KU PERMEA-OEDOMETER FOR INVESTIGATING ELASTIC MODULUS OF CUSHION MATERIAL IN CONCRETE FACED ROCKFILL DAM

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ABSTRACT : Cushion material in Concrete Faced Rockfill Dam (CFRD) plays an important role as the support of concrete slab. Cracking of the concrete slab generated the flow path through the cushion layer. Some finer particles may be migrated and causes major change in elastic modulus of cushion material. In order to find out the modulus losses due to the seepage, the device called KU Permea-Oedometer is being developed. Preliminary test on dry and flow specimens show performance of the device and some results of the test are discussed later in the paper.

KEYWORDS : Oedometric modulus, cushion materials, concrete faced rockfill dam

1. INTRODUCTION

A common CFRD is constructed by compacting sound rock and laying reinforcement concrete slab over upstream slope called as face slab. Upstream zone (3A, 3B) of rockfill is needed to be low compressible zone to resist the water pressure and to limit the deflection of face slab. Cushion material (2B) which is located beneath face slab provides support to face slab and control drainage if water seeps through crack on the face slab [1].

2. ONE DIMENSIONAL COMPRESSION TEST FOR CUSHION LAYER

Several tests of granular soil and scaled rockfill were executed to find out the stress-strain relationship and time dependent strain by 1D compression or oedometer test. Gravelly soil was tested by oedometers which have configuration as shown in Figure 1. It was proved that fixed ring type of oedometer result a larger wall friction than floating ring [2]. To minimize the wall friction, a small ratio of height to diameter of specimen (H/D) is recommended.

The soil sample which is confined by the rigid wall can be reasonably assumed that lateral deformation is neglected. Elastic modulus in one dimension or Modulus of constrained, E_{oed} can be estimated by elasticity theory as shown in (1).

$$E_{oed} = \mathrm{d}\sigma_v / \mathrm{d}\varepsilon_v \qquad (1)$$

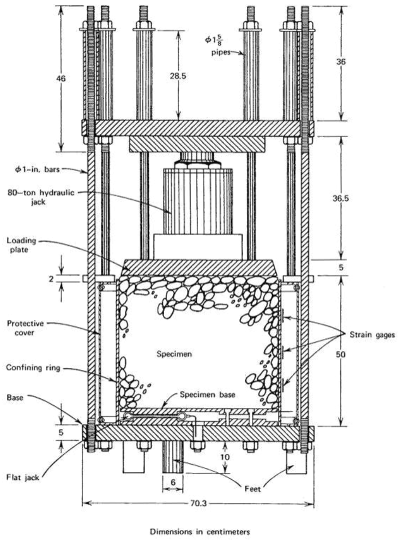
In order to design concrete slab on elastic foundation, the modulus of subgrade reaction, ks is applicable. From the results of Oedometer test, the modulus can be estimated by equation of Recodon [5] as follow:

$$k_s = \frac{(\sigma_2 - \sigma_1)}{(e_1 - e_2)} \frac{(1+e_m)}{h_0} \qquad (2)$$

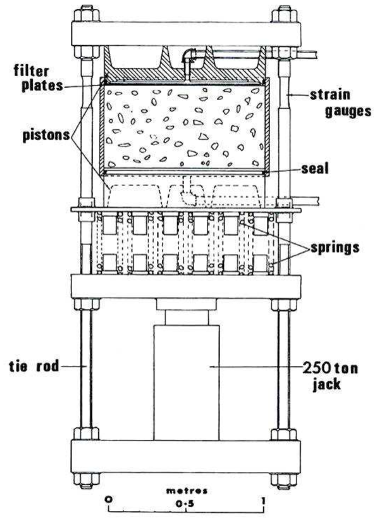
where

k_s = Modulus of subgrade reaction (t/m^2/m)
$\sigma_2 – \sigma_1$ = Difference of vertical stresses (t/m^2)
e_1, e_2 = Void ratio under vertical stress σ_1 and σ_2 respectively
e_m = average void ratio equals to $(e_1+e_2)/2$
h_0 = initial thickness of sample (m)

The term of $(e_1–e_2)/(1+e_m)$ in (2) is equal to volumetric strain $(\Delta V/V)$. The result of Oedometer test can be considered as one dimensional deformation, therefore the term of $h_0(e_1–e_2)/(1+e_m)$ is the vertical displacement.



(a) Fixed ring [3]



(b) Floating ring [4]

Figure 1 Oedometer for testing rockfill

Time dependent deformation or Creep can be investigated in granular soil such as cushion material; the total vertical strain can be described by equation (3)

$$\varepsilon = A + B\log(\frac{t}{t_1} + 1) + C\,t \qquad (3)$$

where

ε = Total strain
t = Elapsed time from a reference time
t_1 = Reference time
A = Elastic strain
B = Primary creep parameter
C = Secondary creep parameter

The testing herein can give only elastic strain, A and primary creep parameter B. Because the applied stress can not be reached to the rupture stress, secondary creep parameter C is not found.

3. SEEPAGE STABILITY OF COHESIONLESS SOIL

Kenney and Lau (1985) introduced a seepage test which looking like permeability test as shown in Figure 2. Soil specimen is contained within permeameter cell. Water in upper reservoir is flowing through the soil, mild vibration is introduced. Turbidity of flow out is observed during the test. The test gives stability index that shows what soil particle size is stable.

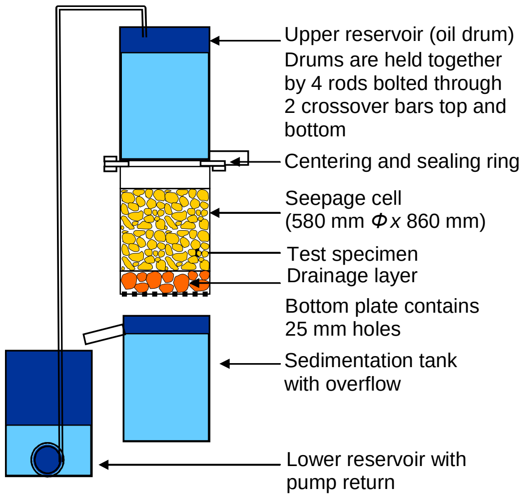


Figure 2 Permeameter cell [6]

Tomlinson and Vaid (2000) and Moffat and Fannin (2006) developed the apparatus for internal stability test served their purposes on the overburden pressure but not for a modulus test.

4. KU PERMEA-OEDOMETER

KU permea-oedometer is a combination of oedometer cell and permeameter cell, its schematic diagram is illustrated in Figure 3. Figure 4 and 5 show the details of the cell.

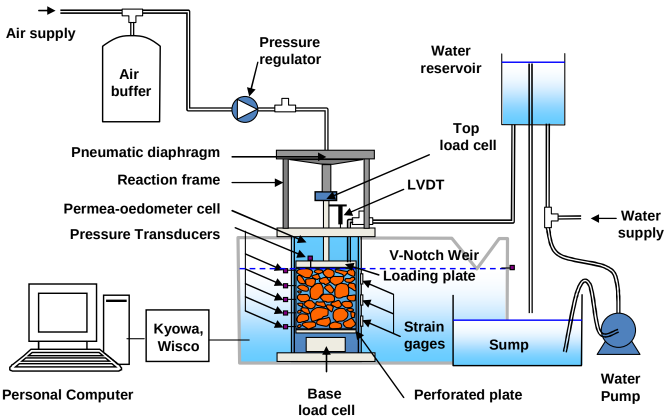


Figure 3 Schematic diagram

The device is designed to meet the requirement for compressive pressure of over 100 t/m^2 (or water head of 100 m), wall friction is minimized to acceptable range and inlet and outlet of the water are provided for seepage stability test. The device can be divided into 4 components as follows:

4.1 Permea-oedometer cell

The cell is a steel cylinder with 300 mm inside diameter, 505 mm height and 10 mm thickness. The specimen size is 300mm in diameter and 300 mm in height. A perforated steel plate provides support to the specimen. It is 296 mm dia. and 20 mm thick with 19 holes of 12 mm dia. Drain holes are drilled at the bottom of cell. Their size should be larger than maximum migrated particle size.

4.2 Loading system

Vertical loading is generated by pneumatic diaphragm inside loading frame. Its capacity is 7 ton at maximum. A pressure regulator and a pressure gauge are used for controlling pressure. Air buffer tank is used to stabilize the supplied air pressure when electricity shuts down.

Loading ram directly transmits the applied force to loading plate and the specimen. A top load cell is used to measure the applied vertical loading. The loading plate was drilled to provide holes or slot to permit water flows through the specimen.

4.3 Water supply and circulation system

Water is controlled to flow downward from upper reservoir to the cell through a hose. Water head can be kept constant using an overflowable tube. After seeping through the specimen, the water then overflows the V-Notch weir and flows into a sump. Water in the sump will be pumped to the upper reservoir for circulation.

4.4 Instrumentation

Load cells at the top and base of specimen are used to measure the applied loading and reaction loading, respectively. LVDT which has capacity of 25 mm and accuracy of 0.01 mm is used. Dial gauge which has capacity of 25.4 mm and resolution of 0.254 mm is used for visual observation.

Biaxial strain gages are attached on the side of cell wall for measuring lateral strain. During the loading, all data were recorded by Kyowa PCD-300A for every 1 sec interval.

Pressure transducers used for monitoring pressure along the specimen are used to determine the hydraulic gradient. The V-Notch weir is used to measure the discharge of seepage. Also the pressures along specimen and V-Notch weir are recorded by Wisco AI210 for every 1 sec interval.

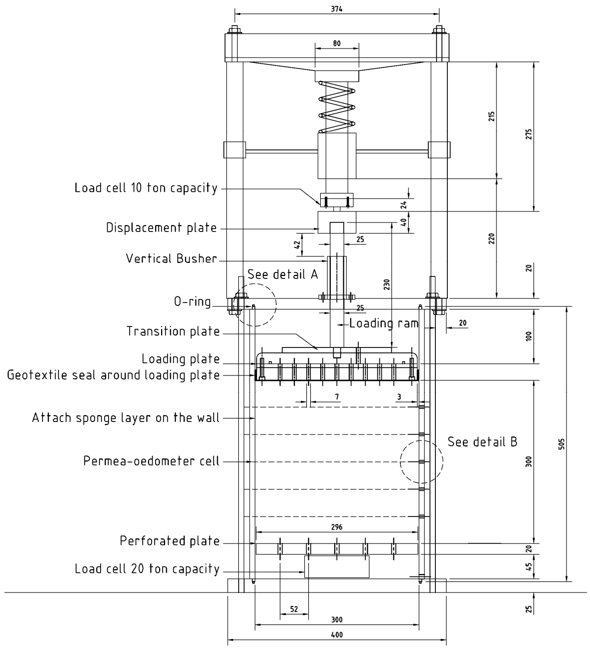
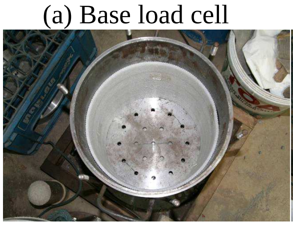


Figure 4 KU (Kasetsart University) permea-oedometer cell


(a) Base load cell


(b) Perforated plate


(c) Polystyrene rings

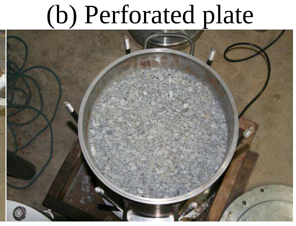

(d) Compacted soil

Figure 5 Device assembly

(e) Loading plate

(f) Loading frame

(g) Full assembly in dry condition

Figure 5 Device assembly (Continue)

5. PROCURMENT

Before the testing commences, all testing steps have been verified. The friction between cell wall and soil sample should be less than 20 percent of applied load in general [2]. A few means of minimizing the friction have been tried out (Figure 6). In case of without any liner, it showed that the friction loss is about of 60%. Five rings of polystyrene foam were then lined inside the wall with coating grease; the friction loss was deducted to 33%. To minimize the friction as much as possible, nine rings and less viscous grease were applied. The 20% friction loss was reached.

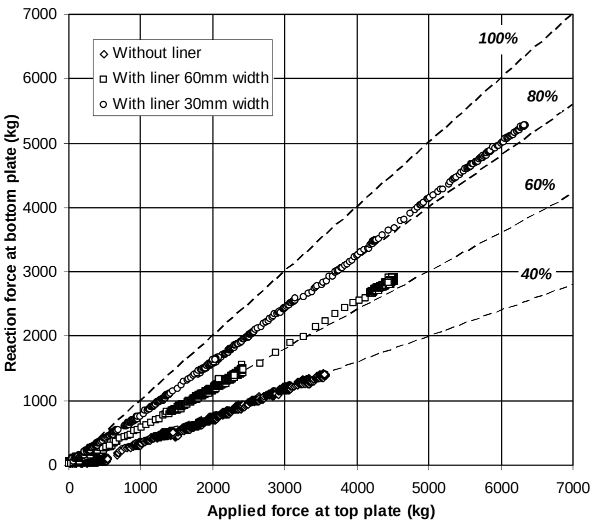


Figure 6 Effect of wall friction on the stress in soil sample

Soil sample was obtained from stockpile at the dam site. The grain size of the sample is 5 times smaller than the actual size as shown in Figure 7. The soil specimen was compacted in layer to achieve the total density conforming to field density value of about 2 ton/m^3.

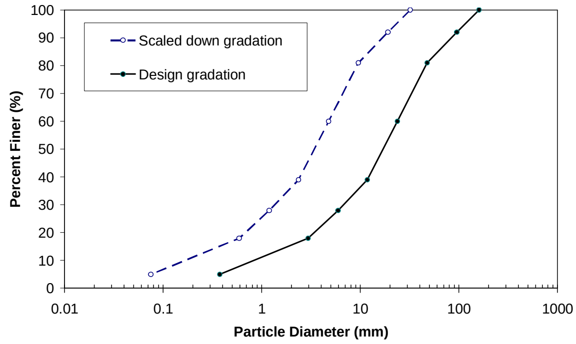
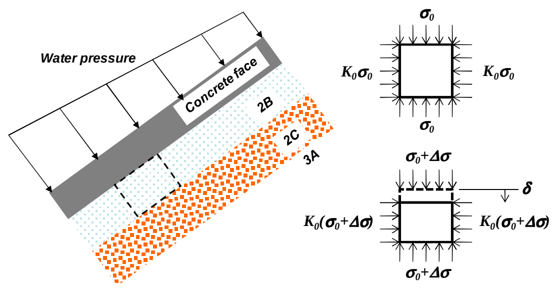


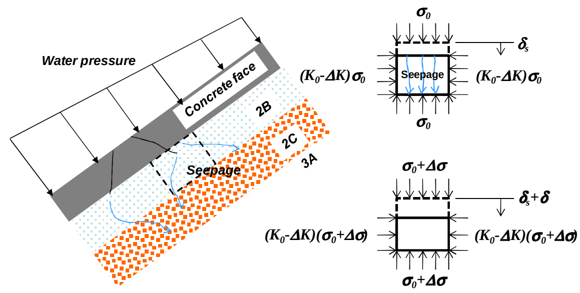
Figure 7 Grain size distributions of cushion layer and specimen

6. TESTING METHODOLOGY

The testing for modulus of cushion material was done under 2 conditions namely (1) design condition and (2) after seepage through crack condition. Figure 8 depicts the simulation of seepage through crack in laboratory.



(a) Normal (dry) condition as design



(b) Seepage through condition

Figure 8 Testing conditions of cushion layer

6.1 Normal condition as design

During operation, the cushion layer supports the face slab usually without crack and seepage flow. Pressure from concrete weight and water pressure play a role as vertical stress. If water head of 50 m restores over face slab, vertical stress σ will equal to 50 t/m^2. Vertical loadings, vertical settlements and lateral strains are measured and recorded during the test.

Steps of applied stress are 5, 10, 25, 50 and 100 t/m^2. The test will be terminated when rate of settlement is small (less than 0.0001 mm/min) or if the test was carried on longer than 24 hrs.

On the contrary, steps of unloading are 50, 25, 10, 5 t/m^2. The test will be terminated when rate of swelling is small or the load has been maintained longer than 12 hrs.

Reloading is carried on as same steps of the loading.

6.2 Seepage through condition

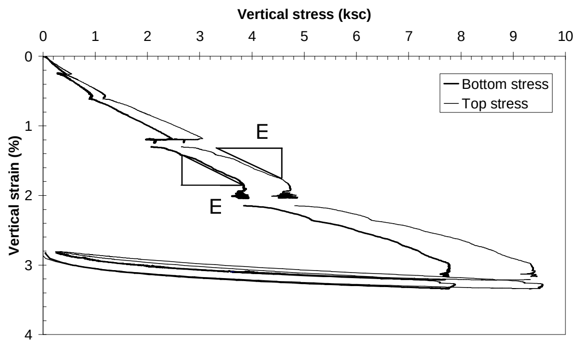
Vertical stress due to water pressure provides confining pressure on soil particles which resisting the migration [7]. Seepage flow is controlled by the hydraulic gradient. Because of the downstream head tend to be constant; therefore upper reservoir should rise up to create the head difference. During saturation, hydraulic gradient equals to zero and it will gradually go up but not more than 20. Discharge of seepage, settlement and pore pressures are monitored until water flow out is turbid longer than 30 minutes or the rate of settlement over 10 mm/min [8]. Oedometer test is then performed after ending of seepage test. The loading steps of testing follows as the first condition. Finally gradation of tested materials will be determined.

7. RESULTS

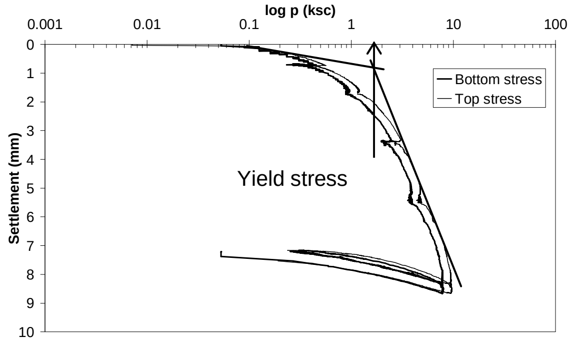
The test under normal condition as design was executed. The basic plots of stress–strain relationship are shown in Figure 9. The slope of σ_v – ε_v curves show elastic modulus which seems to increase with vertical stress. The δ – *log* σ_v plot gives yield stress that some particles in the specimen could have broken or crushed. Table 1 summarizes constrained modulus and modulus of subgrade reaction at each stress level.

Table1 Summary of modulus of cushion material from dry test

Stress level (ksc)	Constrained Modulus, E_{oed} (ksc)	Modulus of subgrade reaction, k_s (t/m^2/m)
Loading		
0 – 0.55	150 – 200	530 – 700
0.55 – 1.2	190 – 250	640 – 860
1.2 – 3.0	270 – 330	860 – 1075
3.0 – 4.7	270 – 315	800 – 940
4.7 – 9.6	470 – 540	1260 – 1430
Reloading		
0 – 9.7	2350 – 2500	7200 – 7400
Unloading		
9.7 – 0	2960 – 3040	7200 – 7800



(a) $\sigma_v - \varepsilon_v$



(b) δ – *log* σ_v

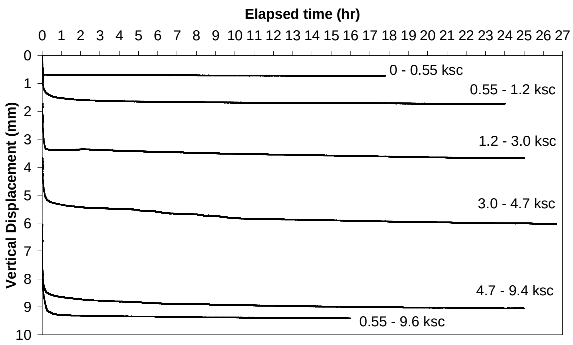
Figure 9 Stress–strain relationships

Yield stress which some particles has been broken and crushed at this stress level can be estimated from δ – *log* σ_v [9, 10] as shown in Figure 9b. Yield stress of cushion layer is around 1.5 t/m^2. After stress reached yield stress , grain structure then rearranged and modulus increase as listed in Table 1.

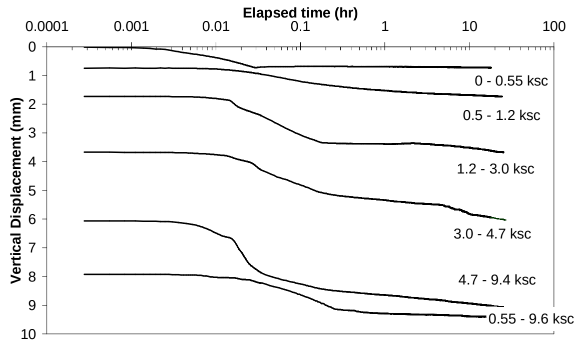
Strain or settlement depends on time of stress applied. Figure 10a shows the elastic settlement entirely develops within 1 hour. *B* parameters can be indicated in semi-log plot as illustrated in Figure 10b and tend to be constant after 2 hrs of the test. For loading stage, *B* value is in the range of 0.015 and 0.220 depending on stress level as drawn in Table 2. For unloading, primary creep reached after 4 hrs with *B* value is in the range of 0.019 and 0.070.

Table 2 Summary of creep parameter, *B* at each stress level

Stress (t/m^2)	Compression	Swelling
0 – 0.55	0.0152	
0.55 – 1.2	0.0430	-0.0197
1.2 – 3.0	0.1290	-0.0189
3.0 – 4.7	0.2203	-0.0316
4.7 – 9.6	0.1082	-0.0699
0 – 9.7	0.0468	-0.0308



(a) Normal plot



(b) Semi log plot

Figure 10 Time dependent displacement

8. CONCLUSIONS

To determine elastic modulus of cushion layer and other time-dependent parameters under problem on leakage, a particular apparatus has been devised. Result of the test can satisfyingly give elastic modulus, yield stress and time-dependent strain.

The cushion material of limestone show the hardening behavior after stressed. The moduli of cushion have increased with compressive increasing of compressive stress. The time-dependent parameters can be found within 24 hours.

9. ACKNOWLEDGEMENTS

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