was the so called Eastern Scheldt sand sieved between 125μm and 180μm. Fresh sand was used for each test. The triaxial apparatus used was modified as proposed by Pedersen and Molenkamp (1981).

3. End Lubrication

Based on the preliminary results of pull-out tests which were performed to evaluate the quality of end lubrication (see Tatsuoka, Molenkamp, Torii, Hiro and Takagi, 1982), the composition shown in Fig. 1 was selected for the lubrication layer. Lubrication layers were prepared as follows.

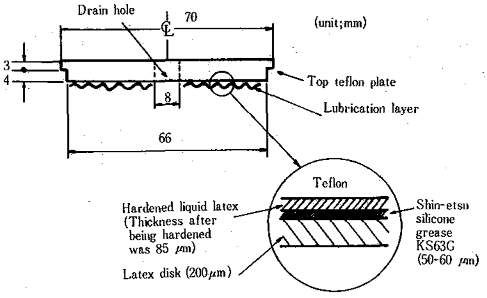

Fig. 1　Composition of lubrication layer at top plate

1. Place a uniform latex liquid with a thickness of 200μm in the liquid condition on a teflon disk using a tool which was developed in order to place a thin uniform oil or grease layer on end plates. After liquid latex hardened, a smooth and uniform latex disk with an average thickness of 85μm fixed to the teflon disk was obtained.
2. Place a uniform silicone grease (Shin-etsu silicone grease KS 63 G) layer on a hardened latex disk.
3. Place a latex disk with a thickness of 200μm on a grease layer so that air bubbles are not involved between the latex disk and the grease layer.
4. Place a weight (0.5821 kg) on the lubrication layer thus prepared for several minutes (around five minutes) to obtain a flat surface. It was observed that no grease was squeezed out by application of this small weight.

4. Sample Preparation Methods

The procedures of preparation or reconstitution of

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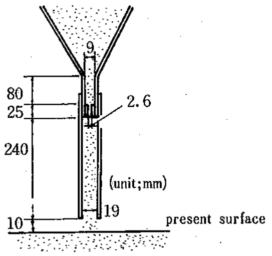


Fig. 2　Air-pluviation method employed

a sand sample may be decomposed into several steps.

(0) Assemble a latex membrane and a split mold. In this stage, the following two points are important.

① Ensure that the membrane is in good contact to the inside face of mold when a vacuum pressure is applied to the void between the membrane and the inside face of the mold. This is to obtain a uniform outer surface and diameter of sample.

② Ensure that there is no tensile or compressive stress in the membrane. For this purpose, it will be useful to write marks on the membrane.

(1) Place sand in a mold. In this investigation, the air pluviation method was employed (see. Fig. 2). In this method, air-dry sand particles were poured from an outlet having an inner diameter of 0.3 cm. The fall height from the outlet of tube to the present sand surface was 25 cm. Of course, different stress and strain histories are obtained during different methods of placing sand particles in a mold. For example, the horizontal stress becomes much higher in the wet tamping method than in the air pluviation method. In this study, the horizontal stress was not measured during pouring of sand particles into a mold.

Smoothen and flatten the top surface of sample. This stage is essentially important. In particular, when the seating stress is very small and the position of cap is fixed in the following stages (vacuum application, saturation or so), a poor contact between sample and the top lubrication layer may be obtained if the surface finishing is not proper. In this method, the surface finishing was made by scraping with use of a thin wooden plate. However, it was observed that several particles were located inevitably above the average top surface. By the existence of these several particles, the surface was rough with respect to the good contact between the top cap and the sand surface. Therefore, in principle, the top surfaces of the samples made in this study were rougher than the bottom surfaces. This may have resulted in a poorer quality of lubrication and a larger bedding error at the top than at the bottom. In addition to this, it should be noted that a poor contact between the top cap and the sample results in a larger reduction in vertical stress by disturbances during the stages 7, 8 and 9 described below in Method III. Alternative methods for finishing the surface should be tried to improve the smoothness of the top surfaces.

(2 and 3) Place a cap and other accompanied parts on the top surface of sand. In this stage, the seating vertical stress should be carefully controlled. Too large seating stress values may compress the sample, probably resulting in an overestimation of vertical rigidity by later triaxial compression test. Too small seating stresses may give poor contacts, probably resulting in an underestimation of vertical rigidity by later triaxial compression test. In addition rougher surfaces may give larger bedding errors and lower quality of lubricatios. In this study, two seating stresses were originally proposed : $2.92\times10^2 N/m^2$ (0.003kgf/cm^2) in Methods II and III or $1.99\times10^4 N/m^2$ (0.203kgf/cm^2) in Method I. However, due to the limitation of time, only Method II and III were examined in which the seating stress was $2.92\times10^2 N/m^2$. This very low seating stress value was selected in order to keep the effects of preloading minimum.

(4) Clamp the loading ram (Turn to 〝displacement control〟).

(5) Seal the latex membrane to the cap.

(6) Release the loading ram only in Methods I and II with a seating stress being the prescribed values.

(7) Release the vacuum which has been applied to the void between the latex membrane and the inner face of the mold. Any small disturbances to the sample should be avoided from this moment to until the application of vacuum to the sample. Apply a vacuum pressure of $1.176 kN/m^2$ to the sample. The vacuum value of $1.176 kN/m^2$ was selected as the minium operationable value which exceeds the horizontal effective stress at the bottom of sample before

application of vacuum ; namely,

$$K_0\times\left(\rho_d\times h+\frac{P}{A_s}\right)\fallingdotseq 0.4\times\left(\frac{1.58\times 15}{1000}+0.003\right)$$

$$=0.0105\,\mathrm{kgf/cm^2}\fallingdotseq 1\,\mathrm{kN/m^2}$$

The diameter of sample was measured at three heights by using a π tape to 0.05 mm. The heights were measured at three locations with each being 120° apart from the others.

(8) Remove the mold.

(9) Assemble the triaxial cell.

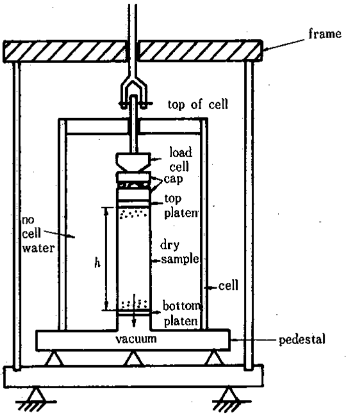
The stress condition in the sample during the stages 8 and 9 can be calculated as shown in Fig. 3.

(10) Fill the inside of triaxial cell with water up ot 2 cm above the top of the sample. The effective stress condition after filling up of cell water can be calculated as shown in Fig. 4.

(11) Replace vacuum with cell air pressure (see Fig. 5).This is not a simple operation because two valves, for vacuum and air pressure, should be adjusted simultaneously.

(12) Saturate the sample. The most critical (the largest value of σ_1'/σ_3') condition will occur during this stage. The head of water to circulate water from the bottom of sample should be carefully selected. In this study, the values of head Δh were selected not to destroy the sample. The most critical condition will be achieved at the moment shown in Fig. 6. At this moment, $\Delta h=\Delta h^+$ giving $(\sigma_h')_{\mathrm{BOTTOM}}=$ cell air pressure $-\Delta h^+\rho_W$. when the Δh^+ is 2 cm and cell air pressure$=12$ cm H_2O then : $(\sigma_h')_{\mathrm{BOTTOM}}=12-2=10$ cmH$_2$O. At the moment when the saturation is just starting, $\Delta h=\Delta h^*$ giving $(\sigma_h^*)_{\mathrm{BOTTOM}}=$ cell air pressure$+(\Delta h_{CW}+h-\Delta h^*)\rho_W=12+2+15-\Delta h^*=29-\Delta h^*$.

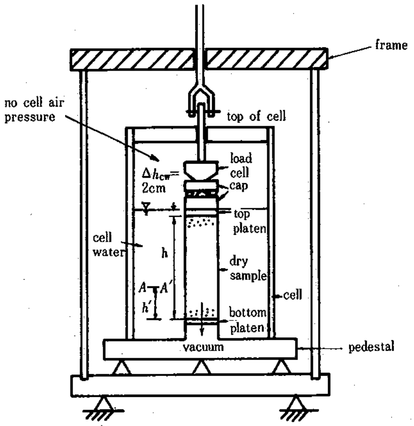
- P : Read in load cell $P=0$ when the seating stress equals zero.
- ρ : Dry density of sample
- u_v : Vacuum pressure (positive)
- A_s : Cross sectional area of sample
- h : The height of sample



- The effective vertical stress at the top of specimen;
  $(\sigma_v')_{\mathrm{TOP}}=u_v+P/A_s$
- The effective horizontal stress at the top of specimen;
  $(\sigma_h')_{\mathrm{TOP}}=u_v$
- The effective vertical stress at the bottom of specimen;
  $(\sigma_v')_{\mathrm{BOTTOM}}=u_v+P/A_s+h\rho_d$
- The effective horizontal stress at the bottom of specimen;
  $(\sigma_h')_{\mathrm{BOTTOM}}=u_v$

Fig. 3 Effective stress condition in sample during stages 8 and 9

- Δh_{cw} : Cell water height from the top of the specimen
- σ_c : Cell pressure defined as zero for arbitary level A-A' having a height h' from the bottom of sample
- ρ_w : Unit weight of water



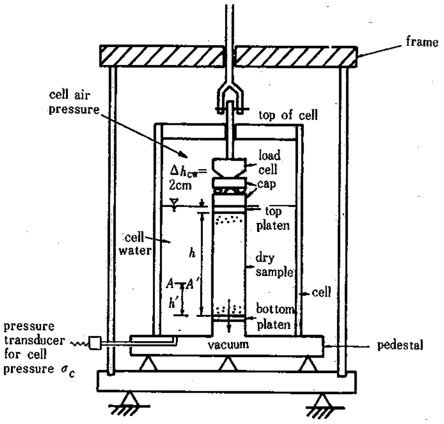
$$(\sigma_v')_{\mathrm{TOP}}=u_v+\frac{\mathrm{P}}{\mathrm{A}_s}-\left\{\frac{\Delta \mathrm{h}_{cw}\times(3.5^2\pi-A_s)}{A_s}\right\}\rho_w$$

$$(\sigma_h')_{\mathrm{TOP}}=u_v+\Delta h_w\rho_w$$

$$(\sigma_v')_{\mathrm{BOTTOM}}=(\sigma_v')_{\mathrm{TOP}}+h\rho_d$$

$$(\sigma_h')_{\mathrm{BOTTOM}}=(\sigma_h')_{\mathrm{TOP}}+h\rho_w$$

Fig. 4 Effective stress condition in sample after filling up of cell water



$$(\sigma_v')_{\mathrm{TOP}}=u_v+\frac{P}{A_s}+\sigma_c-(h+\Delta h_{cw}-h')\rho_w-\frac{\Delta h_{cw}\times(3.5^2\pi-A_s)}{A_s}\rho_w$$

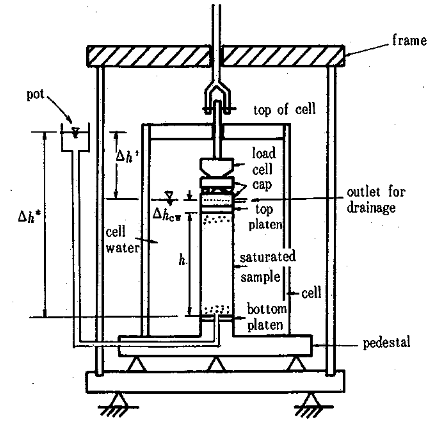
$$(\sigma_h')_{\mathrm{TOP}}=u_v+(\text{cell air pressure})+\Delta h_{cw}\rho_w$$

$$=u_v+\sigma_c-(h-h')\rho_w$$

$$(\sigma_v')_{\mathrm{BOTTOM}}=(\sigma_v')_{\mathrm{TOP}}+h\rho_d$$

$$(\sigma_h')_{\mathrm{BOTTOM}}=(\sigma_h')_{\mathrm{TOP}}+h\rho_w$$

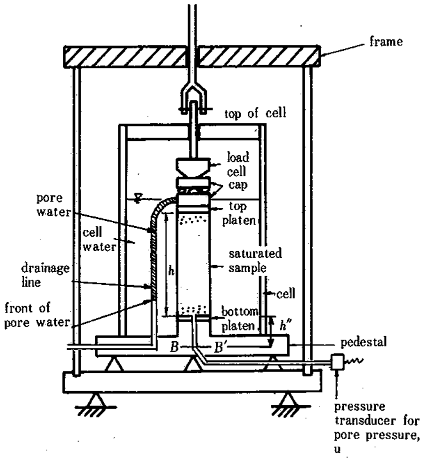
Fig. 5 Effective stress condition in sample after application of cell air pressure



NOTE: Δh: head, Δh*: initial head at the start of saturating, and Δh⁺: the head when the level of water in sample is the same as Δh_{cw} from the top of sample. At this moment the head Δh^+ is defined as shown above. The head Δh is in general defined as the difference in the water surface height between in the pot and in the sample.

Fig. 6 Moment when pore water comes up 2 cm above the top of sample

u: Pore water pressure defined as zero for arbitary level $B-B'$ having a height h' from the bottom of sample



NOTE:
h'' is negative when the $B-B'$ plane is below bottom platen.

$$(\sigma'_v)_{\mathrm{TOP}}=\frac{P}{A_s}+\sigma_c-(h+\Delta h_{cw}-h')\rho_w-\left\{u-(h-h'')\rho_w\right\}-\left\{\frac{\Delta h_{cw}\times(3.5^2\pi-A_s)}{A_s}\right\}\rho_w$$

$$\begin{aligned}(\sigma'_h)_{\mathrm{TOP}}&=\{\sigma_c-(h-h')\rho_w\}-\{u-(h-h'')\rho_w\}\\&=\sigma_c-u+(h'-h'')\rho_w\end{aligned}$$

$$(\sigma'_v)_{\mathrm{BOTTOM}}=(\sigma'_v)_{\mathrm{TOP}}+h\,\{\rho_d-(1-n)\rho_w\}\qquad(n:\text{porosity})$$

$$(\sigma'_h)_{\mathrm{BOTTOM}}=(\sigma'_h)_{\mathrm{TOP}}$$

Fig. 7 Effective stress condition in sample afrer saturation of sample

When Δh^* is 19 cm H_2O, $(\sigma^*_h)_{\mathrm{BOTTOM}}$ becomes 10 cm H_2O. For safety, $\Delta h=\Delta h^*=10$ cm was selected as the initial value of head and then the value of Δh was gradually decreased during saturation to $\Delta h^+=2$cm at the moment shown in Fig. 6.

The stress condition during saturation is very complicated and difficult to know, because the measurements of pore air pressure at the top of the sample and the pore water pressure at the bottom of sample should be determined in order to calculate the values of effective stress at the top and bottom of sample. These reasurements were not performed in this study. However, it could be assumed that the excess air pressure in the voids during saturation is neglilible, especially because at a later state also water could flow out through the porous stone in the top platen.

The effective stress values after the sample is saturated can be calculated by assuming that there is no pressure gradient in the system as shown in Fig. 7. These equations can be used hereafter also. Note that when a differential pressure transducer is used, the values of σ'_h can be directly measured. It is also to be noted that the front of water is falling down in the drainage tube. Then, the value of σ'_h is increasing due to the decrease in excess pore water. Therefore, the effective stress values are a function of the location of the front of water in the drainage tube.

(13) Connect the drainage line to the "balance". It is to be noted that during this operation there may also be the change in effective stress values due to the change in the level of free water which is connected to the pore water.

(14) Unclamp the verical ram in Method III.

(15) Increase the cell pressure to 20 kN/m^2.

(16) Perform triaxial compression test with a constant cell air pressure. (to be continued).

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