OPEN ACCESS

Indian Journal of Structure Engineering (IJSE)
ISSN: 2582-922X (Online), Volume-2 Issue-1, May 2022

Study of the Strain-Stress Behavior of the loess Soil and Its Numerical Modeling by ABAQUS

Ali Al-abdullah, Najla Al-hassan, Mohammad Eid

Abstract: ***This research aims to conduct a laboratory study to clarify the behavior of creep in Loess soils with the change of moisture content and applied stress. Soil was brought from Joseh area (southwest of Homs city), and its main properties were determined, after that a series of tests (time dependent deformation) were carried out for the Loess soils within the unconfined compression test. The results showed that the change of moisture content and applied stress on sample have a significant effect on the properties of Creeping of Loess soils, and the deformations that occurred are instantaneous deformations at the moment of load application, and creep deformations that begin with the passage of time. Creep deformations can be divided into three stages: primary creep, stable creep, and accelerated creep. The deformations were evaluated using the Singh-Mitchell theory, and the results showed that the Singh-Mitchell theory fits well the description of deformations over time for Loess soils, where the relative error between the largest and smallest value did not exceed 15%.ABAQUS program was used to numerically describe the creep behavior of Loess soils using the Singh-Mitchell theory .The results showed that the Singh-Mitchell theory within the ABAQUS program gave more accurate values than the computational Singh-Mitchell theory, and the reason is that because of the program contains multiple parameters that describe well the properties of elasticity, plasticity and viscosity for any natural body.***

Keywords: Creep, Unconfined Compression Test, Abaqus, Singh-Mitchell

I. INTRODUCTION

Creep deformation: It is the process of continuous deformation with time under the influence of a constant load. Many materials have the ability to deform, starting from colloidal solutions, polymers, and ending with rocks [1]. When testing ideal bodies, the theory of elasticity and classical plasticity assumes that the forms of deformation resulting from combined stress and resulting from simple stress are symmetrical, while in real bodies, the relationship between stress and deformation is nonlinear, and given that soil is a heterogeneous body, the understanding of its rheological properties is A rather complex problem [1]. The loess soils occupy about 10% of the world's area and are spread in Syria in the Euphrates region and along the Al-Assi River and in the Masyaf area. They are windy sediments consisting mainly of silt particles with small amounts of sand and clay. These soils are characterized by high sensitivity to water and high porosity, despite that, they have good mechanical resistance in their dry state, and when wetting them, their structure collapses rapidly, causing a large settlement of structures [8].

The main problem that these soils suffer from is that their deformations are much larger than the elastic deformations and therefore cannot be predicted using the theories of elasticity and traditional plasticity. There are several main things that affect the deformation values including moisture, applied stress, temperature and mineral composition. The deformations that occur are the result of volume changes during humidification on the one hand, and the settlement that occurs with the passage of time on the other hand. In most cases, the result is either a total settlement of the origin or a differential settlement. In addition these soils were one of the main reasons that led to the occurrence of landslides considering that landslides are a process in which the sliding mass is continuously modified with the passage of time under the influence of gravity and external forces [2] [7], by collecting information about these problems shows that the occurrence of these problems is closely related to creep behavior.

Previous studies have shown that the strength, deformation and stability of loess soils are affected by the passage of time, showing a series of time-related properties:

[11] The unconfined compression test was used to study the creep deformations of the frozen clay soils and the frozen silty soils, explaining the effect of low temperatures on the creep deformations of these soils the results indicated that the deformations over time for these soils decrease with a decrease in temperature, stressing that the temperature has a significant impact on the creep deformations of the soils, according to the soil type.[10] The creep properties of loess soil were studied in one dimensional consolidation test (odometer) on undisturbed samples and remolded samples under different moisture contents and different loading conditions, and it was possible to reach at a mathematical model describing creep deformations in terms of time and applied stress.[9] The creep properties of loess subsidence soils were studied using a three-axis shear device with different moistures and confining stresses.

Manuscript received on 29 March 2023 | Revised Manuscript received on 05 April 2023 | Manuscript Accepted on 07 April 2023 | Manuscript published on 30 April 2023.
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Retrieval Number: 100.1/ijse.A75730512123
DOI: 10.54105/ijse.A7573.052122
Journal Website: www.ijse.latticescipub.com

Published By:
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The results showed that confining pressure and water content have a significant influence to some extent on creep properties, as creep deformation increases with increasing moisture under constant confining pressure, while creep deformation decreases with increasing confining pressure under constant moisture. The importance of this research is to provide a clear vision about the change of deformations over time for the loess soil under the influence of different values of moisture and for different values of stresses.

II. RESEARCH SIGNIFICANCE

The importance of this research is to provide a clear vision about the change of deformations with time for the declining soil under the influence of different values of moisture and for different values of stresses.

III. RESEARCH MATERIALS AND METHODS

Soil samples (earth blocks) were brought from Joseh area, southwest of Homs Governorate and the samples were extracted using traditional drilling tools at a depth of (60 cm) in the form of cubes. The samples were wrapped in tightly closed nylon bags and transferred to the Soil Mechanics Laboratory at Al-Baath University - Homs Governorate. The experimental method in this research is divided into two stages:

The first stage was to determine the physical and mechanical properties of a undisturbed soil according to the [ASTM] system by conducting experiments (specific gravity, unite weight, granular analysis (sieves and sedimentation), Atterberg limit, shear .... ..) Soil was classified according to the USCS [3] [5] [4]. Table (1) shows the main properties of the studied soil. The second stage included studying the creep behavior of loess soil within the unconfined compaction apparatus for different values of moisture and different stresses.

IV. EXPERIMENTAL STUDY

A. Sample Preparation

The soil blocks were divided into four groups so that each group will have a different moisture content. In order to prepare samples with a moisture content less than the moisture content of the original soil, the blocks within this group were dried by air at laboratory temperature to reach the required wet weight. As for preparing samples with a moisture content Moisture greater than the moisture content of the original soil. The samples were moistened by wrapping the blocks with a cloth to preserve the soil structure and placing them in a water basin for 48 hours.

Then the samples (earth blocks) were extracted and divided into three groups, each group will have a different moisture content. The moisture content of each group was adjusted by drying the soil pneumatically and at the laboratory temperature to reach the required wet weight, to ensure the homogeneity of moisture for the four groups, the mass was kept in a wet sampling container for seven days for moisture homogeneity. The moisture content of the four groups was adjusted with the following values (ω=5,8,12,16%), then the unconfined compression strength of the four groups of cylindrical samples from each group was determined with sample dimensions (H=8cm, D=4cm) and a loading speed (0.5 mm/sec) as shown in Figure (1) and Figure (2) Table (2) shows the value of the unconfined compression resistance of the previous groups.

As for the study of creeping behavior, a device called the Uniaxial Compression Test was used, which is very similar to the mechanism of the previous unconfined pressure device, except that it is characterized by a slight difference, which is the possibility of making the sample subjected to constant stress throughout the experiment period. As for the previous device, it needs constant monitoring to ensure the stability of the load, the following figures (3), (4) illustrate the working mechanism of the used device, and the samples were wrapped with a latex membrane to maintain the samples' moisture throughout the experiment period. [6].

B. Strain-Time Curves

Deformation experiments with time were carried out using the previously described unconfined compression test on undisturbed samples of loess soils,the samples were divided, as mentioned earlier, into four groups, where each group corresponds to a specific initial moisture, which is, respectively, ω=(5,8,12,16)%,with a latex membrane to keep the sample moist during the experiment.

The experiment was conducted on undisturbed samples with a dry unite weight $\gamma_d = 1.55\ gr/cm^3$ a series of stresses were applied to each of the previous groups ($\sigma = 0.5, 1, 1.5, 2, 2.5, 3.5\ kg/cm^2$) (the load remains constant throughout the experiment period) and then the deformations were measured with time.

Due to space constraints, we will report results for 8% and 16% moisture content and for different values of the aforementioned stresses.

The following figures (5), and figures (6) show the change of deformation of the loess soils with time at moisture content ω=(8.16)% and from different values of stresses.

It can be seen that creep curves of loess soils have the following characteristics:

1. The deformation that occurred are the sum of two limits, instantaneous deformation that occur at the moment of applying the load and are symbolized by $\varepsilon(0)$, and deformation with time $\varepsilon^{-}(t)$ are called creep deformation.
2. The creep deformation consists of three stages:

The first stage is called the primary creep stage, where the creep rate decreases until it reaches a fixed value, then the second stage begins, which is the stage of stable creep, where we call the deformations of the creep deformations of the decreasing creep. As for the third stage, the accelerated crawl stage, this phase begins when the creep rate returns to the increase these deformations are called viscoelastic-plastic distortions. The general formula for distortions with time can be written as follows:

$$\varepsilon(t) = \varepsilon(0) + \varepsilon_{I}^{-}(t) + \varepsilon_{II}^{-}(t) + \varepsilon_{III}^{-}(t) \quad \dots\dots\dots\dots (1)$$

3. Each curve within the stable creep phase has a line slope related to the applied stress value and the sample moisture content. When low stress and low moisture content are applied, the slope value is low and the slope value increases with increasing stress value and moisture content.
4. When the sample enters the accelerated creep stage, the sample fails within a relatively short period, so we can say that the accelerated creep stage is relatively short compared to the stable creep stage

The creep deformations we obtain are irreversible plastic deformations, and the relationship between creep deformations and stresses is non-linear, and accordingly a mathematical formula has been proposed to express the creep deformations that occur with time as follows:

$$\varepsilon_{sl} = c * (t+1)^{\alpha} \dots\dots\dots (2)$$

The constants α,c are called creep constants and we get their value by plotting the laboratory results of creep deformations with time with a set of logarithmic coordinates in which y axis is (ε_{sl}) and x axis (t+1) as shown in Figures (7) and (8).

The slope of the lines represents the value of the constant α, and the intersection of the lines with y axis represents the value of the constant c. In Table (3) the values of the creep constants mentioned in relationship (2) and from this table it can be noted that the value of the constant α is almost constant and ranges between (0.26-0.2) .

As for the constant c, it was found from the table that its value is related to the stress applied to the sample as well as the approved moisture, as its value increases with the increase in the stress applied to the sample and with the increase in moisture.

C. Stress-Strain Curves:

To show the effect of applied stresses on deformations over time in loess soils, the relationship between deformations and applied stress values for different times (t = 1,3,9,11,18 day) was drawn, and the results were as shown in Figures (10), (811 For a moisture content of ω=(8.16)%.

The results of the (stress - strain) curves show that the curve is taking an increasing shape, that is, the creep deformation increase with the increase in applied stress and with the increase in time the value of the strain increases and this indicates the presence of a variable function that increases with the increase in time. When the moisture content increases, the relationship between (stress - strain) with time becomes more clear. A point of inflection of the curve towards the strain axis is evidence of the sample entering the accelerated creep phase, viscous, plastic deformation.

The relationship between stress and strain remains linear at low times and for different values of moisture, and with increasing time the nonlinear relationship becomes more clear.

A mathematical equation has been proposed to express the effect of applied stress on the creep deformations of loess soils:

$$\varepsilon_{sl}(t) = \xi e^{\kappa\sigma} \dots\dots\dots (3)$$

To determine the values of the constants κ, ξ, we draw the relationship between the logarithm of strain and stress in a system of semi-logarithmic coordinates, where the y axis is in the logarithmic scale, and the x axis is in the ordinary scale.

The constant κ represents the slope of the line, and the constant ξ is the intersection of the line with the y axis. The occurrence of points on the same line as shown in the following figures (11), (12) indicates that the relationship (3) expresses well the development of creep deformations with the change of applied stresses.

D. Evaluation of results according to the Singh-Mitchell theory:

Based on the general relationship of deformation with time:

$$\varepsilon(t) = \varepsilon_0 + \varepsilon_c^{\cdot}$$

where (t): : the total distortions at a moment in time t.

ε_0: are the instantaneous deformation, $\varepsilon_0 = \frac{P}{E_0}$

$\varepsilon_c^{\cdot}$are distortions with time.

Singh-Mitchell suggested a time function to describe creep deformations in soils [13]:

$$\varepsilon_c^{\cdot} = \frac{A * t_1}{1-m} . e^{\alpha * P} . \frac{t}{t_1}^{1-m}$$

P is the applied stress.

t_1: is the reference time $(t_1 = 1\ day)$) is always equal to one of one time.

A, α and m $(m \neq 1)$ are all typical parameters that we define in the following way:

The equation takes the following final form:

$$\varepsilon(t) = \frac{P}{E_0} + \frac{A}{1-m} . e^{\alpha * P} . t^{1-m} \dots\dots\dots (4)$$

We define the creep constants mentioned in relationship (4) according to the following steps:

$$\varepsilon_c^{\cdot} = \frac{A}{1-m} . e^{\alpha P} . t^{1-m} \dots\dots\dots (5)$$

At a moment in time $t = 1$, equation (5) takes the following form:

$$\varepsilon_{c\,t=1}^{\cdot} = \frac{A}{1-m} . e^{\alpha P} \dots\dots\dots (6)$$

We take the logarithm of both sides:

$$\ln \varepsilon_{c\,(t=1)}^{\cdot} = \ln(\frac{A}{1-m}) + \alpha * P \dots\dots\dots (7)$$

By plotting the relationship between $\ln \varepsilon_{c\,(t=1)}^{\cdot}$ and the applied stress at time t=1, we get a line with slope α.

Plotting the relationship between $log\ \varepsilon_c^{\cdot}$and $\log t$ where (t represents the creeping time) at each moisture content of the studied soil, so we get for each ratio a slope that represents the constant m and an intersection with the hierarchical axis from which the constant A is determined. In Table (6) and Table (7) values Parameters A, m, α and values of the instantaneous modulus of elasticity E_0.[13].

The following figures (13), (14) show the values time depended strain for the loess soils, where the continuous part represents the values received from the experiment and the dotted part represents the calculated values received from the relationship (4). [13].

The convergence of the values makes us conclude that Singh-Mitchell's theory of fits the description of the deformations that occur in the loess soils with time, as the relative error between the largest and smallest value did not exceed 15%.

E. Numerical Modeling of Creeping Behavior:

Numerical modeling depends on the idea of finite elements, by dividing the material to be studied into finite-dimensional parts so that the behavior of these small elements can be described individually, and then deducing the behavior of the material by direct assembly of its parts by numerical solution to a set of differential equations subject to appropriate boundary and elementary conditions, which control Or describe the behavior of the elements resulting from fragmentation, that is, numerical modeling depends on the idea of fragmentation analysis and then aggregation. ABAQUS 6.14-2 program was used in this study to describe the deformations of loess soils over time. [12].

1. Rheological behavior of the loess soils within the ABAQUS program:

To study the rheological behavior of loess soils within the ABAQUS program, we will use the Drucker-Prager plastic model and choose the Singh-Mitchell theory, knowing that each model will be expressed with its characteristics (unite weight, modulus of elasticity, properties of plasticity, and.....) and each model will be applied to it. Stresses equal to the previous stresses.

A 3D numerical soil model was adopted, and the C3D8 element was used, which is a solid body (SOLID ELEMENT) that has eight nodes and each node has three degrees of freedom (3 transitions). After creating the model, we create imaginary partitions in the model to facilitate the calculation of distortions (Fig. 15)

Note that the friction angle of the model was found from the direct shear experiment with a shear speed (0.5mm/min) for the two models, while the volumetric expansion angle was imposed so that θ=φ/3.

Creating the stages of work Step: The stage of work is divided into three stages:

- Initial: The initial stage, and within this stage all the previous steps (drawing the model, entering properties, creating and configuring the model) fall.
- As for Step1, Step2 will include the download stages:
- Stage Step 1: It will be Static/General. We choose stage time=1-6.

At this stage we will describe instant defamation at 1-6 time.

- As for the stage Step2: it will be of the Visco type and we choose the duration of the stage time=18.

In this stage, we will describe the creep defamation of the soil over a period of 18 days. Fig (16)

After that, the terminal conditions of the model were fulfilled, considering that the sample is reliable from one end and freed from the other. After setting the terminal conditions, the load is applied to the upper surface of the sample, while the lower part is reliable and prohibited from moving.

Figure (17) shows the shape of the finite element network and Figure (18) shows the shape of the three-dimensional model after the passage of time 18 for the first model, while Figures (19), (20) illustrate the results of numerical modeling with a comparison with the values of deformations calculated from the Singh-Mitchell theory.

It was found through the previous curves that the use of Sing Mitchell's theory within the ABAQUS program using the plastic behavior Drucker-Parger gave more accurate values than Sing Mitchell's theory, and we can give an explanation for this that the ABAQUS program is characterized by containing multiple parameters that describe well the properties of elasticity, plasticity and viscosity of any natural body.

F. Figures and Tables

- **Tables**

Table (1): Basic physical and mechanical properties of soil

Joseh		Site
7.8	$\omega\%$	Water content
1.67	$\gamma_b\ gr/cm^3$	Bulk unite weight
1.55	$\gamma_d\ gr/cm^3$	Dry unite weight
2.7	G_s	specific gravity
1.79	$\gamma_{d\,max}\ gr/cm^3$	Max Dry unite weight
16.8	$\omega_{opt}\%$	water Optimum content
0.7419	e_0	Void Ratio
28.38	sr %	Saturation Degree
27.8	LL %	Liquid limit
17.4	LP %	Plastic limit
10.4	PI %	Plastic index
24.6	$s\%$	sand
52.6	$M\%$	silt
22.8	$C\%$	Clay
24	φ	Internal friction
0.46	$c\ kg/cm^2$	cohesive
CL	USCS	Classified soil

Table (2) Unconfined compression strength of samples

Dry unite weight gr/cm^3	Water content $\omega\%$	Unconfined compression shear test $UCS(kg/cm^2)$
1.55	5%	5.8
	8%	5.5
	12%	4.9
	16%	4.2

Table (3) The values of creep constants α, c given in the relationship (2)

$\sigma\ kg/cm^2$	$\omega = 8\%$		$\omega = 16\%$	
	c	α	c	α
0.5	**0.72**	**0.203**	**1.3**	**0.23**
1	**1.08**	**0.213**	**2**	**0.24**
1.5	**1.6**	**0.219**	**2.876**	**0.245**
2	**1.97**	**0.223**	**4.2**	**0.51**
2.5	**2.75**	**0.227**	**5063**	**0.254**
3.5	**5.55**	**0.232**	**10.81**	**0.258**

Published By:
Lattice Science Publication (LSP)

Indian Journal of Structure Engineering (IJSE)
ISSN: 2582-922X (Online), Volume-2 Issue-1, May 2022

Table (4) values of creep constants α, c given in the relationship (3)

Time	ω = 16%		ω = 8%	
	ξ	κ	ξ	κ
1 day	0.6	0.676	1.08	0.703
3 day	0.721	0.685	1.33	0.724
9 day	0.827	0.69	1.46	0.752
11 day	0.886	0.71	1.69	0.755
18 day	0.91	0.715	1.85	0.76

Table (5) Characteristics of the first model with a moisture content of (8%)

γ_b	ω	μ	φ	ψ	σ=kg/ 〖cm〗 ^2	E=kg/ 〖cm〗 ^2	Creep Parameter		
							A	α	m
1.67	8%	0.3	24	8.6	0.5	71.43	0.000428	0.0764	0.59
					1	96.15	0.000431	0.0766	0.57
					1.5	100	0.000433	0.0769	0.54
					2	96.15	0.000436	0.0717	0.5
					3.5	63.06	0.000441	0.0774	0.47

Table (6) Characteristics of the first model with a moisture content (16%)

γ_b	ω	μ	φ	ψ	σ=kg/ 〖cm〗 ^2	E=kg/ 〖cm〗 ^2	Creep Parameter		
							A	α	m
1.8	16 %	0.3	22	7.3	0.5	38.4	0.00081	0.078	0.078
					1	50	0.00083	0.081	0.081
					1.5	52.1	0.00085	0.083	0.083
					2	50	0.00086	0.086	0.086
					3.5	32.56	0.00089	0.089	0.089

γ_b: Unite weight, **ω**: moisture, μ: Poisson module,

φ: Internal friction . **ψ**:Dilating angle
σ: stress , **E**: Elastic module ,
A, , m : Creep Parameter.

- **Figures:**

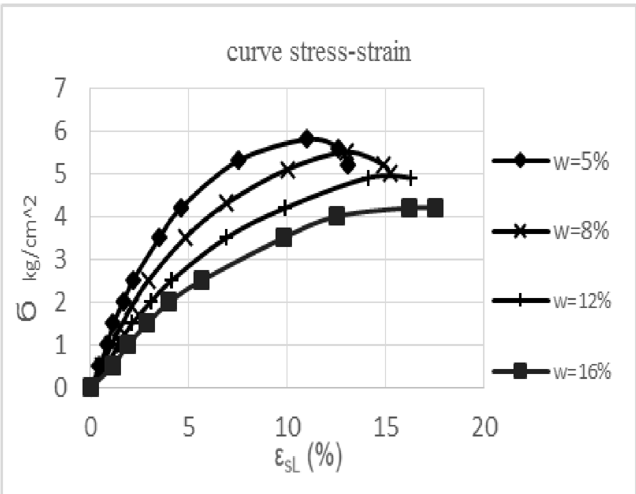

Figure (1): The stress-strain curve of the previous groups within the unconfined compression test.

Figure (2): Unconfined compression test used to determine the unconfined compression strenght of samples.

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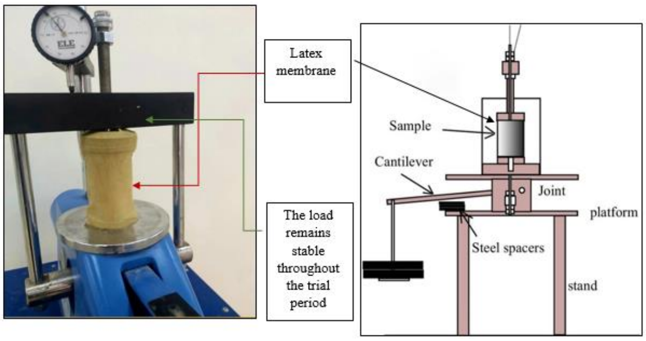

Figure 3 & Figure 4: Unconfined Compression Test Used in creep Experiments

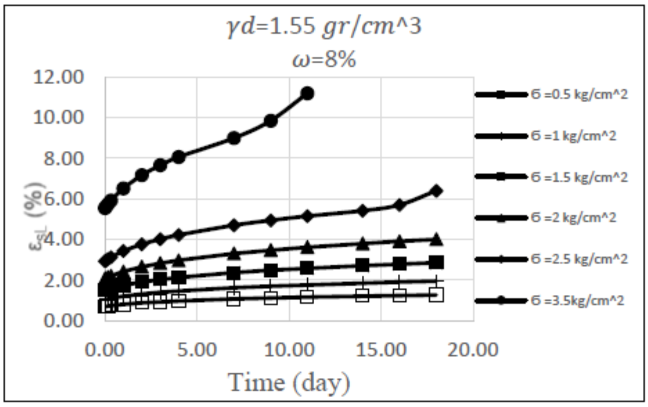

Figure (5): Change of loess deformations over time for (ω=8%)

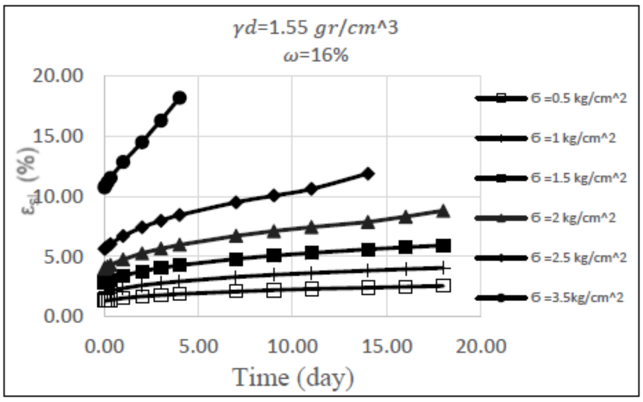

Figure (6): The change of loess deformations over time for (ω=16%)

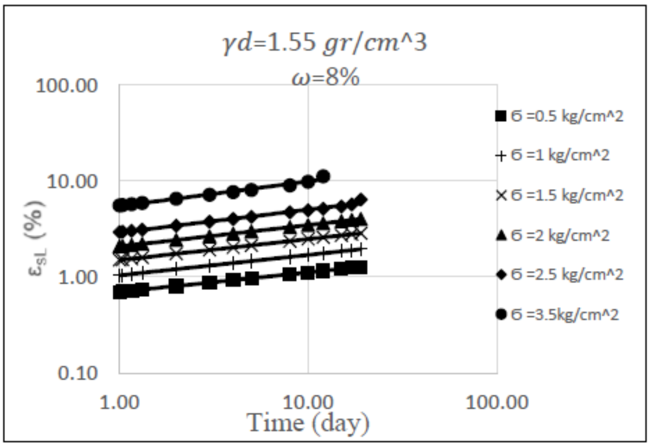

Figure (7): Determination of the constants α, c for moisture ω=8%

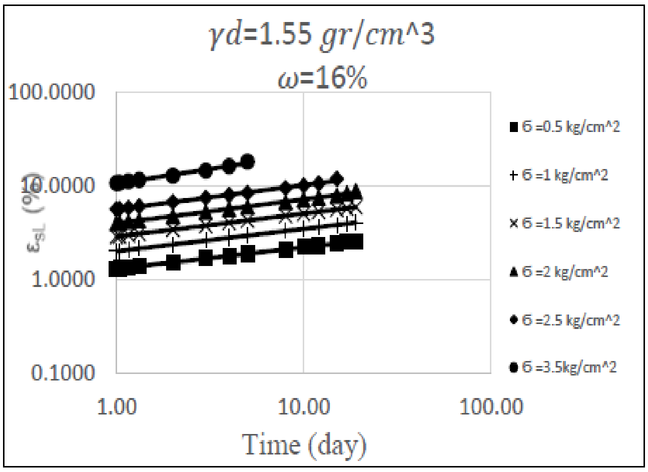

Figure (8): Determination of the constants α, c for moisture ω=16%

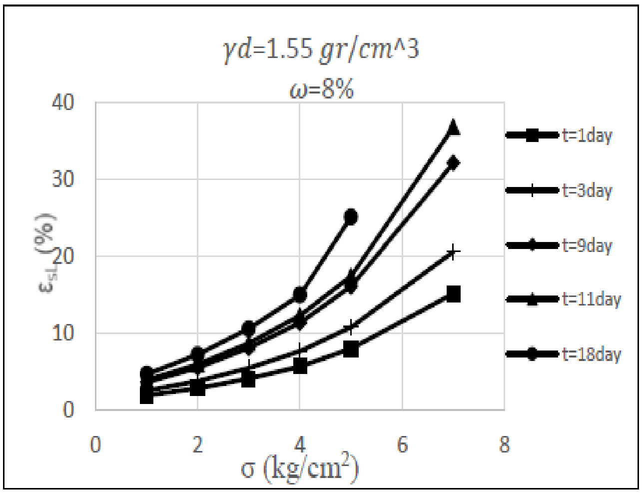

Figure 9: The relationship between the deformations of loess soils with time and the applied stresses for (ω=8%)

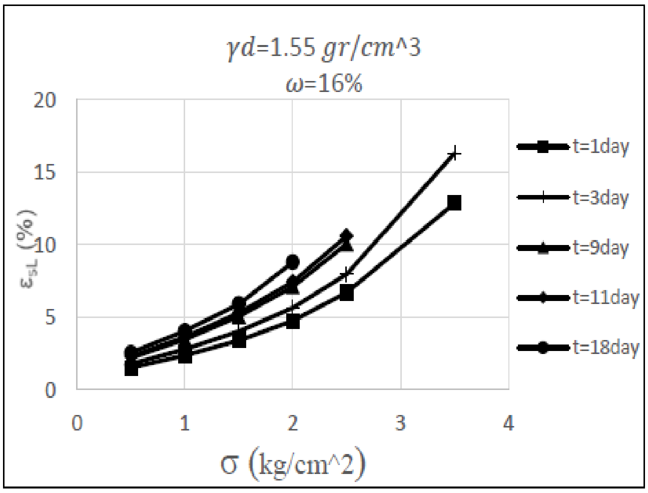

Figure 10: The relationship between the deformations of loess soils with time and the applied stresses for (ω=16%)

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Published By:
Lattice Science Publication (LSP)

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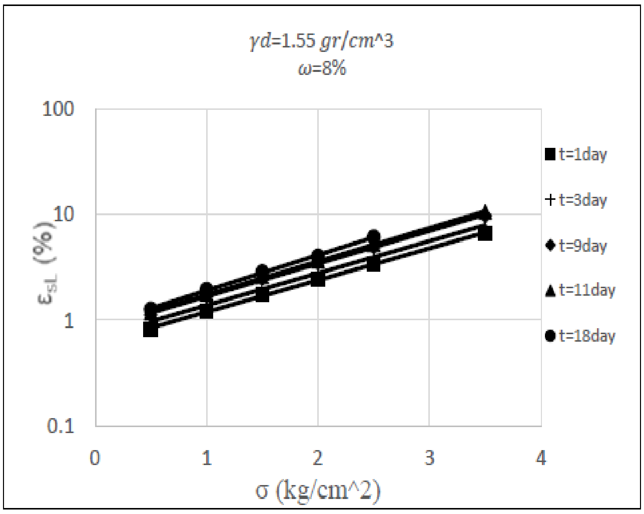

Figure (11): Determination of the constants $\xi, \kappa,$ for moisture ω=8%

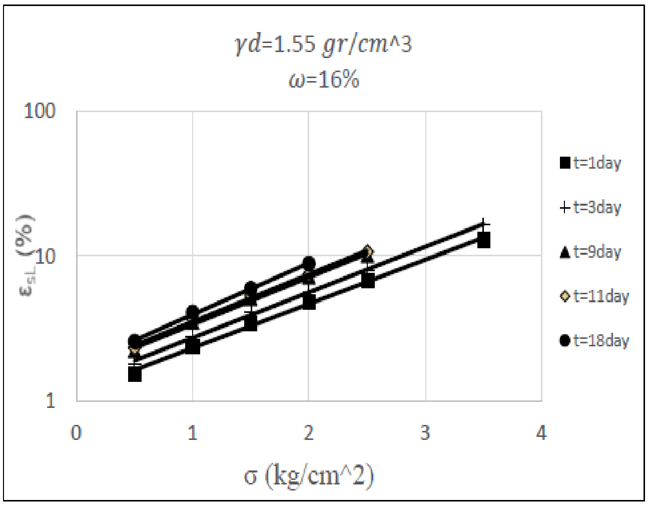

Figure (12): Determination of the constants $\xi, \kappa,$ for moisture ω=16%

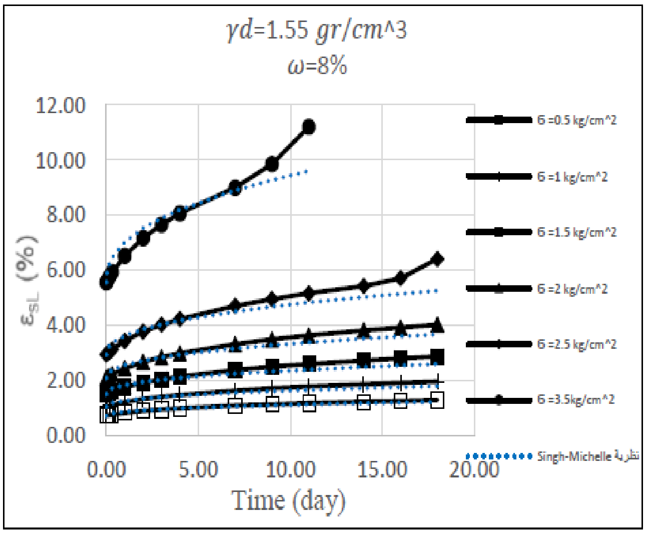

Figure (13): Comparison of the deformations over time for the declining soils with values calculated from Equation (4) for ω = 8%

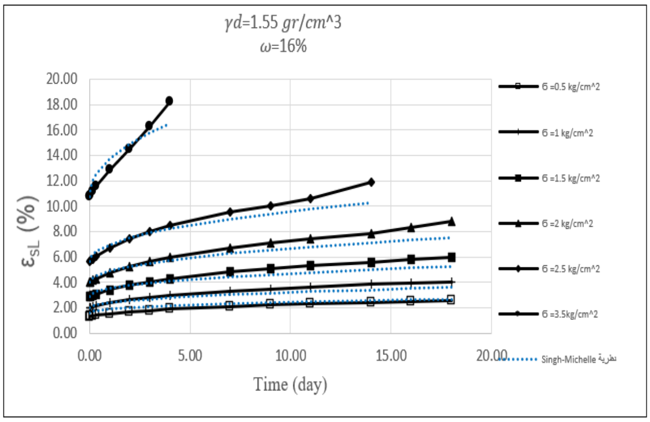

Figure (14): Comparison of the deformations over time for the declining soils with values calculated from Equation (4) for ω = 16%

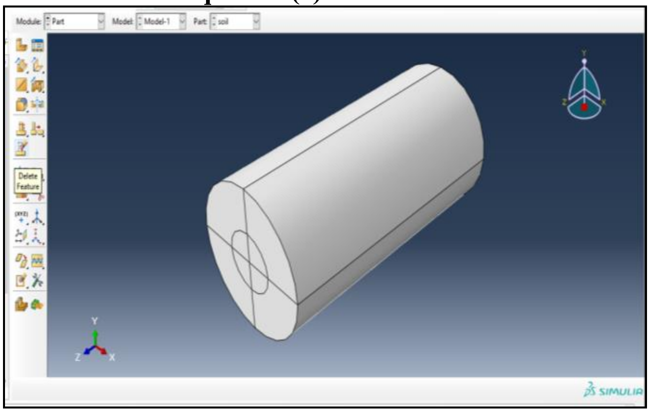

Figure (15): The final model of the soil within the ABAQUS program

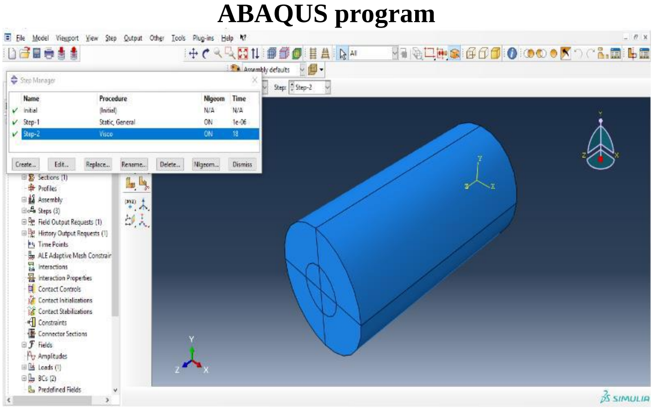

Figure (16): The division of work stages within ABAQUS

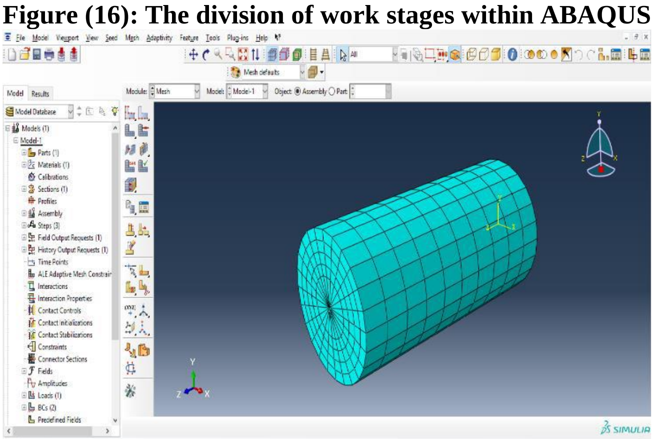

Figure (17) The figure of a finite element network

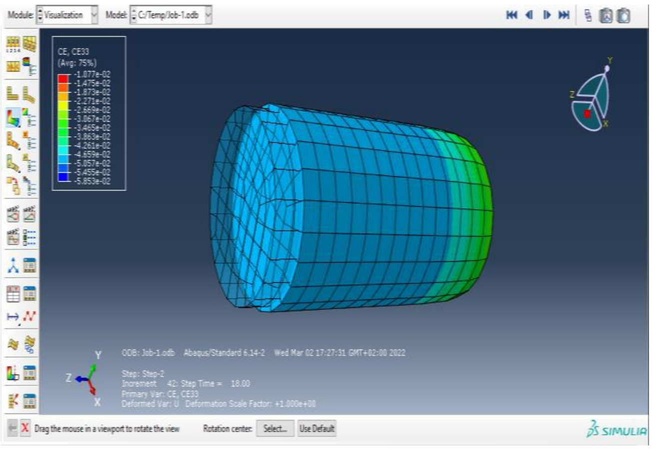

Figure (18): Creep deformations using Drucker Parger plasticity behavior at time 18 day, ω=8% t=18day $\sigma = 3.5\ kg/cm^2,\ \gamma_d = 1.55\ gr/cm^3\ ,\ \omega = 8\%$

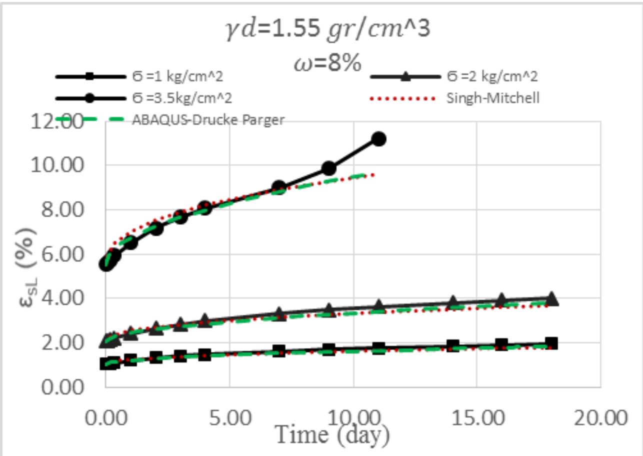

Figure (19) Comparison of deformation over time between Singh-Mitchell theory and ABAQUS program ω=8%

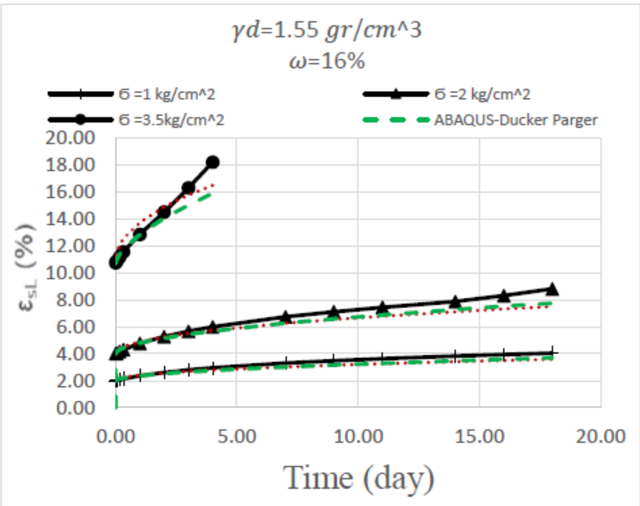

Figure (20) Comparison of deformation over time between Singh-Mitchell theory and ABAQUS program ω=16%

V. RESULT AND DISCUSSION

1. The moisture content has a significant effect on the value of the unconfined pressure resistance of the samples, as the value of the unconfined pressure resistance of the samples decreases with the increase of the moisture content.
2. The value of the moisture content and the stresses applied to the sample have a significant effect on the values of deformations with time for the loess soils, as the values of the deformations increase with time with the increase in moisture content and applied stress.
3. The stress causing failure or the so-called yield stress of the sample has reached (70≅80%) of the value of the unconfined pressure resistance of the samples, and the moisture content has a great influence on determining the value of the yield stress of the sample.
4. When the moisture content is increased, the water dissolves the salt bonds and weakens the internal friction forces and reduces the cohesive forces, causing significant softening of the soil and making the soil more susceptible to deformation.
5. The results of deformation with time for the loess soils were evaluated according to the Singh-Mitchell theory and they were close, as the relative error between the experimental and theoretical values of deformation did not exceed a maximum of (15%).
6. When comparing the values according to the theory of Singh-Mitchell calculated from ABAQUS program and the values calculated according to the theory of Singh-Mitchell relationship (2), the values calculated from the program were more accurate because the program contains multiple parameters that describe well the properties of elasticity, plasticity and viscosity of any natural body.

VI. CONCLUSION

Conducting research on the rheological properties of Loess soils not only has educational significance for solving geological problems, but also has some guiding and innovative importance in the research related to solids mechanics, especially after soil rheology research in recent years has become a pressing issue within the scope of geotechnical engineering. Numerical modeling does not in any way replace practical experiments, but numerical modeling can contribute to the correction and development of mathematical models.

DECLARATION

Funding/ Grants/ Financial Support	No funding was received for this work.
Conflicts of Interest/ Competing Interests	The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.

Availability of Data and Material/ Data Access Statement	The data that support the findings of this study are available from the corresponding author upon reasonable request.
Authors Contributions	Ali alabdullah: Visualization, Supervision and editing
	Najla Al-hassan: Visualization, Supervision and editing
	Mohammad Eid: Conceptualization, Methodology, Writing-original draft.

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