Compression and Creep Indices of Organic Clayey Soil

Mudhafar K. Hameedi¹  Raid R. Al Omari²  Mohammed Y. Fattah³
¹Lecturer, Civil Engineering Department, University of Technology, Baghdad, Iraq, mthfaralgh14@gmail.com
²Professor, Civil Engineering Department, Al-Farabi University College, Baghdad, Iraq, tosharaid@yahoo.com
³Professor, Civil Engineering Department, University of Technology, Baghdad, Iraq, myf_1968@yahoo.com.

Abstract For construction of structures on soft clay layers, engineers must have to consider the consolidation behaviours of such soil. Due to the viscosity of clayey soils, their organic content strongly influences on consolidation behaviours as well effecting on vertical stress. Laboratory studies on soft soil have offered better understanding and thus better prognosis of these behaviour, and several related tests are performed and presented in this research. Two odometer tests were done, the first being a conventional odometer test for three soil types to find their compressibility parameters, while the second consisted of a series of long term odometer tests to find the creep coefficient for each type of soil. Seven incremental consolidation pressures were applied to each soil sample with different organic content (25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa and 1600 kPa). A detailed study of the results obtained from this incremental loading was then undertaken. From the consolidation test, the values of different parameters such as the compression index (Cc) and secondary compression index (Cα) were obtained, and it was found that Cc and Cα values increased with increased organic content in the soil. The study also found that, generally, Cα decreases with incremental loading.

Keywords: compression index, secondary compression index, organic matter, preloading effect.

1. Introduction

Peat is associated with the accumulation of part rotten and disintegrated plant remains under conditions of incomplete aeration and high-water content (Hobbs, 1986). Various physico-chemical and organic chemistry processes thus cause this organic material to stay in a state of preservation over a long time.

Macroscopically, organic matter is classified into three groups, amorphous granular, coarse fibrous, and finely fibrous (Landva and Pheeney, 1980). In recent years, however, there has been
little information derived about the engineering behaviour of soils with slight to moderate organic content (0.5-3.0%).

Casagrande (1936) was the first researcher who suggested a procedure to determine the creep index from odometer tests by suggesting that time-strain dependency be plotted in a semi-logarithmic diagram. The end of primary consolidation is calculated as the crossing point of the two tangents of the curve.

Mesri (1973) examined creep coefficient values and showed that most values for soils lie within the range 0.002 to 0.032. Further, Mesri and Castro (1987) outlined the Ca/Cc concept, which fully defines the secondary compression behaviour of any soil in terms of a continuing Cu/Cc, showing that the EOP e-Logσv offers a reasonable tool for determining settlement outlines and understanding deformation-controlled and load-controlled consolidation tests. The researchers showed that evaluating Cu/CC for any soil offers an associate expression for the behaviour of the constant of earth pressure at rest, K0, throughout secondary compression. This approach predicts a rise in K0 throughout secondary compression and additionally predicts that the K0 = 1 condition will not be reached in standard geological age soft clay deposits.

Havel (2004) investigated the consolidation of organic clay using long-term odometer tests on different types of soil (undisturbed and remoulded samples). All tests were performed in progressive loading odometer equipment with a lever arm, with two rings sizes used in the research. A soft-soil-creep model was thus presented, and analysis of the deviatoric creep behaviour supported the time resistance construct; a detailed description of the test conditions was also reported.

Augustesen et al. (2004) investigated the time-dependent behaviour of soil using one-dimensional and triaxial testing. The researchers studied time-dependent phenomena that were found to be more obvious in clay than sand.

The objective of the present paper is to determine the compression and creep indices from conventional consolidation tests for clayey soil with varying organic matter content levels. This paper also presents the effects of preloading on the creep coefficient.

2. Experimental Work

2.1 Soil

The un-disturbed soil samples were collected from depths of 1.5 m, 2.5 m, and 3.5 m below the soil surface in the Halfaya oilfield, which lies east of Missan governorate in southern Iraq. They were then designated as soil A, soil B, and soil C, respectively. The soil samples were subjected to routine laboratory tests to determine their properties, as seen in Table 1.
Table (1): Properties of the soils used

| Property                                | Soil A | Soil B | Soil C |
|-----------------------------------------|--------|--------|--------|
| Liquid limit (LL), %                    | 48     | 46     | 47     |
| Plastic limit (PL), %                   | 22     | 24     | 23     |
| Plasticity index (PI), %                | 26     | 22     | 24     |
| Liquidity index (LI), %                 | 0.26   | 0.31   | 0.37   |
| Activity of soil (A)                    | 0.26   | 0.22   | 0.24   |
| Specific gravity (GS)                   | 2.69   | 2.67   | 2.66   |
| Sand content %                          | 0      | 2      | 0      |
| % Passing sieve No. 200                 | 100    | 98     | 100    |
| Silt content %                          | 25     | 19     | 25     |
| Clay content %< 0.005 mm,               | 75     | 79     | 75     |
| Unified Soil Classification System (USCS)| CL    | CL     | CL     |
| Natural unit weight kN/m³               | 17.6   | 18.1   | 17.91  |
| Natural water content, %                | 20     | 32     | 39     |
| Undrained shear strength, Cu            | 22-25  | 20-22  | 16-18  |
| Organic matter %                        | 12-15  | 8-10   | 4-6    |
| Compression index, Cc                   | 0.266  | 0.259  | 0.270  |
| Recompression index, Cr                 | 0.045  | 0.049  | 0.058  |
| Preconsolidation pressure, $\sigma_c$ (kPa) | 90     | 75     | 65     |
| Sulphate content $SO_3$, %              | 1.7    | 0.35   | 0.36   |
| Gypsum                                  | 3.6    | 0.75   | 0.77   |

2.2 Testing model

The one-dimensional consolidation test was conducted according to the standard procedure prescribed by ASTM D 2435. The axial load was connected to the soil specimen in this test and load added in incremental steps while the sample was restricted laterally. Various stress increments continued until the full dissipation of the excess pore water pressure occurred. In the conventional testing procedure, the duration of each load increment is 24 hours. However, according to Lambe and Whitman (1979), secondary compression is defined by expressing the vertical strain $\Delta H/H$, as a function of logarithm of time. Thus, the secondary compression was determined in this model based on long-term tests, and the duration of load step could be as long as 10 to 30 days. Seven incremental consolidation pressures were applied on each soil sample with different organic content levels (25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa and 1600 kPa).

3. Results and discussion
Two parts odometer tests were done; the first part was a conventional odometer test for the three soil types to determine their compressibility parameters, while the second included a series of long-term odometer tests to find the creep coefficients for the three types of soil. Curing of samples occurred for 14 days in order to ensure uniform distribution of moisture before testing.

Figures (1) and (2) show the consolidation test results on the three soils. The compression index, $C_c$ and the initial void ratio increase with any increase of organic matter; thus, the maximum values of compression index $C_c$ and void ratio were found in soil A, which had an organic matter content percentage of 12 to 15%. The results showed that the high capacity of the OM to absorb water plays a key role in the soil’s primary consolidation and compressibility behavior. Thus, the increase in the OM content induces an increase in the void ratio, compressibility, and swelling indices.

This result can be discussed in conjunction with the finding of MacFarlane and Radforth (1965) who studied the structural arrangement of peats and the physical processes taking place during loading using a microscope and photo-micrographic techniques. The fibrous peat has an open structure, with the interstices filled with a secondary structural arrangement of fine non-woody fibrous elements. Most of the water is classed as free or capillary water, rather than viscous adsorbed water. These descriptions indicate that peat provides an excellent example of both viscous and micro-pore mechanisms of consolidation. However, organic soil or peat is a more complex material than inorganic clay and may require consideration of such factors as a moving drainage boundaries caused by large strains, and greatly decreasing permeability as the macro-pores are compressed.

![Figure 1: Results of conventional consolidation test.](image-url)
3.1 Creep index calculation.

Secondary compression denotes the volume change of soil sample independent of the change in water content or the excess pore water pressure. Thus, the secondary compression is the dependent change of the stress and it has resulted in the change in the void ratio ($\Delta e$) upon rearrangement of soil particles into a more stable form.

Sexton (2014) classified settlement into three stages, as shown in Figure (3); the creep coefficient is measured as the relationship of the void ratio and logarithmic time after the end of consolidation:

$$C_\alpha = \frac{\Delta e}{\log t}$$

Where

$C_\alpha$: Coefficient of secondary compression,

$e$: Void ratio, and

$t$: Time.

Figure 2: Variation compression index with organic matter content relationship.
3.2 Effect of preloading on the creep

The series of one-dimensional tests examined the effect of the organic matter content and the preloading level on the efficacy of the preloading methodology to creep index; moreover, analysis of the effect of the organic matter content on the secondary consolidation parameters was undertaken.

In the oedometer tests designated as creep tests, the samples were subjected to load increments every 10 to 20 days.

The effect of the preloading on creep behavior for the three different OM content levels was studied using two types of creep tests: one without curing the sample before testing and the second after curing the samples for 14 days before starting the test. Figures 4 to 9 show the results of a series of oedometer test with multi stage stress to determine the creep coefficients for Soil A, Soil A with curing, Soil B, Soil B with curing, Soil C, and Soil C with curing. From these figures, the following observations can be drawn:

- The behavior of the curves is comparable with that seen in Figure (3).
- At the end of primary consolidation, EOP was observed to take place after 150 to 200 minutes from the start of the test for most curves on different soils.
- The curing of samples did not effect EOP.

Table 2 shows the creep coefficient, $C_\alpha$, of different soils and loading stages.

![Diagram showing immediate compression, primary consolidation, secondary compression, and tertiary compression.](image)
Figure 4: Cumulative change in void ratio with time relationship for Soil A under different pressures.

Figure 5: Cumulative change in void ratio with time relationship for Soil A with curing under different pressures.

Figures 4 and 5 show that most behaviors look similar to those seen in Figure 3; the secondary compression starts at 150 minutes and the tertiary compression happens in most cures after about
10,000 minutes. This means that the secondary compression period is from 150 minutes to 10,000 minutes.

In Figure 4, the maximum Δe is at a stress of 25 kPa, but in Figure 5 the maximum Δe is at a stress of 50 kPa. In both Figures 4 and 5, it is observed that the maximum creep coefficient occurs at 25 kPa, then the creep coefficient decreases with every stage.

Figures 6 and 7 show that most behaviours are similar to Figure 3; the secondary compression starts at 100 minutes and the tertiary compression occurs in most curves after about 4,000 minutes. This means that the secondary compression period is from 100 minutes to 4,000 minutes.

In Figure 6, the maximum Δe occurs at 25 kPa, but in Figure 7 the maximum Δe occurs at 400 kPa. From Figures 6 and 7, the maximum creep coefficient occurs at 25 kPa, then the creep coefficient decreases with every stage.

Figures 8 and 9 show that most behaviours are similar to those in Figure 3. The secondary compression starts at 150 minutes and the tertiary compression happens in most curves after about 8,000 minutes, which means that the secondary compression period is from 150 minutes to 8,000 minutes.

From Figure 8, the maximum Δe is at 400 kPa, but in Figure 9, the maximum Δe occurs at 25 kPa.

![Figure 6: Cumulative change in void ratio with time relationship for Soil B under different pressures.](image-url)
Figure 7: Cumulative change in void ratio with time relationship for Soil B with curing under different pressures.

Figure 8: Cumulative change in void ratio with time relationship for Soil C under different pressures.
From Figures 10 and 11, the maximum creep coefficient occurs at 25 kPa, then the creep coefficient decreases with every stage.

Figures 10 and 11 show that the creep strains increase with the organic matter content regardless of whether a sample has been cured or not. However, the samples without preloading showed a constant strain rate (for times over 100 minutes), whereas the samples subjected to preloading showed an increase in the creep strain rate with time, which induces the increase in the creep

---

**Figure 9:** Cumulative change in void ratio with time relationship for Soil C with curing under different pressures.

**Table 2 Result of creep coefficient.**

| Soil type | Soil A     | Soil A (curing) | Soil B     | Soil B (curing) | Soil c     | Soil c (curing) |
|-----------|------------|-----------------|------------|-----------------|------------|-----------------|
| Stress kPa|            |                 |            |                 |            |                 |
| 25        | 0.0090     | 0.00614         | 0.006916   | 0.003707        | 0.002861   | 0.00277         |
| 50        | 0.00771    | 0.00592         | 0.004347   | 0.003322        | 0.00241    | 0.002279        |
| 100       | 0.00629    | 0.00576         | 0.0043     | 0.003638        | 0.0023     | 0.00101         |
| 200       | 0.00572    | 0.00515         | 0.00431    | 0.003623        | 0.002174   | 0.001532        |
| 400       | 0.00576    | 0.00512         | 0.003422   | 0.003341        | 0.002039   | 0.001288        |
| 800       | 0.00514    | 0.00482         | 0.003213   | 0.002861        | 0.0017     | 0.001          |
| 1600      | 0.00429    | 0.00386         | 0.003577   | 0.003122        | 0.001411   | 0.0014          |
coefficient $C_\alpha$ with time. The results also indicate that the preloading methodology is more efficacious for a higher preloading levels and when the OM content is higher.

![Figure 10: Variations of creep coefficient with organic content for the three soil types.](image)

![Figure 11: Variations of creep coefficient with organic content for three types of soil with curing of samples before testing.](image)
In terms of creep compressibility (Figure 12), when the sample is cured, most the creep coefficient results show a reduction, though this effect decreases linearly with the loading stages. Figure (12) shows that the difference between creep coefficients at the initial stress stages is greater than in the last stages of stress.

Figure 12: Variation of creep coefficient with effective pressure for different soil types.

Figure 12 shows that the odometer creep tests clearly reveal a significant reduction in the creep coefficient \( C_\alpha \) when preloading is applied, and that this effect grows with any increase of the preloading, both with and without curing. This reduction is because when most strain takes place, the organic matter has already been affected, so its impact reduces with time.

Organic composites are known to act with clay minerals to create organic-clay complexes of different stabilities. Many characteristics of clay minerals are changed by such effects, as noted in these results. The compressibility parameters and creep coefficient were increased, and both the strain-rate coefficient and the creep coefficient in shear showed fundamental time independent associations between strain and stress which are prescribed by the type of bonds within the clay particles.

The changes observed in the soil characteristics of deposits with increased organic matter could be associated with the changes occurring in the characteristics of organic clay complexes. Increased organic matter causes moisture-holding capacity to increase and indirectly affects plasticity. Therefore, increasing the bound water of hydration and at the same time increasing the relative mobility of individual grains. Compressibility and shear strength also increase with organic matter increases because the organic matter causes increases in the electrostatic bonding between clay particles, organic matter, and salts and other minerals (Rashid and Brown, 1975).
4. Conclusions

1- The high capacity of the OM to absorb water plays a key role in primary consolidation and compressibility behavior. Thus, increase in OM content induces an increase in the void ratio, compressibility, and swelling indices of soils.

2- Odometer creep test results clearly reveal a significant reduction in the creep coefficient Cα when preloading is applied; this effect grows with increases in preloading with and without curing. This reduction is because most strain takes place once the organic matter has been compressed, so its effects are reduced with time.

3- The compressibility parameters and creep coefficient increase as organic matter content increases.

5. References

- ASTM, D. (2011). 2435-11. Standard Test Method for One-Dimensional Consolidation Properties of Soils Using Incremental Loading. American Society for Testing and Materials (ASTM).
- Augustesen, A., Liingaard, M., and Lade, P., 2004, “Evaluation of Time-Dependent Behavior of Soils,” Int. J. Geomech., Vol.4, No. 3, pp. 137–156.
- Casagrande, A. (1936). The determination of the preconsolidation load and its practical significance. In 1st International Conference of Soil Mechanics and Foundation Engineering, Volume 3, page 60. Cambridge, Massachusetts, USA.
- Havel, F. (2004). Creep in soft soils. Doctoral thesis. Norwegian University of Science and Technology.
- Hobbs, N., B. (1986). Mire morphology and the properties and behavior of some British and foreign peats. Quarterly Journal of Engineering Geology and Hydrogeology, Vol.19, 7-80.
- Lambe, T. W., & Whitman, R. V. (1979). Soil mechanics SI version. John Wiley & Sons.
- Landva, A.,O., and , Pheeney, P. E. (1980). Peat fabric and structure. Vol. 17, No. 3 : pp. 416-435
- MacFarlane, I.C. and Radforth, N.W. (1965). A Study of Physical Behavior of Peat Derivatives Under Compression. Proceeding of The Tenth Muskeg Research Conference. National Research Council of Canada, Technical Memorandum No 85
- Mesri, G., (1973). Coefficient of secondary compression. Journal of Soil Mechanics and Foundations Division, ASCE, 99 (1), 123–137.
- Mesri, G., & Castro, A. (1987). Cu/Cc concept and K₀ during secondary compression. Journal of Geotechnical Engineering, ASCE, 113(3), 230-247.
- Rashid M. S and Brown J. D., (1975). Influence of marine organic compounds on the engineering properties of a remolded sediment. Engineering Geology, 9(1975)141-164 @Elsevier Scientific Publishing Company.
- Sexton B., (2014). The influence of creep on the settlement of foundations supported by stone columns. A thesis of the doctor. National University of Ireland, Galway.