Effect of Creep Rate on Behavior of Clay-cement Soil

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Abstract

The time- dependent behavior of a clayey soil-cement was studied, using the triaxial compression test throughout the test programs under the unconsolidated undrained condition. The undrained condition represents the controlling drainage condition in which a creep failure may occur.

The undrained creep behavior of soil-cement was investigated, using the following cement content (4, 8 and 12%), under three various stress-strength levels (60, 75and 85%).

The creep time relation, effect of stress level on creep, effect of cement content on creep, creep rate, and the effect of creep on strength was studied thoroughly.

Test results of 35 models showed that creep strain increases with the logarithm of time and stress level but decreases as the cement content increases. Also, increases in the strength and modulus of elasticity augment after creep but was affected by increases in cement content.

On the other side, this research shows a particular stress level below which soil-cement sample will not fail; this is termed the critical stress level. Little increases in the critical stress level was indicated with increases in the cement content.

Finally, linear relationship appears between logarithmic of creep rate and time, the slope of this relationship was found to be independent of stress level. Creep strain decrease rapidly with logarithmic of creep rate for specimens of 0% and 4% cement content while insignificant changes in creep properties occurred in specimens with 8% and 12% cement content.

Key Words: Soil Cement, Triaxial Tst, Clayey Soil, Laboratory Models and Stress level.

تأثير معدل الزحف على تصرف التربة الطينية – الاسمنت

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الخلاصة

درس تأثير الزمن على تصرف التربة الطينية المثبتة بالإسمنت. استخدام فحص ثلاثي المحاور تحت حالة الفحص عديم الانضمام وغير المبزول، حيث يمثل هذا الفحص الحالة المسيطرة على البزل في حالة امكانية حصول فشل الزحف (creep) في التربة المثبتة بالإسمنت. درس الزحف غير المبزول (undrained creep) لثلاث قيم من محتوى الاسمنت (4, 8 و 12%) وثلاث قيم مختلفة لمستوى الاجهاد (60, 75 و 85%)، فضلاً عن دراسة علاقة الزحف مع لوغاريتم الزمن، تأثير مستوى الاجهاد على الزحف، تأثير محتوى الاسمنت على الزحف ومعدل الزحف وتأثير الزحف على مقاومة ومعامل المرونة للتربة المثبتة. أوضحت النتائج ان انفعال الزحف للتربة المثبتة يزداد مع الزمن ومستوى الاجهاد و يقل مع زيادة محتوى الاسمنت، كما اشارات النتائج الى ان معدل الزيادة في كل من المقاومة ومعامل المرونة يزدادان بعد الزحف لكن هذه الزيادة تتأثر بمحتوى الاسمنت، من ناحية اخرى وجد في هذا البحث ان نموذج التربة المثبتة يفشل بمستوى اجهاد اقل من المستوى المحدد للفحص ويعرف هذا المستوى بـ(مستوى الاجهاد الحرج) كذلك وجدت زيادة قليلة في هذا المستوى مع زيادة محتوى الاسمنت. أخيراً اظهرت النتائج وجود علاقة خطية بين لوغاريتم الزمن ولوغاريتم معدل الزحف، وميل هذه العلاقة لا يعتمد على مستوى الاجهاد. انفعال الزحف يقل بسرعة مع لوغاريتم معدل الزحف للنموذجين 0% و4% محتوى الاسمنت بينما لوحظ تغيير غير مؤثر لخصائص الزحف للنموذجين 8% و12 % محتوى الاسمنت.

الكلمات المفتاحية: التربة السمنتية، الفحص ثلاثي المحاور، التربة الطينية، الموديلات المختبرية ومستوى الاجهاد

Introduction

Soil-cement has been used very extensively in the construction of pavement of various types, such as modern highways, parking lots, air fields, urban streets and successfully used as a base course in many cases including low cost roads, platforms, and warehouses.

In Iraq, stabilization of soil with cement may be useful and economic to improve the engineering properties of the soil, so that it can modify to be more practical for construction (Al- Hashimi and Chaplin, 1973).

Time effect on soil behavior may take variety of forms, one of this is creep, which is defined as the strain under a sustained stress; and stress relaxation (variety in stress with time at constant strain) (Lambert *et al*., 2012).

Studies of the effect of time on stress-strain behavior are valuable in understanding the fundamental mechanisms contributing to the shearing resistance of cement-stabilized soils (Lambert *et al*., 2012, Zhang, *et al*., 2015).

Some soils may fail under a sustained creep stress at a value significantly less than the peak strength measured in an undrained test, this is termed as a creep rupture or creep strength loss (Osterberg, 1970 **,** Prevost, 1976; Karstunen, 2010).

The time-dependent deformation and stress relaxation in soils are important in a variety of geotechnical problems where long time behaviors are of concern (Mitchell, 1976 and Degago, 2014**)**. However, there is only limited information on the creep behavior of soil-cement which lacks generality (Bofinger, 1970, George, 1969). Al- Hashimi and Chaplin (1973) stated that at low rate of loading the creep strains in the cementing material are limited by the granular material. The creep behavior of cement-stabilized soils had been studied by many investigations (Bofinger, 1970 and George, 1969), but the available information does not cover the entire subject sufficiently and there are some contradictions in the results.

Gorge (1969) conducted a series of creep tests to study the viscoelastic properties of soil-cement in relation to shrinkage cracking of pavement layers. He concluded that creep is higher for lower relative humidity.

Bofinger (1970) studied the tensile creep behavior of 6% cement stabilized heavy expansive clay to evaluate its effect on shrinkage stresses.

In this study, some factors affecting the stress-strain –time behavior of soil-cement are investigated and analyzed through correlation of test results. Some indications are obtained serving in understanding the general behavior of such materials and helping in reducing maintenance costs.

Materials and Methods

Experimental Work

Soil Used

The soil used throughout this study was brown silty clays was brought from Al-Nasiriya city from a depth of 2 m According to the AASHTO classification systems, the soil is classified as A-7-6 and according to the Unified soil classification systems, soil is CL. Table (1) showed the physical properties of the soil used and Figure (1) showed the grain size distribution. While Table (2) showed the chemical properties of this soil **.**The cement used was Portland cement type one. All the experimental work and tests were carried out at the "**National Center for Construction Laboratories and Research**".

Table (1) Physical Properties of the Soil

Specific gravity	Liquid limit (%)	plastic limit (%)	Plasticity index (%)	Max. dry density (KN/m^3)	Optimum moisture content (%)
2.7	46	23	23	18.1	19.6

Table (2) Chemical Properties of the Soil

pH value	Organic matter content (%)	Total soluble salts (%)	Total SO_3 (%)	Gypsum $CaSO_4.2H_2O$ (%)
6.7	1.2	2.93	1.5	0.28

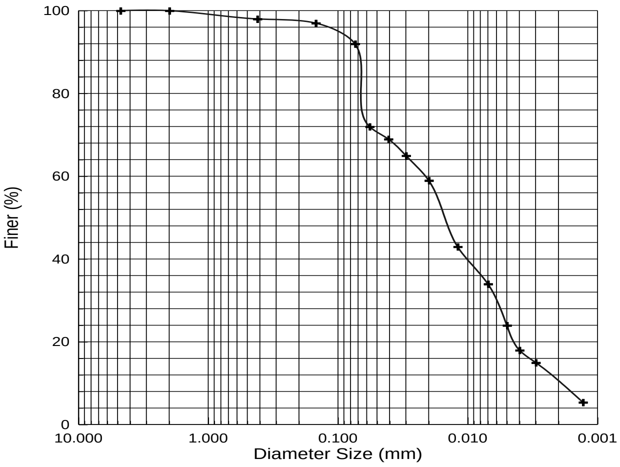


Figure (1) Grain Size Distribution of the Soil

Preparation of the Samples

The modified proctor according to ASTM (D1557) was used during the experimental work. A model hammer and mold was used to prepare specimens of 50mm in diameter and 100mm in height according to ASTM (D1632).

Before conducting the compaction test, the required percentage of cement content was determined according to AASHTO classification as shown in Table 3, in this study the range of cement content was 4, 8 and 12%. soil and cement content were mixed with optimum moisture content which has been determined already for about ten minutes by mixer. The mixture was compacted in the mold in 5 layer with 36 blows per each layer were required in order to give a compaction effort equivalent to the modified proctor compaction. Figure (2) showed the compaction curve for soil using the model compaction. Table (4) showed the results of compaction test for different cement content. The reduction in dry density is a result of flocculation and agglomeration of fine grained soil particles which occupies larger space leading to a corresponding drop in maximum dry density. It is also the result of initial coating of soils by cement to form larger aggregate, which consequently occupy larger spaces.

The specimens were removed from the mold weighed, wrapped in plastic sheet and placed in container at room temperature then tested after curing period of 14 days to minimize the effect of strength gain and thixotropic on creep tests.

Table(3) Normal Range of Cement Requirements Soils

AASHTO Soil Group	*Cement (percentage by weight of soil)*	*Cement (pounds per cubic foot of compacted soil cement)*	*Cement (kilograms per cubic meter of compacted soil cement)*
A-1-a	3–5	5–7	80–110
A-1-b	5–8	7–8	110–130
A-2-4, A-2-5, A-2-6, A-2-7	5–9	7–9	110–140
A-3	7–11	8–11	130–180
A-4	7–12	8–11	130–180
A-5	8–13	8–11	130–180
A-6	9–15	9–13	140–210
A-7	10–16	9–13	140–210

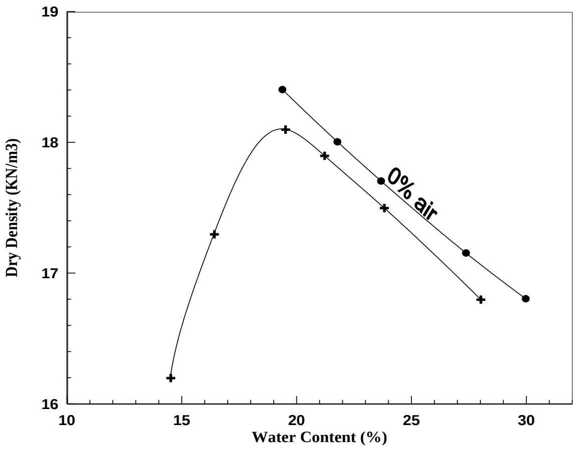


Figure (2) Compaction Curve of the Soil

Table (4) Maximum Dry Density and Optimum Moisture Content.

Cement content (%)	Optimum moisture content (%)	Max. dry density (kN/m^3)
0	19.6	18.1
4	19.1	17.6
8	18.7	17.2
12	18.3	17

Only two specimens from each batch were made at a time as any delay between mixing and compaction may affect the compaction level and the dry density obtained.

Testing

Stress Controlled

The triaxial compression machine was employed in the testing program. The applied load was calculated as the desired percentage of the 14 days undrained compression strength obtain from unconsolidated undrained test (UU) was applied directly by means of dead weight on a hanger which was supported by the arm as shown in Plate (1). A constant cell pressure of 150 kN/ m^2 was applied for all tests that corresponding to the range of stresses relevant to site condition, the membrane used in all test provide commercially from scientific office. For each cement content (4, 8 and 12%), three stress levels were applied (60, 75, 85%) these levels represented as percentage from strength of soil. The load was maintained for 25 hours (1500 min.), and then the specimens were load until failure.

Plate (1) Triaxial Test Machine.

Results and discussion

Analysis of the Results

Creep Time Relation

Figure (3) showed the relations between creep strain and logarithmic of time. The relations indicate that linear relations exist under sub failure stress level for each cement content investigated. The slope of these lines is shown to be steeper for the lower cement contents and higher stress levels. This is because the failure is approached earlier at 85% stress level. Also the relation indicate the existence of certain stress level which leads to failure, this stress level is the critical stress levels. For soil specimen the failure criterion adopted which assumes failure to occur at 10% axial strain. Under stress level of 85% the axial strain at (65 min.) after creep loading became 10% and the test was terminated. For specimens with 4, 8 and 12% cement contents, failure was found to occur at stress levels of 87, 89and 90% respectively.

At higher cement contents, lead to a little increase in critical stress level. This could be due to an increase in cement content which makes the specimen less susceptible to what is called creep strength.

Therefore, it could be concluded that, there is a particular stress level below which a soil-cement specimen will not fail under the applied load.

Typical relationship for cement stabilization silty clays soil under 60% stress level present by Wang and Lee (1973) the relations indicates some similarity with arrived results of this study. Their results, along with that of George, (1969) indicate that the relations proceeded without abrupt changes up to time duration of (10000 and 7200 min.) respectively. Creep versus logarithmic time relations are not available.

Values of the critical static stress levels for cement stabilized soils are not available in the previous study and hence no comparison can be made with the test results of this study.

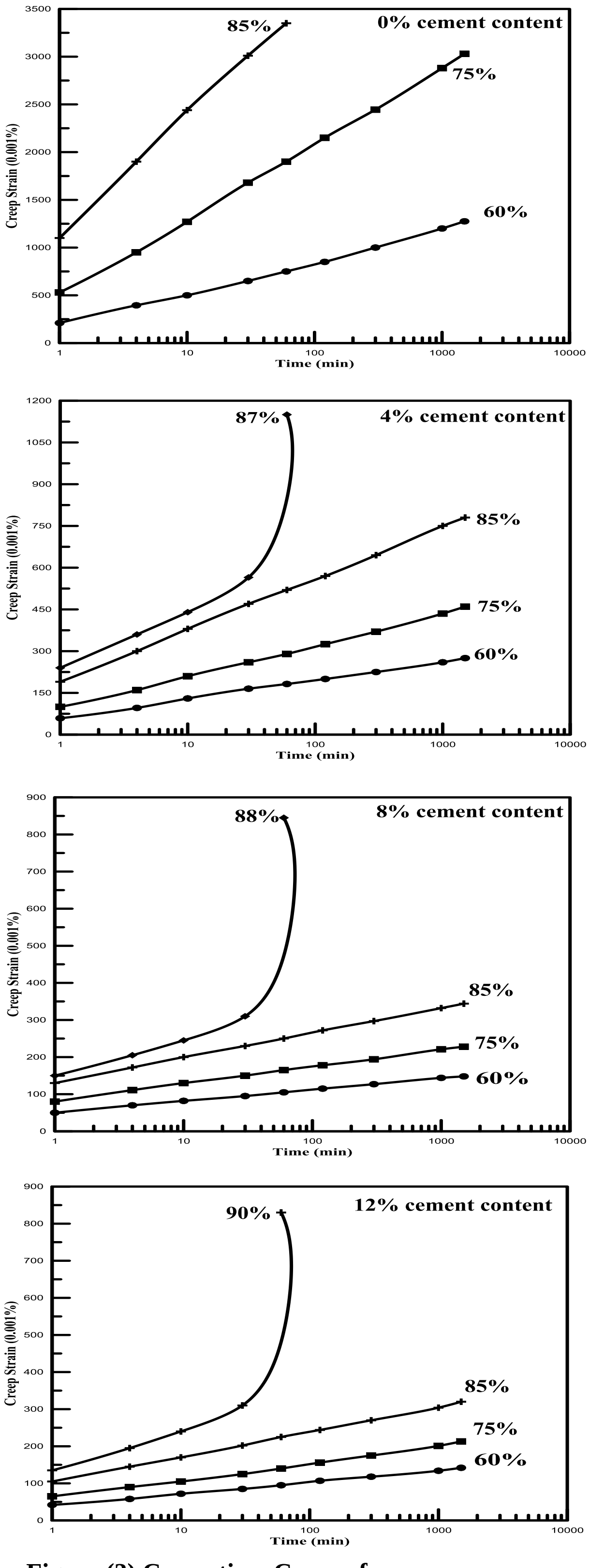


Figure (3) Creep-time Curves for Different Cement Content.

Effect of Stress Level on Creep

The variation in creep strains with applied stress level under different cement contents is presented in Figure (4). The relationships are generally nonlinear. However the curves indicate the critical stress levels are approached; higher increase in creep takes place.

The relation for the case of 0% cement content presented the time duration to failure is (60 min) , this is due to no result were obtained for (300 and 1500 min.) under 85% stress level as the test were terminated after this time.

For the case of 8% cement content ,the relation does not indicate any increase in creep at the critical stress level because the failure was not impending after (10 min.) from the start of creep. The effect of the critical stress level on creep is well indicate in case of 12% cement content for creep duration (30 min.).

Wang and Lee (1973) presented a nonlinear relationship for soil-cement specimens between creep and stress level up to a stress level of 60%. Behavior at higher stress level was not studied by them.

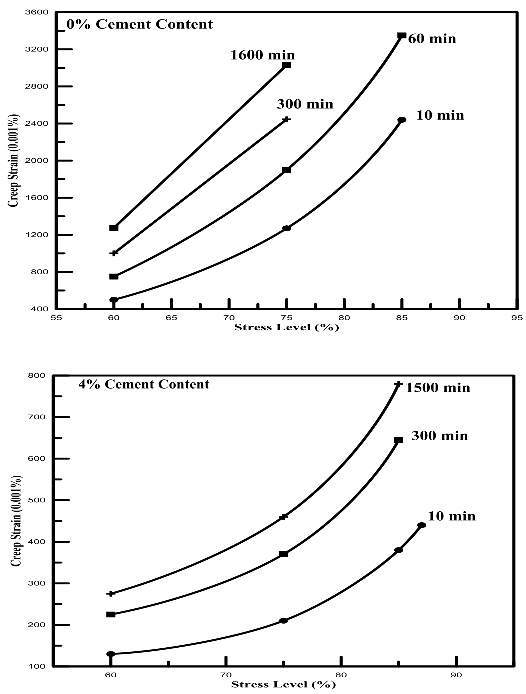
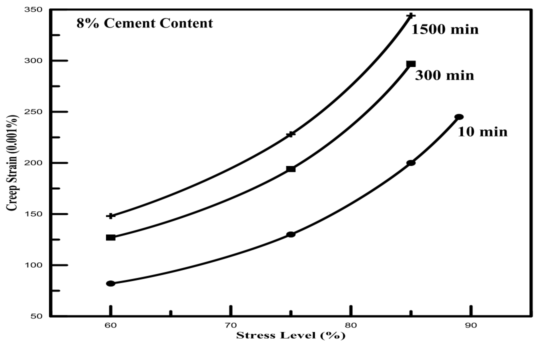
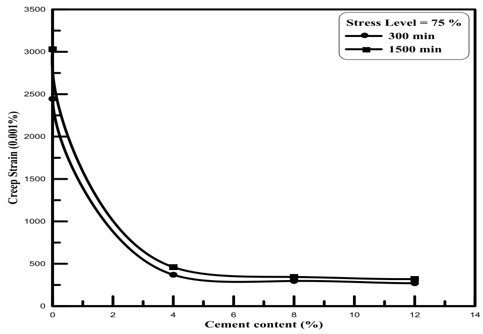


Figure (4) Relation of Creep Strain with Stress Level.





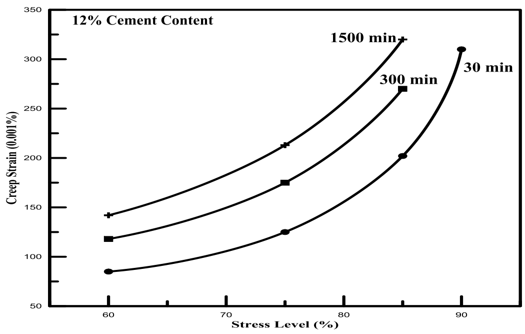


Figure (4) Continued.

Effect of Cement Content on Creep

It is observed from Figure (5), creep values decreased considerably as the cement content increases from 0 to 4% up to cement content of approximately 6% the rate of creep decrease becomes less pronounced while between 6% and 12% cement content insignificant decrease in creep strain is indicate. This behavior appears may be attributed to change in the structure of the specimens by the addition of cement and change in the mechanism of the creep. The results reported by Wang and Lee (1973) are shown similar relation.

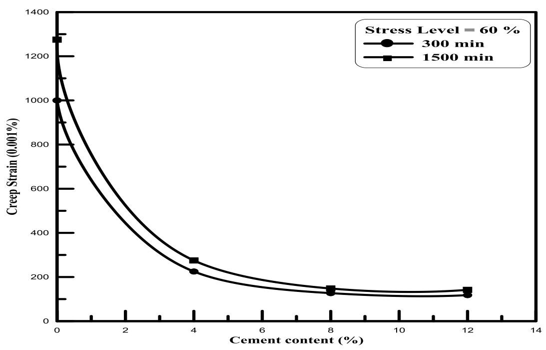


Figure (5) Effect of Cement Content on Creep

Figure (5) Continued

Effect of Creep on Strength and Secant Modulus (E)

The deviator stress at failure was found to increase after the specimen had crept for all tests conducted stress levels. Figure (6) showed this increases as affected by cement content, comparison in strength was based on (14-day) of deviator stress at failure. The increases in strength believed to be the result of a strain hardening (strengthening) process as illustrated by several researchers (Abdulla, 1983**;** Pusch, 1980**,** Ter-Stepanian, 1968). Also it can be noticed that the rate of increase in strength becomes less pronounced between 8% and 12% cement content and approximately little effect after 12% cement content. Figure (7) showed the increases in E which was found to be higher for lower cement contents and higher stress level. This may be attributed to that higher stress level create more changes in the specimens structure by causing more densification to cracks and the decrease in particle spacing (Lambert et al., 2012).

The increase in strength and E for soil specimens did not included in Figures above because soil sample when loaded after creep failure occur before the complete effect of creep.

Strength increases for soil- cement due to creep and repeated loading was also reported by many investigators (Wang and Lee 1973, Bofinger, 1970; George, 1969).

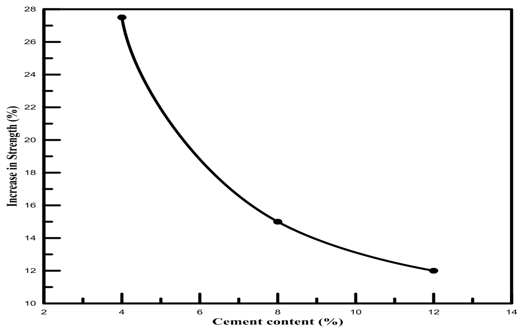


Figure (6): Effect of Cement Content on Strength

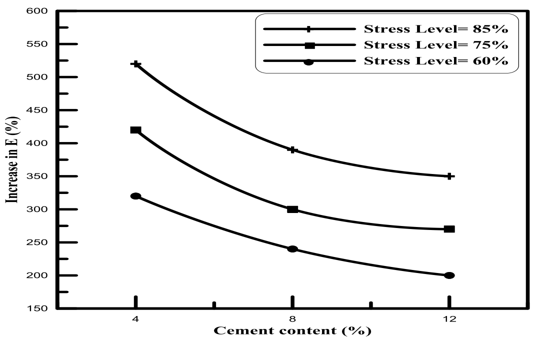


Figure (7) Effect of Cement Content on Modulus of Elasticity.

Creep Rates Time Relation

Creep rates are defined as the change in creep strain per unit time. Creep strain rates at various values of time may be computed graphically or mathematically. In this study creep rates were computed mathematically to obtain more accurate values. From the test results in Figure (3), the creep time relation can be expressed by the relation:

$C_s = A + B \log(t)$ ……. (1)

Where:

C_s = creep strain

A & B = constant

log (t) = logarithm of time

The creep rate (C_r) at any time is:

$C_r = C_s / t$ …… (2)

The typical relations are presented in Figure (8), linear relations appear to exist between the logarithm of creep rate and logarithm of time for sub failure stress levels. Generally, the slope of these relations seems to be independent of the applied stress level and cement content.

Linear relations were also reported by Wang and Lee (1973) under stress level between 5% and 60% for a silty soil stabilized with 6% cement.

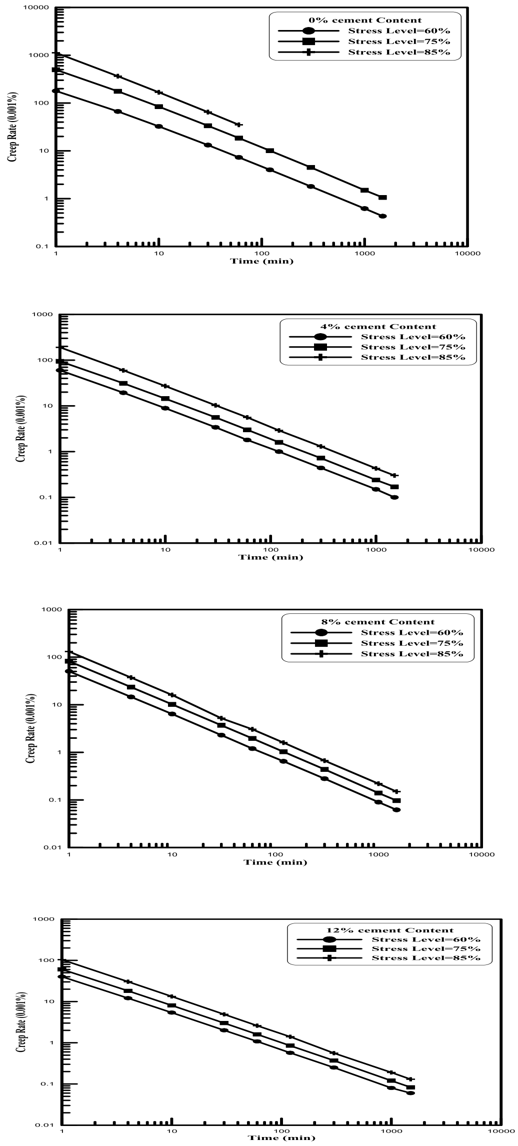


Figure (8) Relation of Creep Rate- time.

Effect of Stress Level on Creep Rate

Typical effect of stress level on the logarithm of creep rate at various durations is shown in Figure (9); linear relations appear between creep rate and stress levels. The slope of these lines was found to be depended on the cement content only irrespective of creep rate duration. Singh and Mitchell (1968) stated that these slope indicates the stress level effect on creep rate, which reflects composition, structure, and stress history of the soil.

Wang and Lee (1973) reported similar relations for stress level between 5% and 60%, but Mitchell presented nonlinear relations at low stress levels for untreated soil.

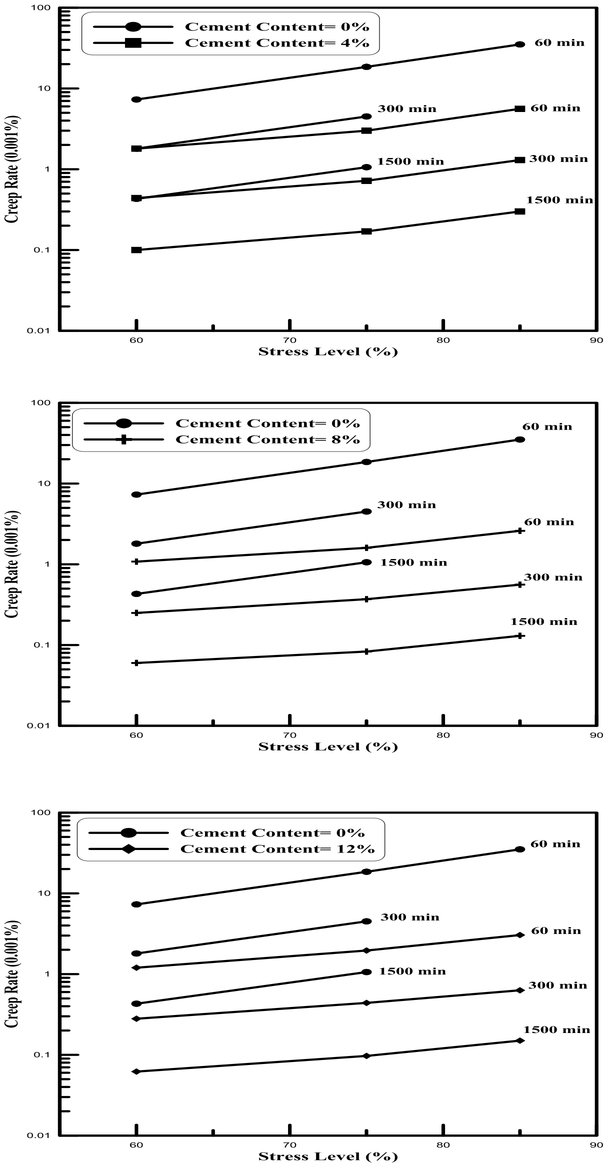


Figure (9) Effect of Stresses Levels on the Creep Rate of Creep Rate – time

Effect of Cement Content on Creep Rate

Figure (10) illustrated the relation between creep rate and cement content. The figure indicated that creep rate decrease with an increase in cement content ,the change seems to be rather high between 0% and 4% cement content and steeper relation appear. For higher cement content, the decrease in creep rate is smaller and the relations indicate little variation in creep rates.

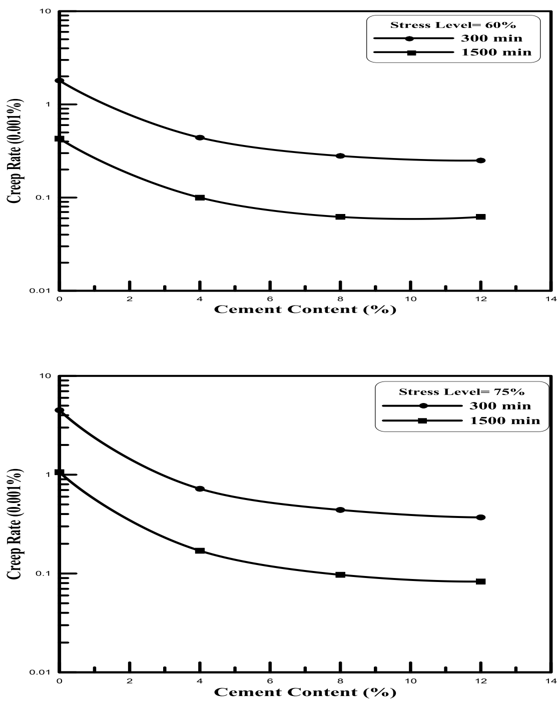


Figure (10) Effect of Cement Content on Creep Rate

Conclusion

1. Linear relations were obtained between creep strain and logarithmic time under subfailure stress levels.
2. A nonlinear relation holds between creep strain and stress level. There is particular stress level below which a soil-cement sample will not fail, this is termed as a critical stress level which was found to increase with a decrease in creep rate. Increasing the cement content cause a little increase in the critical stress level.
3. The critical stress level is little affected by the rate of creep.
4. creep values decrease considerably as the cement content increase from 0 to 4% up to cement content of approximately 6% the rate of creep decrease becomes less pronounced while between 6% and 12% cement content insignificant decrease in creep strain is indicate
5. Creep causes an increase in compressive strength; the rate of increase in strength becomes less pronounced between 8% and 12% cement content and approximately little effect after 12% cement content.

6. Secant modulus increase with creep and it was found to be higher for lower cement contents, higher stress level.
7. The increase in strength and E for non-treated soil specimens was not compute because soil sample when loaded after creep failure occur before the complete effect of creep.
8. A linear relationship was observed between logarithmic creep rate and time. The slope of this relationship is independent of stress level.
9. Creep strain and logarithmic of creep rate decrease rapidly between 0% and 4% cement content while insignificant changes in creep properties occur in specimens with 8% and 12% cement content.
10. Linear relationship appear between the logarithmic of creep rate and stress level, the slope of this relationship was found to be independent on creep rate duration.
11. Creep rate decrease with an increase in cement content ,the change seems to be rather high between 0% and 4% cement content and steeper relation appear.
12. For higher cement content, the decrease in creep rate is smaller and the relations indicate little variation in creep rates.

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