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CREEP CHARACTERISTICS OF CHALK MARL UNDER UNIAXIAL AND CONFINED COMPRESSION STATE STRESS

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This paper studies the time-dependent deformation of chalk marl under uniaxial state of stress in a specially built creep rigs, and confined compression stress state. The tests carried out include: six uniaxial creep tests with vertical and lateral deformation measurements, at different stress levels which lasted for 75 to 268 days, six oedometer creep tests under different stress intensities and different loading conditions which lasted for 80 to 250 days. All tested samples were trimmed from 113 mm diameter cores. For uniaxial tests 0.5% axial strain occurred almost instantaneously in the first series subjected to a stress level of 80%. In the second series subjected to a stress level of 40%, the average initial strain was 0.25% which indicate clearly their stress level dependency. After 75 to 150 days creep period, the measured average creep strain was 0.33% for the first series, which represents 57% of the consolidation strain. For series 2 the average creep strain = 0.26%.which represents 54% of the consolidation strain. This implies that the proportional creep ratio Cr = (Et - E1) / E1 is independent of the applied stress level, where Et strain at any time t, E1 strain at one day. For 1-D creep tests E1 and the proportional strain (Et - E1) are not affected significantly by the intensity of applied creep stress, while both of them are highly influenced by the method of load application. From these results, it can be concluded that creep deformation constitutes an important part of the total deformation of chalk marl.

Keywords: Creep strain, Creep ratio, Lateral strain, Poisson's ratio, Uniaxial loading, Confined compression loading.

1 GENERAL APPEARANCE

When a saturated soil mass is subjected to an effective stress change, it will undergo deformation which can be separated into three phases. The first phase is the undrained phase which is considered as a shear distortion without volume change. The second phase is a time- dependent phase controlled by the hydrodynamic flow of water through soil pores, this is known as consolidation phase, which is directly related to the dissipation of excess pore water pressure u_e. The third phase of deformation is also a time – dependent phase which is not directly related to the dissipation of u_e, but it may be related to the continuous realignment of soil particles under eventually constant effective stress. This phenomenon is called creep; Larson (1986), Hansbo (1975), or secondary compression Bjerrum (1967). Most research in literature was directed to studying time- dependent deformation of clayey soil, but Zhang *et al.* (2006) studied creep deformation of saturated sand in oedometer tests. The main purpose of this paper is to derive information concerning the time dependent rheological or viscous, creep properties of Chalk Marl, which may be essential for the design of tunnel lining and other deformation problems.

2 EXPERIMENTAL STUDY

The creep behavior of Chalk Marl has been studied experimentally under; (a) uniaxial state of stress in specially built uniaxial creep test rigs with vertical and lateral deformation measurements, which lasted for 75 days to 268 days. The base of loading rig accommodates a neoprene diaphragm connected to a tapered steel piston. The stress is applied to the sample by pumping up hydraulic oil connected to a gas- oil accumulates, Hannant (1968). Figure 1 shows details of the loading creep rig.

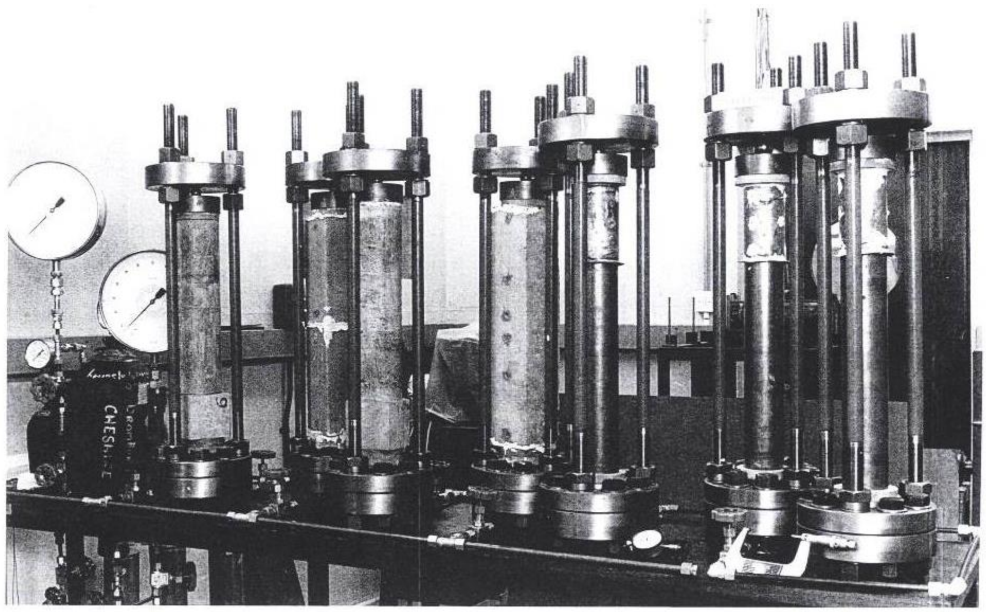

Figure 1. Details of the loading creep rig.

The samples used in uniaxial creep test series were 76 mm diameter x 152 mm long. Stainless steel studs were glued in short holes drilled in the sides of each sample. Three pairs of studs were positioned above each other at 120 degrees around the periphery of the specimen with a vertical distance of 102 mm between the upper and lower studs to measure the average vertical deformation. Another two pairs of studs were glued in the middle of the specimen at 90 degree intervals, thus providing two perpendicular diameters for lateral deformation measurement. The samples were consolidated in the triaxial cell to an effective stress of 345 kN/m2 for the first series and 690 kN/m^2 for the second series, applying a back pressure of 758 kN/m^2. When consolidation is completed, the samples were removed from the triaxial cell, enclosed all around in a thin copper sheath and soldered at the joints, to seal the samples completely against any moisture loss. Prior to testing, a control sample from the same core and similar depth was consolidated in the triaxial cell to the same effective stress as for the creep tests. The sample was loaded undrained at zero cell pressure to determine the control strength of the material, under unconfined compression. Each series of tests consists of one control test and three creep tests. Two series were carried out. For the first series (Tests UC 1, 2 and 3) the sustained creep stress was 2,740 kN/m^2 which is equivalent to 80% stress level. For the second series (tests UC 4, 5 and 6), creep stress was 1,370 kN/m^2 which is equivalent to 40% stress level. Axial deformation was measured with a Demec strain gage which can read to an accuracy of 0.02 mm per division.

Lateral deformation was measured with a precision micrometer which can be read to an accuracy of 0.001 mm (b) Confined compression creep test Oedometer creep samples 76 mm diameter x 19 mm high were trimmed from 113 mm cores using CNC machine. Six tests were carried out with duration of 80 to 250 days. Two tests were subjected to a creep stress of 3,140 kN/m^2 and two tests to a stress of 1,570 kN/m^2. In these four tests, the stress was applied in increments, doubling the load every 24 hours. The fifth test was subjected to a stress of 3,140 kN/m^2 applied in increments with cycles of loading and unloading before the final stress was kept constant. The sixth test was subjected to a stress of 1,570 kN/m^2 applied in one increment. Table 1 shows the details of the testing program.

Table 1. Result of uniaxial creep tests.

Series No.	**Test No.**	**Stress Level 1 %**	**Axial Strain %**					**Axial Strain Recovery**	
			ε_i	ε_1	ε_{150}	ε_c	$\varepsilon_c/\varepsilon_1$ %	ε_r %	$\varepsilon_r/\varepsilon_1$ %
1	UC1	80	0.50	0.59	0.93*	0.34	58	0.25	42
1	UC2	80	0.44	0.51	0.79	0.28	55	0.24	47
1	UC3	80	0.45	0.53	0.83	0.30	57	0.24	45
2	UC4	40	0.27	0.36	0.56	0.20	56	0.13	36
2	UC5	40	0.22	0.27	0.42	0.15	56	0.10	37
2	UC6	40	0.60	0.87	1.29	0.42	48	0.29	33

*At 75 days after application of stress

ε_i = axial strain at 10 minutes after application of stress

ε_1 = axial strain at 1 day after application of stress (consolidation stress)

ε_c = creep strain = $\varepsilon_{150} - \varepsilon_1$

ε_r = strain recovery at 5 minutes after stress relief = Axial strain at 5 minutes – Axial strain before stress relief , Stress Level = (Applied stress / Strength)*100

3 RESULTS AND DISCUSSION

3.1 Uniaxial Creep Tests

3.1.1 *Development of axial strain with time*

Upon application of stress, about 0.5% axial strain occurred almost instantaneously in first series, (tests UC 1, 2, and 3) and 0.27 %, 0.22%, and 0.69% for tests 4, 5, and 6 in the second series. The high initial strain for test no 6 is due to high moisture content observed at the lower half of the sample. This result indicates that initial axial strains are directly related to the applied stress level. From the plots of axial strain versus square root of time, the time required for 90% consolidation range from 100 min to 400 min, which means that after 1 day of stress application, the consolidation process will be completed. All strain which will occur after the first day will be considered to be due mainly to creep, although some creep strain may accompany the process of consolidation. 75 days after application of stress in test 1 and 150 days in tests 2 and 3, creep strain were 0.29% to 0.34% which represents n average of 57% of the consolidation strain for the first series. In the second series, the average creep strain for the three tests was 0.26% which represents 54% of the consolidation strain. However, in both series, if the results of test UC1 which was approaching failure, and test UC6 which exhibited high initial strain are excluded, the average value of the proportional increase of axial strain (ϵ t- ϵ1) is 0.29% for the first series and 0.18% for the second series, which represent a promotional creep ratio (ϵt - ϵ1) /ϵ1 *100%, of 57% and 56% for series 1 and 2 respectively, which clearly indicates that the proportional creep ratio is independent of stress level in this case , see Table 1. Bishop and Lovenbury (1969) found that for London Clay, there is some tendency that proportional strain is higher for lower stress level. This is in contrary to the above result for Chalk Marl. Axial strains were plotted versus log time in days in Figure 2. In the first series, subjected to a stress level of 80%, the relationship is generally nonlinear characterized with a concave upwards curve, except for a very limited period of 1 to 2 days where the curves are approximately linear. In the second series subjected to a stress level of 40% a linear relationship exists for a period of 10 to 13 days after load application for tests UC 4 and 5, after which the curve become gently nonlinear concave upwards. In test UC6 the relationship is nonlinear concave upwards over the whole period of time. From this discussion, it seems that the range of linearity of axial strain vs. (log t) decreases as the applied creep stress level increases, which is similar to the results reported by Bishop and Lovenbury (1969) on London clay and Pancone clay. These results have demonstrated that the time dependent deformation of Chalk Marl subjected to uniaxial creep stress cannot be predicted by logarithmic or power laws for any reasonable period of time which can be of practical significance.

3.1.2 *Lateral strain and creep Poisson's ratio μ*

Lateral deformations were measured successfully with a precision micrometer which measures to an accuracy of 0.001 mm lateral strain increases instantaneously upon application of stress, then decreases to a certain level to become steady or increase only slightly during the short-term behavior (less than 1 day). The instantaneous increase of lateral strain is due to underained behavior; shortly after application of stress, excess pore water pressure u_e has not sufficient time to dissipate from center of specimen to its periphery, where the confining stress is zero. Therefore, it is expected to be close to the undrained value of 0.5, when u_e dissipates μ will drop gradually to reach the drained value of 0.2 to 0.3

3.1.3 *Axial strain recovery*

Axial strain recovery is defined as the axial strain at time before the stress is released minus axial strain at any time after removal of creep stress. Initial axial strain is taken at 5 minutes after removal of creep stress. These values are summarized in Table 2. Average values of initial axial strain recovery are 0.25% and 0.17% for stress levels of 80% and 40% respectively, which represent 46% and 36% of axial strain at 1 day. It appears that strain recovery is proportional to the applied creep stress level. The strain recovery ratio R = strain recovery / strain at one day is also stress level dependent, see Table 2. Most of creep strain recovery occurred during the first day after unloading, after which there is little creep recovery.

3.2 Creep Deformation in One-Dimensional Compression

From plots of ε versus √t, the time required for 90% consolidation ranged from 14.5 to 26.0 minutes with an average value of 23 minutes. Therefore, it is reasonable to assume that all consolidation strain will occur during the first day, although it will be associated with some creep strain. The proportional increase of axial strain $(t - \varepsilon_1)$ and the increase of strain ratio $(\varepsilon_t - \varepsilon_1)/\ \varepsilon_1$, ($\varepsilon_t$= strain at time t days, ε_1= strain at 1day). The proportional increase of strain ratio after 80 days of creep time, ranged from 12% to 28% for tests with incremental loading. It appears that the ε_t and Rε are not affected significantly by the intensity of the applied stress, e.g. compare results of tests 1 and 2 subjected to a creep stress of 3,140 kN/m^2 with tests 3 and 4 subjected to a stress of 1,570 kN/m^2, see Figure 2 for test no.5 subjected to incremental loading accompanied with cycles of loading and unloading, ε_1, was very low, about half of the corresponding value of tests without the loading and unloading cycles. $(\varepsilon_t - \varepsilon_1)$ after 80 days of creep is very high and

Rε = 86% of the initial strain. It can be concluded that in one – dimensional creep, the method of load application has a significant effect on initial strain and creep strain. As shown on Figure 3 the relationship between strain and log t is linear up to 14 to 20 days, except in test no 4 where the relationship is linear up to 60 days. In test no 6 where the stress is applied in one increment, the curve was concave upwards during the whole period of creep time. It appears that there is no typical characteristic pattern of creep curves which can be related to stress intensity or method of load application. This behavior cannot be predicted by any single logarithmic or power law. It clearly demonstrates the limited period of applicability of these laws and the dangers involved in applying them to predict long term creep deformation. Bishop and Lovenbury (1969) showed similar behavior of the Pancone clay from two oedometer tests which lasted for 400 days.

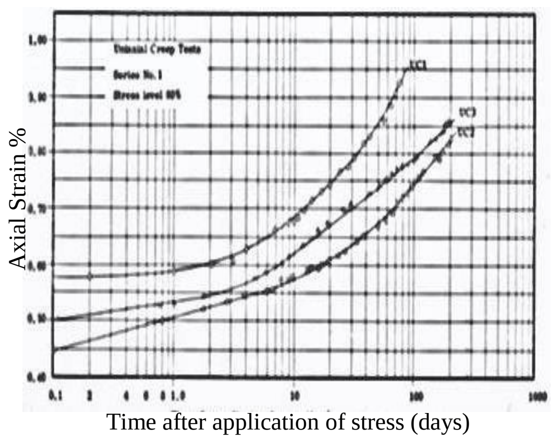

Figure 2. Development of axial strain with log time (uniaxial tests).

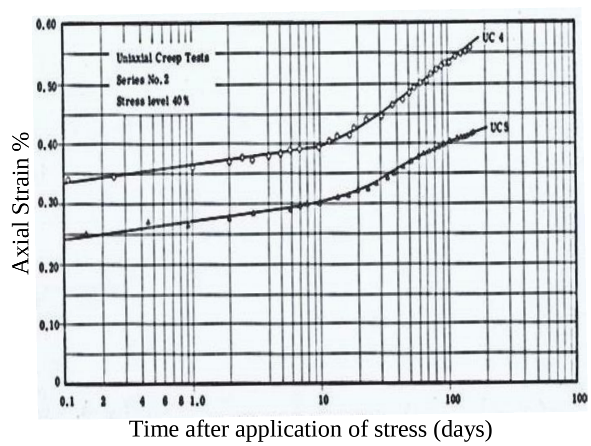

Figure 3. Development of axial strain with log time (uniaxial tests).

4 CONCLUSIONS

4.1 Creep Deformation in Uniaxial State of Stress

Consolidation strain ε_1 is directly proportional to the applied stress level, the higher the stress level, the higher ε_1 will be. The proportional creep ratio Rε $(\varepsilon_t - \varepsilon_1)/\varepsilon_1$* 100% was independent of the applied stress level. Rε = 57% for stress level 80% and 56% for stress level 40%. The curves of ε vs. log t are generally nonlinear at high stress levels with concave upwards characteristics, while at low stress levels, the curves are linear up to 10 to 13 days, after which they become concave upwards. Lateral strains are characterized with an instantaneous increase upon application of stress, to reach a peak value after 5 to 15 days, and then decreased gently with time without approaching zero even after 160 to 268 days. Poisson's ratio is near 0.5 (which is for undrained loading) upon application of stress then decreased to a lower value shortly after application of stress and continue to decrease slowly with time. It was found that most of creep strain recovery εr after removal of creep stress, occurred during the first day, afterwards, there is little creep recovery.

4.2 Creep Deformation in One-Dimensional State of Stress

The relationship between ε and log t is linear only for a limited period of 14 to 20 days in most cases, after which the relationship become concave upwards.

Creep deformation under conditions of zero lateral strain cannot be predicted by any single logarithmic or power law, since the period of applicability of these laws is very limited.

The consolidation strain ($\varepsilon 1$) and the proportional increase of axial strain ($\varepsilon t - \varepsilon 1$) are not affected significantly by the intensity of creep stress, whereas both of them are highly influenced by the method of stress application. If the stress is applied in one increment, ($\varepsilon 1$) will be very high and ($\varepsilon t - \varepsilon 1$) will be very low, on the other hand, if the stress is applied in increments associated with cycles of loading and unloading ($\varepsilon 1$) will be very low and ($\varepsilon t - \varepsilon 1$) will be very high.

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