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Effect of thickness of clay layer on C_α

Effet de l'épaisseur de la couche d'argile sur C_α

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ABSTRACT: Secondary compression is more significant in consolidation of high plasticity clays and peats. The effect of the various specimen heights on the secondary compression is examined in laboratory tests. The coefficient of C_α is determined for various specimen heights. A new oedometer cell is designed to measure pore pressures at the undrained base of the specimen and the friction between the ring and specimen. The side friction does not remain constant during the test and slightly increased with time (at a decreasing rate). The amount of the side friction depends upon the level of the applied vertical consolidation pressure on the specimen. Friction is found significant at low stresses when the clay was still over-consolidated. It is also observed that friction occurring between the specimen and ring is connected with the pore pressure dissipation. The development of friction largely ceases once the pore pressure dissipation is complete.

RESUME: La compression secondaire est plus efficace sur la compression des argiles de la haute plasticité et des tourbes. L'effet de différentes hauteurs des échantillons sur la compression secondaire est examiné dans les essais faits dans le laboratoire. Le coefficient de C_α est déterminé pour les différentes hauteurs des échantillons. Une nouvelle cellule de l'œdomètre est projetée pour mesurer les pressions interstitielles à la base non-drainée de l'échantillon et le frottement entre l'anneau et l'échantillon. Le frottement latéral ne reste pas constant pendant l'essai et augmente légèrement avec le temps (avec une vitesse qui diminue). La quantité du frottement latéral dépend du niveau de la pression de la consolidation verticale appliquée sur l'échantillon. Le frottement est trouvé significatif aux petites contraintes quand l'argile est encore sur-consolidée. C'est aussi observé que le frottement formé entre l'échantillon et l'anneau est attaché à la dissipation de la pression interstitielle. Le développement du frottement cesse largement une fois que la dissipation de la pression interstitielle est terminée.

1 INTRODUCTION

The specimen thickness plays important role on creep or secondary compression of clays of high plasticity and peats. Murakami (1988) and Ima & Tang (1992) showed that the amount of strain due to secondary compression developed during pore pressure dissipation increases as the thickness of a clay sample increases. This conclusion seems reasonable since thicker specimens require longer times for primary consolidation. This observation has been confirmed by Kabbaj et al. (1988) in the field. Imai (1989) verified from his experimental work in the laboratory that creep acts during the whole consolidation.

Material near the center of the deposit (assuming double drainage) will therefore have longer times to undergo creep compression during primary consolidation. Imai & Tang (1992) showed the effects of the layer thickness on the compression taking place during primary consolidation. The amount of secondary compression was strongly dependent on the thickness of the sample (Barden 1968, Kabbaj et al. 1988, Murakami 1988 and Imai et al. 1992). However, Wahls (1962), Newland et al. (1960) and Mesri & Choi (1985) indicated that it appears most likely that the coefficient and magnitude of secondary compression is independent of sample thickness.

Yin & Graham (1996) recently investigated the influence of the thickness of the sample on total settlements, dissipation of pore pressures, strain and stress, and concluded that the relationship between strain and effective stress at the end of the primary consolidation is not unique, but depends on the thickness of the clay layer.

It is very important to know the effect of the height of the clay specimen on the stress-strain relationship in order to understand the difference between the behaviour of the thick clay stratum and thin clay stratum. However, to find the stress-strain behaviour of a high specimen in the laboratory we must face the major problem of friction.

To obtain acceptable, accurate results it is necessary to look into the friction between the ring and the specimen. Without knowing the friction, the data obtained from the high specimen is not easy to interpret. Because friction between the soil and the ring reduces the mean stress in the soil during loading and increases the mean stress during swelling.

Contributions to the understanding of the stress-strain (or void ratio) characteristics in the consolidometer were made by Hansbo (1960), Kallstenius (1963) and Berre & Iversen (1972) in their investigations of the friction between the consolidometer ring and the clay specimen. The frictional loss was found to be dependent on the material of the consolidometer ring and also to a great degree on the surface smoothness (Hansbo 1960 and Kallstenius 1963). In practice the diameter to thickness ratio is maintained as per ASTM (1976, Part 16), $D/H > 2.5$. Therefore frictional effects can be minimized by using wide thin specimens to get rid of frictional problems.

Olson (1986) showed that Taylor (1942) examined friction in a simple but useful concept. Let p be the applied stress and q the average effective stress at any depth z in the sample. The average stress, q , over a depth H is then:

$$q = p \lambda \quad (1)$$

where λ = a reduction factor given by

$$\lambda = [(C_c/H)/(2K_0\mu)] \{1 - \exp[-(2K_0\mu)/(C_c/H)]\} \quad (2)$$

where $C_c = \Delta\varepsilon/\Delta\log\sigma'_v$; $K_0 = \sigma'_h/\sigma'_v$ = adjacent to the ring and is assumed equal to $K_0 = 1 - \sin\phi'$ for a normally consolidated sample; μ = coefficient of friction between clay and ring ($\mu = \tan\delta$, δ is the wall friction angle)

$$F/100 = 1 - \lambda \quad (3)$$

Where F (%) = the proportion of total applied stress transferred to the ring in side friction.

The equations are quite approximate. Any consideration is not given to creep, and the coefficients are approximate. However, the equations indicate that frictional effects can be minimized by using wide thin specimens and by reducing the soil/ring friction.

2 LABORATORY INVESTIGATION

Bothkennar soft clay is used for the tests carried out in the Soil Mechanics Laboratory of Department of Civil Engineering, Faculty of Engineering, University of Bristol. Samples had been taken from the research site at Bothkennar near Grangemouth in Scotland in 1989 as part of SERC funded soil characterisation study and these samples were kept in the cool sample store.

2.1 Reconstituted samples

A number of samples are obtained from a piston sample from 6.10-6.35 m depth and from a Laval sample from a depth of 5.13-5.36 m in order to make a large sample of reconstituted clay slurry. Atterberg limit tests are performed on the soil from its natural state (see Table 1) and on the day that the samples were opened. Samples were soft, very dark gray and mottled. Test procedures generally followed BS1377 (1975). Index tests on the two samples used for slurry were liquid limits (w_L) of 84 and 85 %, and plastic limits (w_P) of 39 and 40 %, and natural moisture contents (w) 69 and 70 % for the Laval and Piston samples respectively. The specific gravity (G_s) of Bothkennar clay for the tests has been assumed to be 2.70. The salt effect on the void ratio (e) of the specimen was taken into account by assuming that the pore water had a salt content of 1.013 g/cm³ (Nash et al., 1992).

Table 1. Atterberg limits of samples

| Type of sampler | Depth of sample (m) | w_L (%) | w_P (%) | w_n (%) |
|-----------------|---------------------|-----------|-----------|-----------|
| Sherbrooke | 5.10-5.26 | - | - | 66 |
| Laval | 5.13-5.36 | 84 | 39 | 69 |
| Piston | 6.10-6.35 | 85 | 40 | 70 |

As the results of the Atterberg tests are plotted on a plasticity chart it is seen that the soil is classified as inorganic clay of very high plasticity

The sample is reconstituted at a water content of 1.7 times liquid limit by mixing it with salt water to form a slurry. Saline water, obtained from mixing 21 ppt salt with de-aired water, is added to the crumbled clay to raise the water content to 1.7 times the liquid limit, and the mixture is then left to soften for 24 hours before thorough mixing. The sample is then consolidated in a 75 mm diameter stainless steel tube, attached to the consolidation ring, under one dimensional conditions by means of a pneumatic piston (see Figure 1).

They are mixed homogeneously until it was like heavy oil. A vacuum pump is used to draw the air bubbles out from the slurry sample in a desiccator, so that the specimen would be fully saturated. Before the slurry is poured into the cylinder, the inner walls of the tube, the O rings and the piston are lightly greased with silicon grease to reduce friction between clay and tube, and between the piston and tube. Slightly oversized filter paper is used on the porous stones to prevent soil from squeezing out past the piston. After the slurry is poured into the tube the vacuum was reconnected to draw air from the sample in the tube. The sample is assumed to be fully saturated. A spacer is used between the tube and the lower piston in order to reduce the friction between the sample and the tube. While extruding the sample from the tube into the ring, great care is given not to disturb

the specimen. The compression of the specimens is determined by means of displacement transducers. The tests are carried out in a room maintained at a uniform temperature of 19 ± 1 °C.

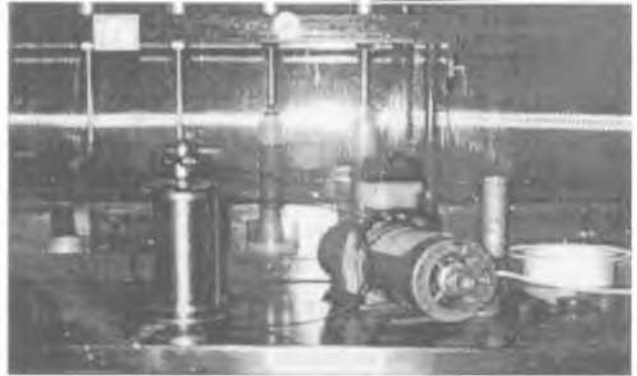


Figure 1. Equipment used for making reconstituted samples

2.2 Side friction and new design of apparatus

For high sample a new oedometer cell is designed in order to measure the pore pressure at the undrained base of the specimen and the friction between the ring and the specimen side in the consolidation tests (see Figures 2 and 3). For the specimen of 60 mm in height the side friction is determined. With this cell the excess pore water pressure at the bottom of the sample is determined so as to observe the end of primary consolidation. Friction is reduced by lubricating the inside of the ring with silicon grease.



Figure 2. New design cell

The vertical load (P) is known for each increment and the load (P') transmitted to the ring, which is directly related to side friction, was monitored by a load cell mounted on the bottom base plate. The friction load is transferred to the load cell by means of the ring, base pillar and transducer mounting plate. In addition pore pressure on the bottom of the specimen is measured by means of the pore pressure transducer mounted on the edge of the cell base (see Figure 3).

Using fixed and polished identical stainless steel consolidation ring, all made of stainless steel (10, 20 and 60 mm in height, 75 mm in diameter), three number of tests were carried out (Sivrikaya, 1997). Great care is taken to minimize the errors due to side friction and air entrapment. To minimise side friction between the rings and clay specimens the insides of the rings were coated with silicone grease.

The compression of the specimens is determined by means of displacement transducers. Friction between the specimen and the

ring is measured in a specially designed apparatus using a load cell. The settlement and the stress are read on the computer by means of the transducers connected to a datalogger (ADU). For the specimens of 10 and 20 mm in heights the presence of side friction is ignored.

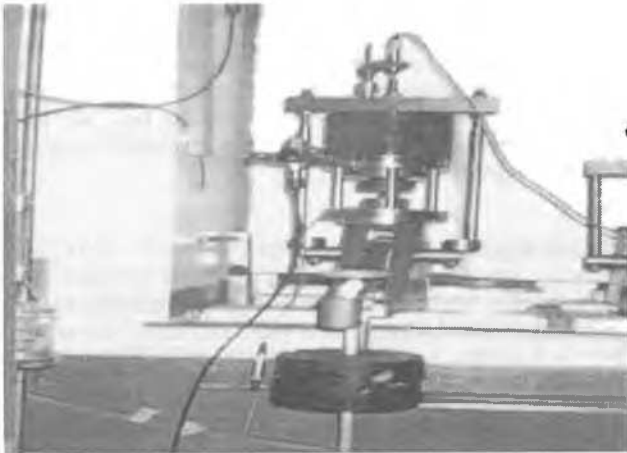


Figure 3. New design apparatus during test.

Specimen designation is shown as ILXY-Z where X= thickness of specimen; Y= test characteristics (Standard); Z= type of specimen (Reconstituted). Pore pressures on the bottom of the specimen of 60 mm and friction stresses between the specimen and ring are measured. All IL consolidation tests are conducted with the table model consolidation test apparatus.

3 RESULTS AND DISCUSSION

The effect of the various specimen heights on the secondary compression of the samples in the tests carried out is observed. This effect is shown in Figure 4. The coefficient of C_{α} ($\Delta e / \Delta \log t$) is determined for each specimen height and plotted versus vertical effective consolidation stress in Figure 4. As can be seen clearly there is a tendency for C_{α} to increase when the thickness of the specimen increases. As effective stress increases after exceeding the preconsolidation pressure all lines seem to converge.

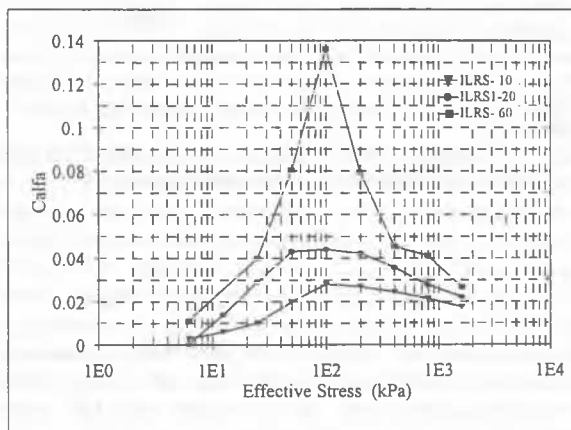


Figure 4. Effect of various specimen heights on C_{α} versus effective stress

In the long term, the creep rate (proportional to C_{α}) could be expected to be similar for specimens of different height. After 24

hours, however, creep rate for thicker specimens might be expected to be greater than for thin specimens, since the latter reach the end of primary consolidation much sooner.

Unfortunately, just one special test is carried out to study the pore pressure and friction between the specimen and ring. The pore pressure and side friction, for ILRS-60, after application of the applied pressure, versus elapsed time are plotted in Figure 5 and 4. The proportion of total applied stress transferred to the ring in side friction is denoted F (expressed in %).

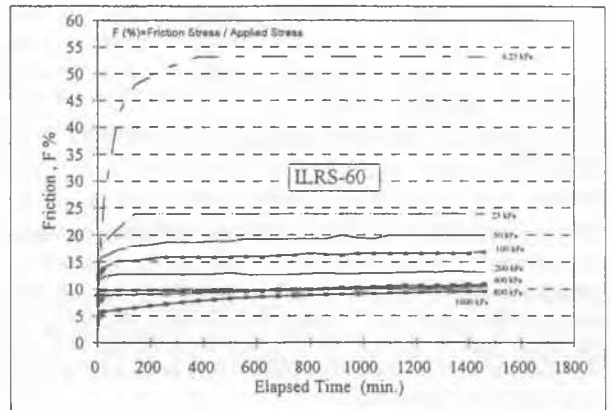


Figure 5. Effect of consolidation pressure on side friction for each applied loading for specimen of 60 mm in height (ILRS-60).

As seen from Figure 5 the side friction did not remain constant during the test and slightly increased with time (at a decreasing rate). Test results, as shown in Figure 5, indicate that the amount of the side friction depends upon the level of the applied vertical consolidation pressure on the specimen. In other words, as the consolidation pressure on the top of the specimen is increased, the amount of side friction decreased. After exceeding pre-consolidation pressure the side frictional loss varied between 9 % and 17 % of the applied vertical stress. Friction is found to be most significant factor at low stresses where the clay was still overconsolidated.

It is also observed that friction occurring between the specimen and ring linked with the pore pressure dissipation. From Figures 5 and 6 it may be seen that the development of friction largely ceases once pore pressure dissipation is complete.

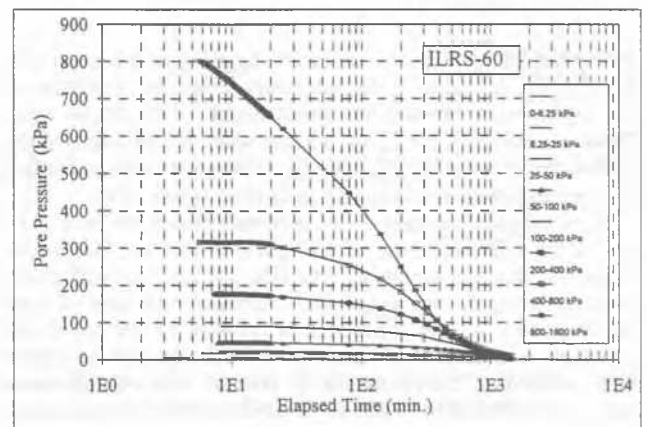


Figure 6. Pore pressure distribution for each incremental loading for specimen of 60 mm in height (ILRS-60)

The friction for various slopes of test ILRS-60 has also been estimated using Equation [1], and is shown in Table 2.

Table 2. Data for friction

| Test ILRS-60 | Effective Stress | C_c | λ | F Theory | F Observed |
|-------------------|---------------------|---------|-----------|-------------|---------------|
| | (kPa) | (%) | | (%) | (%) |
| H:60 mm | 6.25 | 2.4914 | 0.352 | 64.75 | 53.22 |
| $K_0=1-\sin 34^*$ | 25 | 9.3429 | 0.718 | 28.16 | 23.95 |
| $\mu:0.113^{**}$ | 50 | 15.8462 | 0.833 | 16.73 | 19.96 |
| | 100 | 18.2917 | 0.853 | 14.72 | 16.96 |
| | 200 | 18.4777 | 0.854 | 14.59 | 13.14 |
| | 400 | 19.9316 | 0.864 | 13.63 | 10.81 |
| | 800 | 19.3671 | 0.860 | 13.98 | 10.48 |
| | 1600 | 18.5937 | 0.855 | 14.51 | 9.51 |

* $\phi = 34^\circ$ (Hight et al., 1992)

** Coefficient of friction between clay and ring is assumed to give best fit with data

The measured and calculated frictions are shown in Figure 7. The difference between them may be due to the selection of inappropriate scale. In particular, it is unlikely that K_0 would remain constant, bearing in mind that initially the specimen is over-consolidated. In spite of these small differences it seems clear that the friction measured from test is consistent with those calculated from the Equation [1].

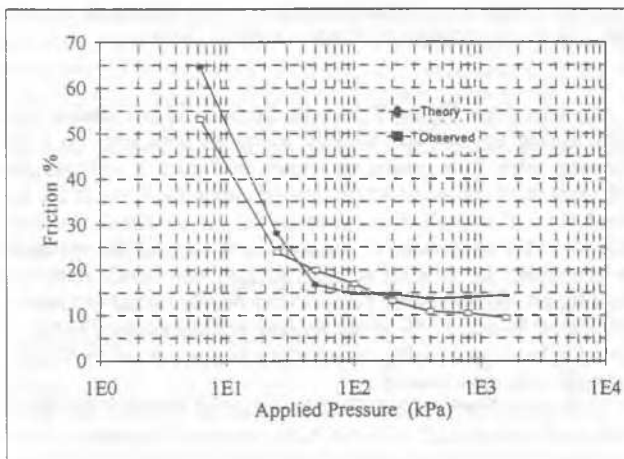


Figure 7. Experimental and computed friction (%) for ILRS-60

4 CONCLUSIONS

The effect of the various specimen heights on the secondary compression is studied in the laboratory tests. The coefficient of C_c is determined for each specimen height (H=10, 20, 60 mm). There is a tendency for C_c to increase when the thickness of the specimen increases. As effective stress increases after exceeding the preconsolidation pressure all lines seem to converge.

A new oedometer cell is designed to measure the pore pressure at the undrained base of the specimen and the friction between the ring and specimen. The side friction does not remain constant during the test and slightly increased with time (at a decreasing rate). As the consolidation pressure on the top of the specimen is increased, the amount of side friction decreases. After exceeding pre-consolidation pressure the side frictional loss varies between 9 % and 17 % of the applied vertical stress. Friction is found to be the most significant factor at low stresses where the clay is still over-consolidated.

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