Long -Term Deformation Of Some Gypseous Soils

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Abstract:

Time-dependent deformation and stress relaxation in soils are important in a variety of geotechnical problems where long-term behavior is of concern.

Previous studies on soils showed that the magnitude of delayed compression (creep) is controlled by compressibility and soil sensitivity in addition to preconsolidation.

In this paper, the time-dependent behavior of gypseous soils is investigated. The soils used in this study were brought from three locations at Al-Tar region west of Al-Najaf city in Iraq. These soils had gypsum content of (66%, 44% and 14.8%). The mineralogical and chemical properties of the soils were determined.

Two series of tests were performed. In the first, collapsibility characteristics were investigated for a long period (60 days) by conducting single and double oedometer tests. In the second series, the effect of relative density on collapse with time was investigated. The samples were compacted to 40%, 50% and 60% relative density and then tested. The results of collapse tests showed that the relationship between the strain and logarithm of effective stress has two vertical lines. The first one represents the collapse settlement taking place within 24 hours, while the second one represents the long-term collapse. The collapse potential in both single and double oedometer tests increases when the gypsum content increases from (14.8%) to (66%) and when the initial void ratio increases.

The results of double oedometer tests showed that the relationship between the collapse potential and logarithm of time, for samples loaded to 800 kPa for 60 days, consist of three distinct segments. The first segment is represented by a curve concave downward in which the compressibility gradually increases. The second segment is a straight line with a higher increase in the strain. The third segment which refers to creep collapse depends on the gypsum content. Gypseous soil with low gypsum content (14.8%) exhibited significant decrease (5.21% at 24 hours to 7.16% at 60 days) in collapse potential with time.

Key Words: Gypseous soil, collapse, time, relative density.

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الخلاصة:

إن التشوهات المعتمدة على الزمن و تراخي الاجهادات في التربة مهمة في العديد من المسائل الجيوتقنية حيث يعتبر السلوك طويل الأمد معتمدا. لقد بينت الدراسات السابقة على التربة أن مقدار الانضغاط المتأخر (الزحف) مسيطر عليه من خلال انضغاطية و حساسية التربة إضافة إلى التحميل المسبق.

في هذا البحث، تم تحري السلوك طويل الأمد لتربة جبسية، و قد جلبت نماذج التربة المستعملة من ثلاثة مواقع في منطقة الطار غرب مدينة النجف في العراق. و قد احتوت هذه الترب نسب جبس مقدارها (66% و 44% و 14.8%) على التوالي، و حددت الخصائص المعدنية و الكيميائية لهذه الترب.

أجريت سلسلتان من التجارب، في الأولى تم البحث عن الخصائص الانهيارية لزمن طويل (60 يوما) من خلال إجراء فحص الأويدوميتر المنفرد و المزدوج. و في السلسلة الثانية درس تأثير الكثافة النسبية على الخواص الانهيارية مع الزمن، حيث تم رص النماذج إلى كثافة نسبية مقدارها 40% و 50% و 60% ثم أجريت الفحوص عليها. و قد بينت نتائج فحص الانهيار أن العلاقة بين الانفعال و لوغاريتم الإجهاد المؤثر تتكون من خطين شاقوليين، يمثل الخط الأول هبوط الانهيار الذي يحدث خلال 24 ساعة بينما يمثل الثاني الانهيار طويل الأمد. و يتزايد احتمال الانهيار في كل من فحص الأويدوميتر المنفرد و المزدوج مع تزايد نسبة الجبس من (14.8%) إلى (66%) و كذلك مع زيادة نسبة الفراغات الابتدائية. كما بينت نتائج فحص الأويدوميتر المزدوج أن العلاقة بين احتمال الانهيار و لوغاريتم الزمن لنماذج حملت إلى 800 كيلوباسكال لمدة 60 يوما تتألف من ثلاثة أجزاء منفصلة، حيث يمثل الجزء الأول بمنحني متجه للأسفل تتزايد خلاله الانضغاطية تدريجيا، و الجزء الثاني يكون خطا مستقيما يتزايد خلاله الانفعال بشكل كبير، أما الجزء الثالث الذي يمثل انهيار الزحف فيعتمد على المحتوى الجبسي. و قد أظهرت التربة الجبسية ذات المحتوى الجبسي الواطئ (14.8%) تناقصا واضحا في احتمال الانهيار مع الزمن (5.21% خلال 24 ساعة إلى 7.16% خلال 60 يوما).

Introduction:

Gypsiferous soils are problematic from both the engineering and the agricultural points of view. There are many problems that have been noticed when structures were constructed on gypsiferous soils in the last three decades in Iraq. These problems are related to collapsing of the soil, increasing leakage of water through the soil, softening of the soil and attack of sulfate to concrete. All these problems are related to the continuous and slow dissolution of gypsum by seeping water through the gypsum-containing soil.

The presence of gypsum in soil affects its engineering properties and behavior in a degree, which is greatly dependent on the amount of gypsum present in the soil. Gypsiferous soil in Iraq constitutes 7.3 to 10 percent of the total world gypsiferous area and it forms 11 to 15 percent of the area of Iraq.

The presence of gypsum in soil alters its behavior, in other words, there is a large influence of gypsum on the physical and mechanical properties of soil. This influence depends mainly on the amount and type of gypsum present in the soil. The question is about the appreciable amount of gypsum that causes a serious change in the soil properties.

Gypseous soils are characterized by decreasing strength upon wetting and increasing primary and secondary compression in addition to the dissolution in continuously seeping water. Under these circumstances, underground canals and cavities are formed, Al-Mufty (1997). In general, gypseous soils are reliable for construction under dry and even under short term flow, but become problematic, collapsible and undergo large settlement under long term flooding with water, Al-Saoudi et al. (2001).

Gypseous soils offer a relatively rapid settlement due to the addition of water because the loose particle structure is cemented together with soluble minerals and/or with small quantities of clay. Water infiltration into such soils can break down the inter-particles cementation, resulting collapse of the soil structure.

Structure of Gypseous Soil

Soil particles in gypsiferous soils are weakly aggregated, as the cohesive forces attracting single soil particles are very weak. Gypsum particles have no cation exchange capacity. Erosion of gypsiferous soils can be very serious because of poor aggregation.

Smith and Robertson (1962), working in Iraq, found that 3 to 10 percent of gypsum does not interfere significantly with soil characteristics such as structure, consistency and water holding capacity; while in soils containing 10 to 25 percent of gypsum, the gypsum crystals tend to break the continuity of the soil mass.

Particle-Size Distribution

Standard laboratory determination of the particle-size distribution of gypsiferous soils is a tedious and time-consuming process. Gypsum, which inhibits soil dispersion, is usually removed from soil samples before analysis by leaching the soil either with distilled water, or by extraction with a solution of ammonium oxalate (Coutinet, 1965), or any concentrated chloride solution in which gypsum is more soluble than in pure water. Because gypsum has marked effects on the physical properties of soils, it is most desirable to determine the particle-size distribution without removing the gypsum fraction.

Nashat (1990) recommended that wet sieving with water falsifies the grain size distribution curves. It is therefore suggested to apply the dry sieving method or wet sieving but using a non-polar solvent, such as methelene chloride or kerosene.

Solubility of Gypsum

Gypsum is soluble, relative to most other rocks. It dissolves in water into calcium ions and sulfate ions. Its solubility in water is about (2.0 gm per liter), but it varies due to the presence of certain types of salt such as NaCl and $MgCl_2$ which increase its solubility and calcium bicarbonate which reduces it, (Barzanji, 1973).

Kemper et al. (1975) studied the dissolution rate of gypsum in flowing water. It was shown that the dissolution coefficient may be dependent on some factors:

- Flow rate.
- Surface area: increases more rapidly than the surface area at a given flow rate, as the fragments become smaller.
- Fragment size: decreases if the particle size increases at a given flow rate.

<u>Experimental Work:</u>

The soil samples were taken from three locations of Al-Tar in Al-Najaf City in Iraq. It lies in a high area about (10 km) west of Al-Najaf. Water can be found in this region about (4 m) below the ground surface. The sand of this area is white tends to pink. It is washed in the seawater, which goes to the seabed. Manual tools were used to take the samples after removing the top sand layer mixed with smooth soil, which is about one meter thick.

Classification Tests

1) Physical Tests

-*Specific Gravity:*

The specific gravity of the soil was determined according to the British Standards (BS 1377: 1975 test No. 6 B, Head 1980). Kerosene is used instead of water to prevent gypsum from being dissolved in water.

- Atterberg Limits:

The liquid limit test was carried out according to the British Standards (BS 1377: 1975 test No.2, A) using the cone penetrometer method, while the plastic limit test was according to (BS 1377: 1975 test No.3).

- Grain Size Analysis:

Grain size analysis was determined by sieve analysis, which was conducted in accordance to the procedure described by Bowles (1978), but Kerosene is used instead of water.

- Minimum and Maximum Density:

Minimum density test was performed according to (BS 1377: 1975), to get a lower density possible to be achieved by slow pouring of the preweighed dry soil in air through a graduated cylinder. Then maximum void ratio can be calculated from which the relative density can be estimated.

Maximum density test was performed according to the procedure described by Bowels (1978). In this test, three trials of maximum density are made by placing the oven-dry soil in the standard mold in five layers, confining the layer with a round steel block at least (12 kg) with rapping the mold sharply (25) times using a rubber mallet. The largest density obtained is used.

2) Compressibility Tests

Three series of tests were performed in accordance with (ASTM 2435, 1996), i.e., the load increment ratio (LIR=1), and load increment duration (LID=1day). To conduct the tests, the fixed type consolidometer cells and loading frame with specimens of (75 and 50) mm, diameter and (19 mm) height are used.

3) Collapsibility Tests

A series of double oedometer tests (DOT) and collapse tests (CT) were performed according to (ASTM D5333, 2003).

Soil Classification

Physical Tests

The results of Atterberg limit tests conducted on fractions passing sieve No. 40 (0.425 mm) indicate that all the samples are non-plastic. The results of dry unit weight, as expected, show that an increase in gypsum content causes a decrease in dry unit weight, because the specific gravity of gypsum crystals which is approximately equal to 2.32 is lower than that of soil particles (about 2.6). As a result, the specific gravity decreases with the increase in gypsum content. Similar results were found by Seleam (1988), Nashat (1990), Al-Aqaby (2001) and Al-Dulaimi (2004).

The grain size distribution curves of the soil samples are shown in Figure (1). From these results, the soil specimens can be classified according to the Unified Soil Classification System as poorly graded sand (SP) for soils N1 and N2 and as well graded sand (SW) for soil N3. It is a coarse grained soil, therefore, it is important to determine its relative density.

The physical properties of the three soils are summarized in Table (1). In this table, N1, N2 and N3 refer to the percent of gypsum (χ) in the three samples. From Figure (1), the effective particle size for the three specimens, D_{10}, in addition to D_{30} and D_{60} can be determined from which the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, can be calculated as given in Table (1).

Chemical Tests

The total soluble salts, SO3% and gypsum content were determined according to British Standards (BS 1377). Table (2) shows the results of some chemical and composition tests conducted on the samples.

X-Ray Diffraction Tests

The results of these tests indicate that gypsum and quartz are the dominant non-clay minerals, while the montmorillonite, palygorskite, illite and chlorite dominant clay mineral components.

Results of Oedometer Creep Tests

1) Collapse Test

The results of collapse tests (CT), shown in Figure (2), are drawn as the vertical strain (ε) versus logarithm of effective stress (log σv). Two vertical lines are noticed in these figures. The first line refers to the settlement that occurs suddenly when water is added to the soil sample under 200 kPa.

The loading period for the first line is 24 hours. The change in strain upon flooding in water points out that the soil is collapsible. The bonds start losing strength with the increase of the water content and at a critical degree of saturation, the soil structure collapses, (Jennings and Knight, 1957 and Barden et al., 1973). A summary of data is given in Table (3).

It can be noticed that the collapse potential, C.P., increases with the increase of gypsum content and initial void ratio. The second line represents the additional settlement caused by creep that occurs under 800 kPa for 60 days.

In Figure (3) the vertical strain is plotted versus time in normal scale for the second line of the three samples. The curve is linear during the entire creep period for sample N3. For samples N1 and N2 a change from the initial linear behavior to another with higher rate of strain is observed and a sudden soil collapse is noticed within the creep stage. This may be explained by high heterogeneity of soil with the existence of gypsum crystals in these samples.

The same results are plotted in Figure (4) in which the time is plotted on a logarithmic scale. No apparent difference is obtained when the results are drawn on a semi-logarithmic scale.

Al-Aithawi (1990) found similar results in his analysis of axial strain versus log time for gypseous soils. A linear behavior was found at (100 and 200) kPa stress intensity. This linearity step was followed by the collapse occurrence.

2) Double Oedometer Test

Figure (5) shows the variation of strain with logarithm of vertical stress obtained from the double oedometer test (DOT). The compressibility of the soil is low when loaded under unsaturated condition. The loading of the unsaturated soil is the same as the loading of the saturated one from 25 to 800 kPa. From Table (3) it can be seen that the collapse potential for samples N2 and N3 obtained from double oedometer tests are greater than those obtained from collapse test at stress level of 200 kPa, while for sample N1, the collapse potential obtained from DOT was smaller than that obtained from collapse test.

The relationship between the collapse potential and logarithm of time from the DOT at 800 kPa for 60 days are plotted in Figure (6). The percents of collapse potential versus log time curves for the N1 and N2 samples consist of three distinct segments. The first segment is represented by a curve concave downward. In this stage, the compressibility gradually increases.

The second segment is generally a straight line with a higher increase in the strain. In the third segment, the rate of strain increases again to form approximately another straight line opposite to C.P. axis for the sample N1 and parallel to time axis for the sample N2 where the rate of strain remains constant after the day (37) to the end of the test. But the curve of the sample N3 differs from the curves of N1 and N2 samples. The curve consists of two segments, the first is a straight line where the strain increases rapidly and the other is a curve concave upward where, the strain decreases. This expansion may be attributed to the presence of montmorillonite clay mineral, since that gypsum is not expansive. Another source of this expansion can be attributed to rearrangement of sand particles which when loaded to higher stresses show some increase in volume.

Dudley (1970) showed that the collapse in fine sand (with 14% montmorillonite) increased with the increase of initial water content until it reached values higher than 10%, the collapse then became less at the same stress level and dry unit weight. Sand deformation response is directly related to the parent minerals, Lambrechts and Leonards (1978). Hossain (2001) found that the swelling pressure decreases with increasing gypsum content for Al-Qatif clay.

The effect of gypsum content on collapse potential for long term under 800 kPa is well illustrated by Figure (7). The relation obtained indicates that creep values increase as the gypsum content increases. It may be ascribed to the continuous dissolution of gypsum.

As shown in Figure (8), the collapse potential increases with the increasing stress for the three samples. When the stresses are low (below 100 kPa), this effect is not apparent.

The collapse may be caused by break-down of the interparticle bonds under high loads. It can be seen that for N1 sample where the gypsum content is 66 %, the same rate of increase of C.P., % takes place at all stress levels. On the other hand, for samples N2 and N3 a continuous increase in C.P. rate occurs when the stress level increases.

Effect of Relative Density

Two identical specimens with relative densities 40%, 50% and 60% for the N1 soil are tested independently; one in the natural moisture content, the others are soaked by water from the beginning. The soil specimens were statically compacted in the oedometer ring to a dry unit weight that maintains the desired relative density. The results of double oedometer test are presented as strain versus logarithm of the effective stress as shown in Figure (9). A summary of data is given in Table (4).

It can be observed that the effect of relative density on collapse strain at 200 kPa is not clear. The effect of relative density is evident at 800 kPa. The strain increases with the increase of relative density from 40% to 60%.

Figure (10) shows the collapse potential-logarithm of time relationship for the three relative densities under 800 kPa. The curves indicate that the C.P increases with time for the soil sample compacted to a relative density 60% and the increase is higher than those compacted to 40% and 50%. The curves start with a straight line then a curve concave downward with a high strain is observed. For samples compacted to 40% and 50% relative densities, the curves interrupted by little soil collapses where another curve setup following the collapse is noticed.

Figure (11) shows the variation of collapse strain with time for dry N1 soil at different relative densities. It can be noticed that the strain decreases seriously when the dry soil is compacted at higher relative density.

A decreases of about (43 %) was noticed when the relative density changes from 40% to 60% at long times, while the inverse behavior was noticed for soaked samples as illustrated in Figure (12). The strain increases when the wet soil is compacted at higher relative density.

The relationship between the collapse potential and relative density at 800 kPa for 60 days, shown in Figure (13), indicates an increase in collapse potential with the increase in relative density for soaked samples.

Coclusions

From the results and analysis of the tests presented in this paper on samples of gypseous soil having percentages of gypsum of 66%, 44% and 14.8%, the following conclusions could be drawn:

1. The results of collapse tests showed that the relationship between the

vertical strain and logarithm of effective stress has two vertical lines. The first one represents the collapse settlement taking place within 24 hours, while the second one represents the long-term collapse.

2. The collapse potential in both single and double oedometer tests increases significantly when the gypsum content increases from (14.8%) to (66%) and when the initial void ratio increases.

3. The results of double oedometer tests showed that the relationship between the collapse potential and logarithm of time, for samples loaded to 800 kPa for 60 days, consist of three distinct segments. The first segment is represented by a curve concave downward in which the compressibility gradually increases. The second segment is a straight line with a higher increase in the strain. The third segment which refers to creep collapse depends on the gypsum content. Gypseous soil with low gypsum content (14.8%) exhibited significant decrease (5.21% at 24 hours to 7.16% at 60 days) in collapse potential with time.

4. As the relative density increases from 40% to 60%, the collapse potential increases with time for the same gypsum content at high stress (800 kPa). The strain decreases seriously when the dry soil is compacted at higher relative density (60 %). A decrease of about (43 %) was noticed when the relative density changes from 40% to 60 % at long times. The saturated samples exhibited opposite behavior; the strain increases from 24.3 % to 29.2 % at 60 days when the saturated soil is compacted at higher relative density, (from Dr = 40 % to 60 %).

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Table (1): Summary of Physical Test Results.

Soil –property	**N1**	**N2**	**N3**
Specific gravity, Gs	2.44	2.56	2.69
Initial void ratio, e_o	1.017	0.619	0.480
Field unit weight, γ_d field (kN/m^3)	12.1	15.5	17.3
Maximum dry unit weight, γ_{dmax} (kN/m^3)	13.13	16.40	19.00
Minimum dry unit weight, γ_{dmin} (kN/m^3)	9.98	12.00	10.87
Relative density, Dr %	73	84	86
Gravel %	15.0	16.0	9.0
Sand %	83.8	82.0	87.0
Fines %	1.2	2.0	4.0
D_{10} (mm)	0.170	0.300	0.042
D_{30} (mm)	0.35	0.48	0.27
D_{60} (mm)	0.75	0.95	0.60
Coefficient of curvature, C_c	0.96	0.79	2.89
Coefficient of uniformity, C_u	4.41	3.17	14.28
Soil classification according to USCS	SP	SP	SW

Table (2): Chemical Test Results.

Type of Soil	TSS %	SO_3 %	Gypsum Content, χ %
N1	9	30.6	66
N2	7.3	20.5	44
N3	6	6.9	14.8

Table (3): The Collapse Potential Values.

Soil Property			Soil Type		
			N1; χ = 66%	**N1; χ = 44%**	**N1; χ = 14.8%**
e_o			1.017	0.619	0.480
γ_d (kN/m^3)			12.1	15.5	17.3
Dr %			73	84	86
C.P. %	200 kPa	CT	11.57	3.42	1.04
		DOT	8.93	4.72	5.21
	800 kPa	CT	---	---	---
		DOT	18.33	14.63	7.16

Table (4): The Effect of Relative Density on Collapse Potential of N1 Soil.

σ_v kPa	Dr = 40 %		Dr = 50 %		Dr = 60 %	
	C.P 1 day	**C.P 60 days**	**C.P 1 day**	**C.P 60 days**	**C.P 1 day**	**C.P 60 days**
200	1.87	---	7.47	---	6.42	---
800	7	9	10.5	13.39	15.4	18.47

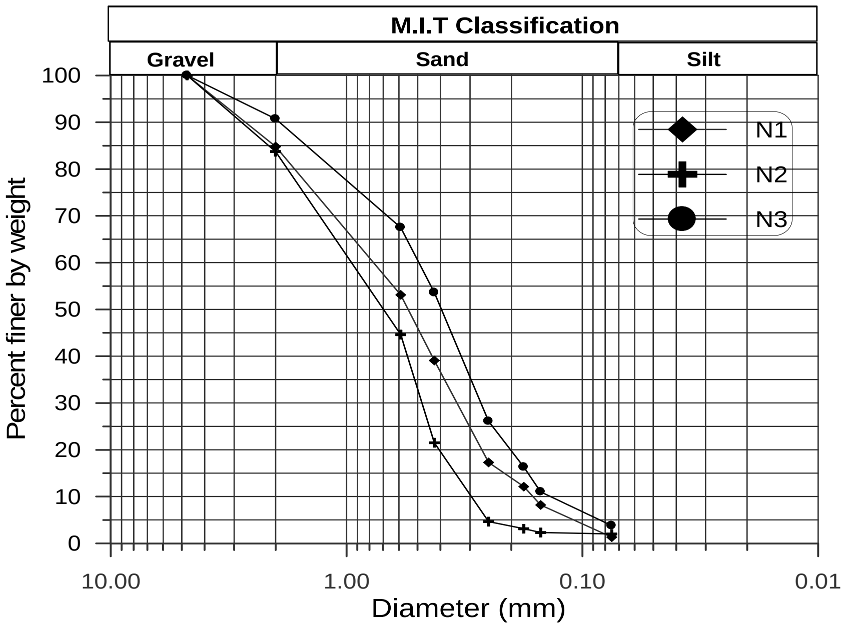


Fig. (1) : Grain size distribution.

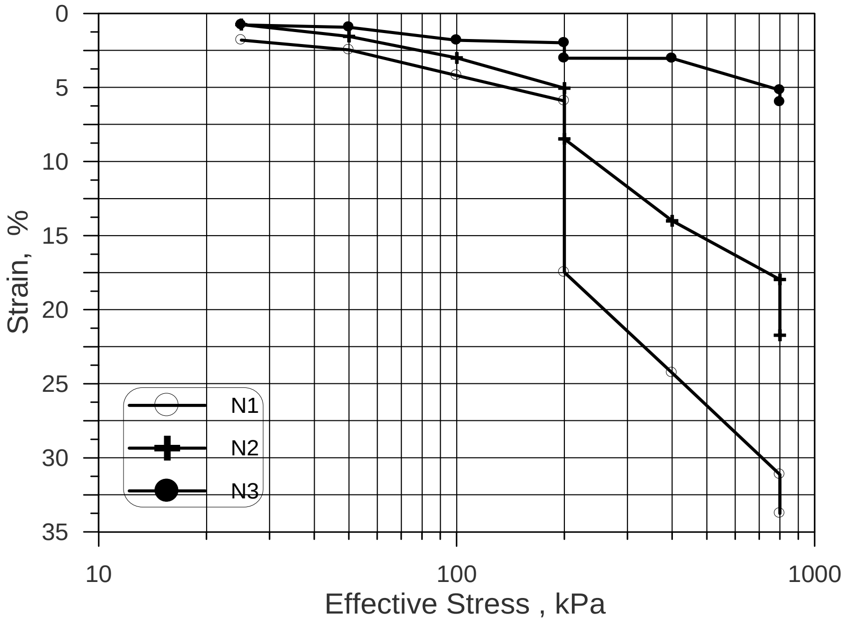


Fig. (2) : The results of collapse test for the three samples.

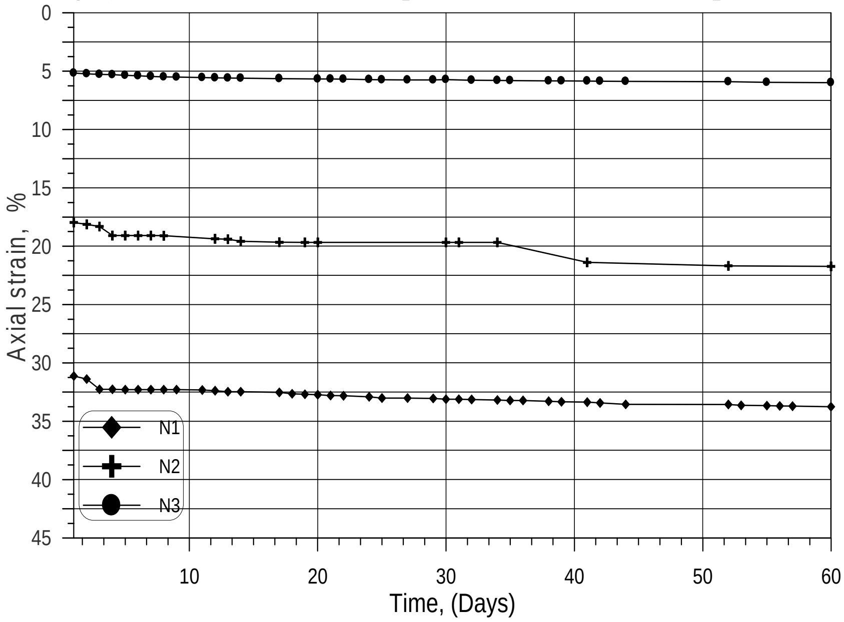


Fig. (3) : Variation of strain with time (creep).

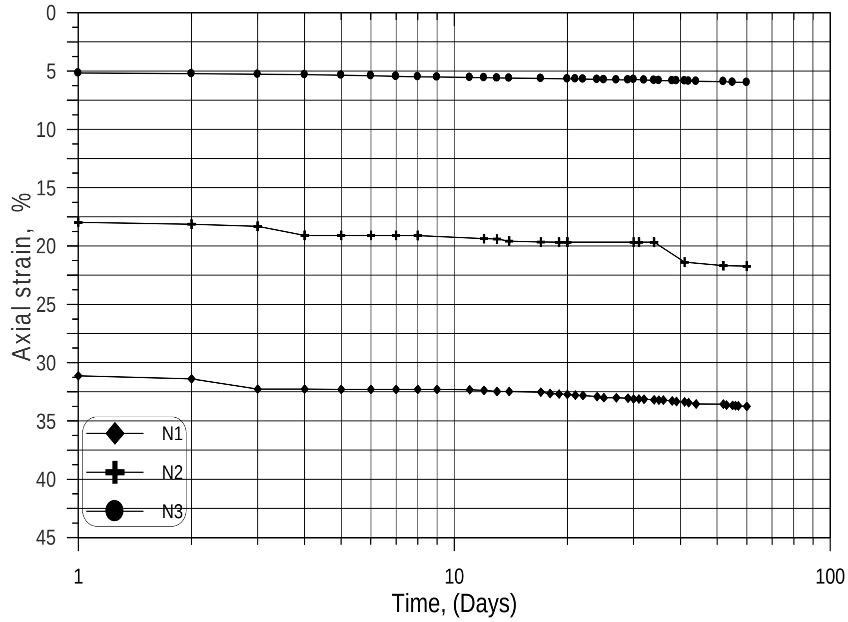
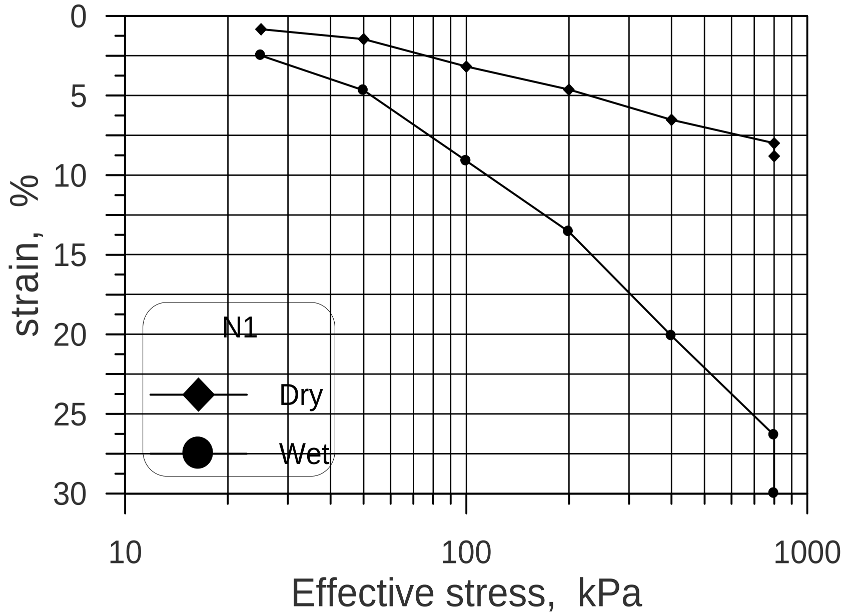
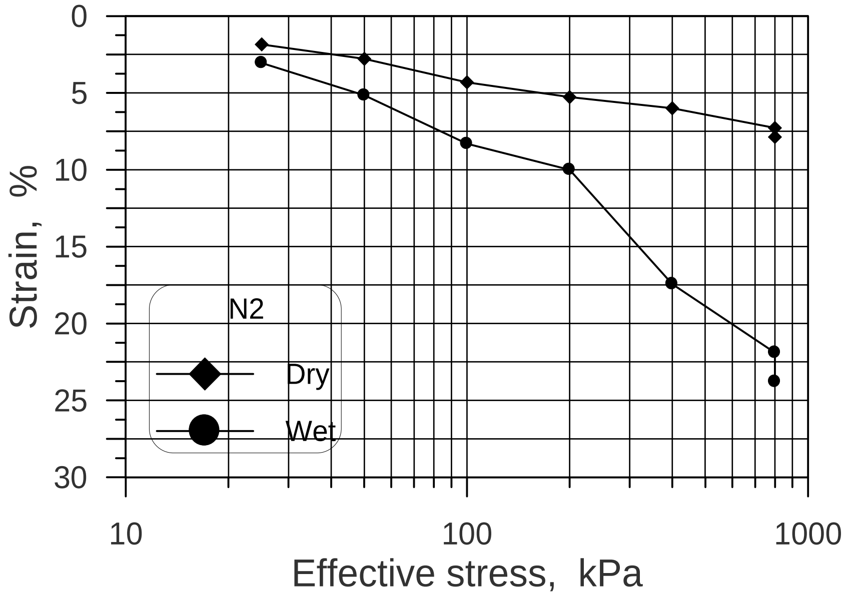


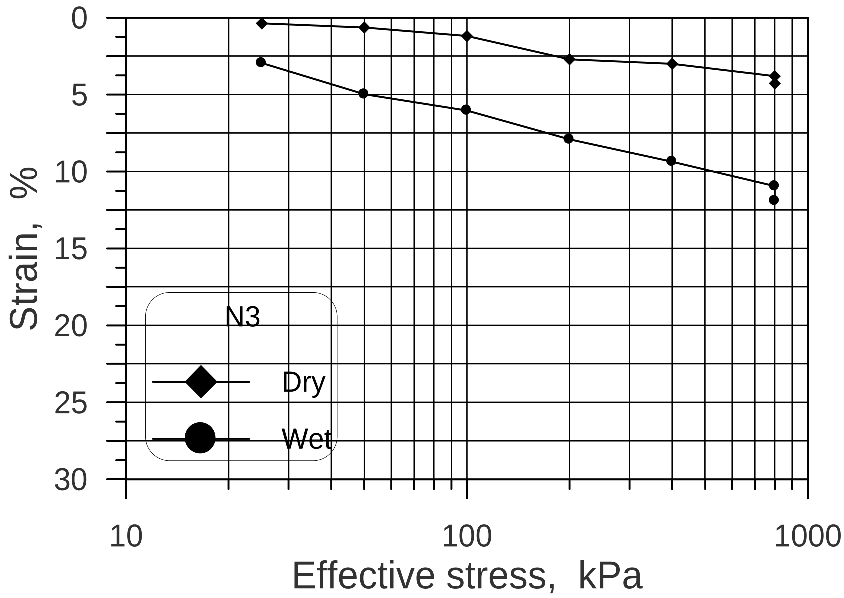
Fig. (4) : Variation of strain with logarithm of time (creep).



(a)

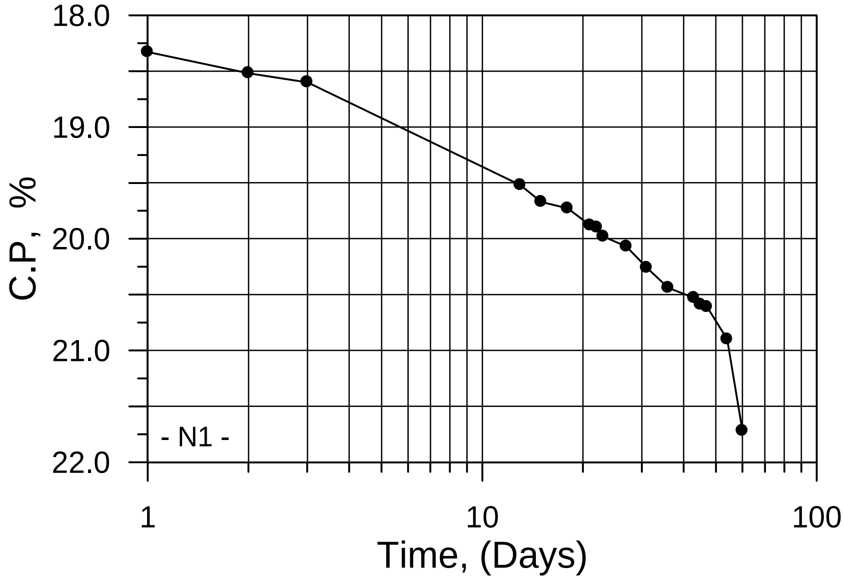


(b)

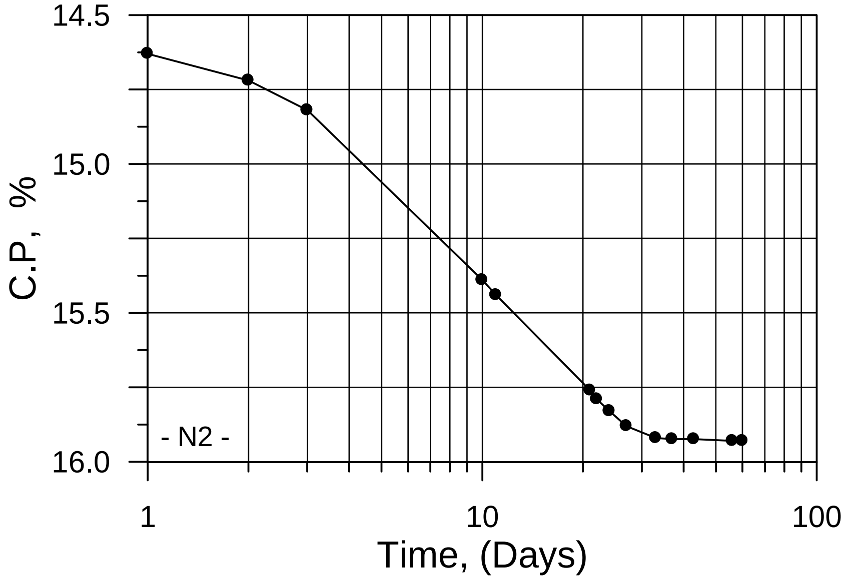


(c)

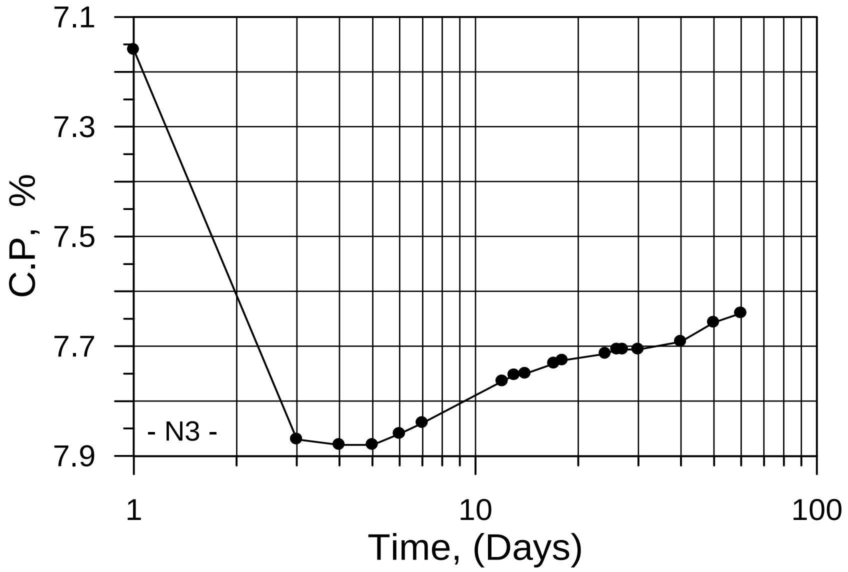
Fig. (5) : Results of double oedometer test on semi-log scale.


18.0
19.0
20.0
21.0
22.0
C.P., %
- N1 -
1
10
100
Time, (Days)

(a)


14.5
15.0
15.5
16.0
C.P., %
- N2 -
1
10
100
Time, (Days)

(b)



(c)

Fig. (6) : Variation of collapse potential with time for DOT.

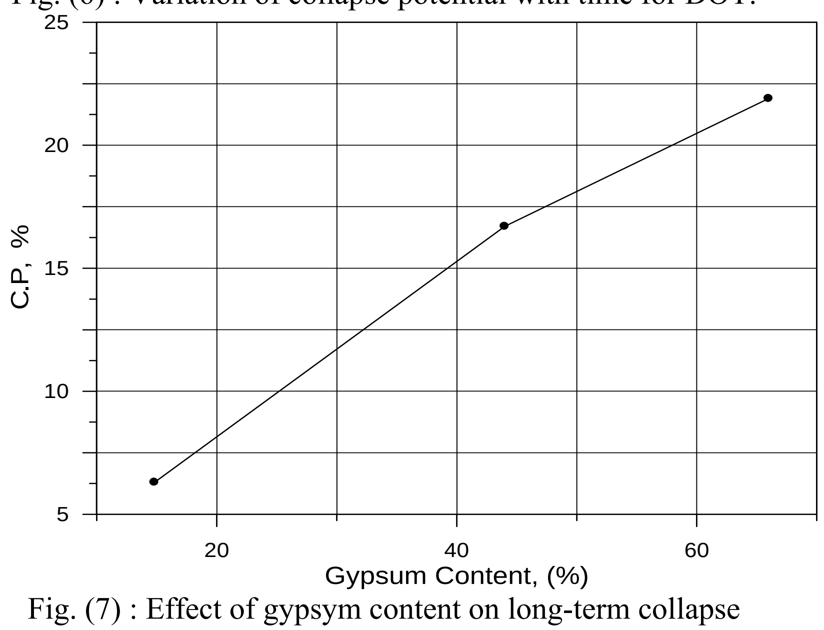


Fig. (7) : Effect of gypsym content on long-term collapse potential (under 800 kPa for 60 days).

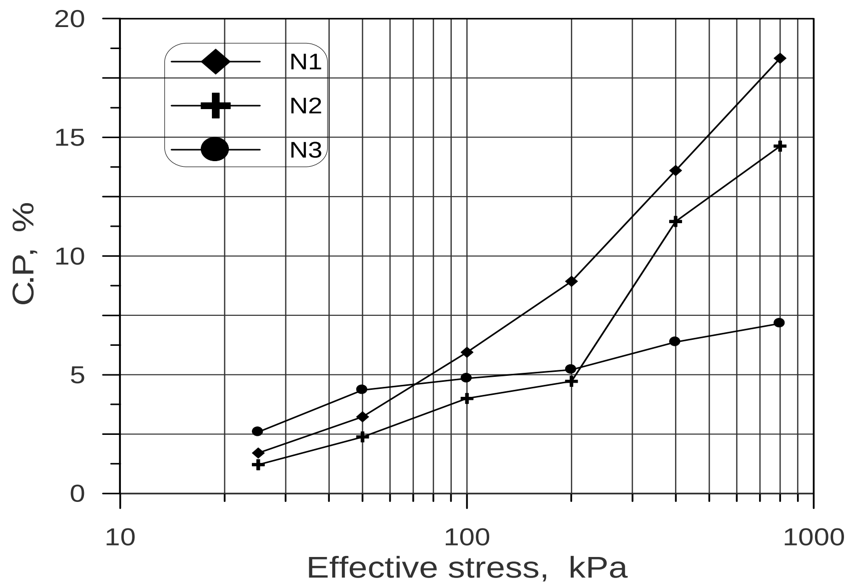
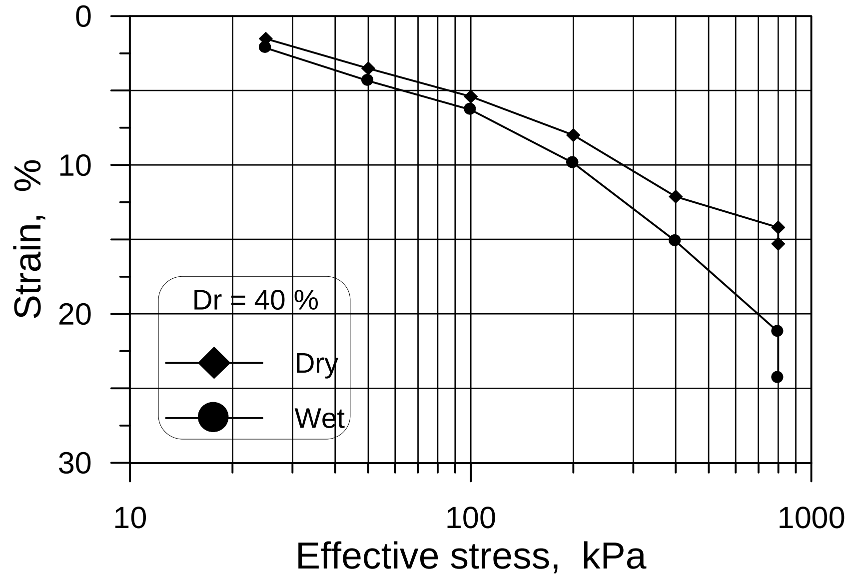
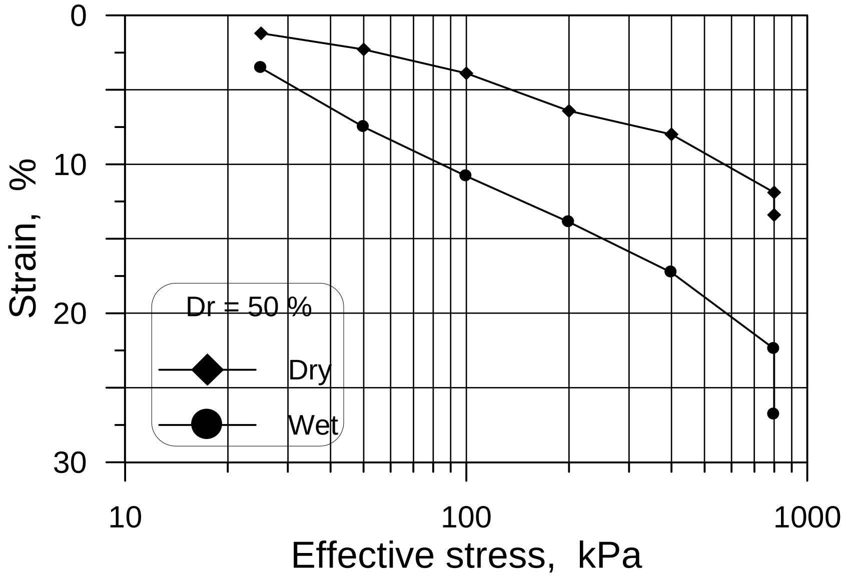


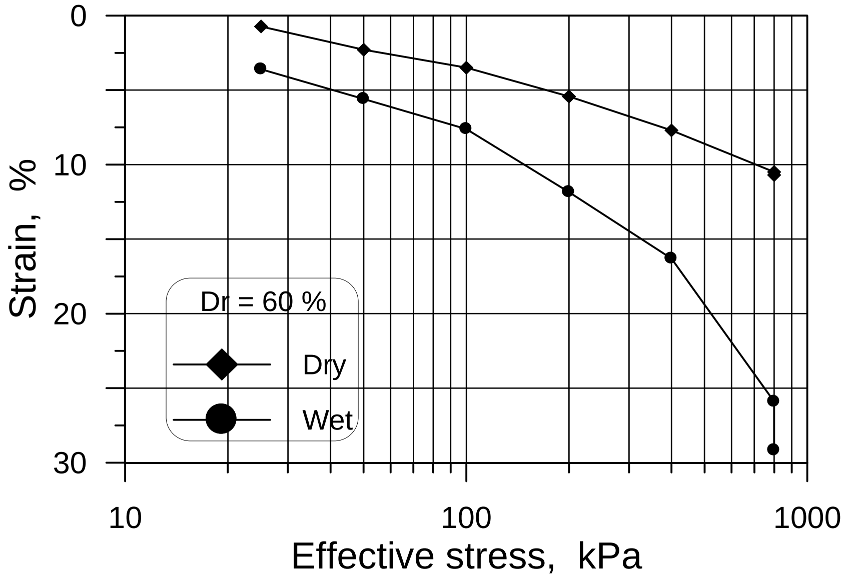
Fig. (8) : Effect of gypsum content on collapse potential under different stresses.



(a)



(b)



(c)

Fig. (9) : The results of DOT for N1 soil at different relative densities.

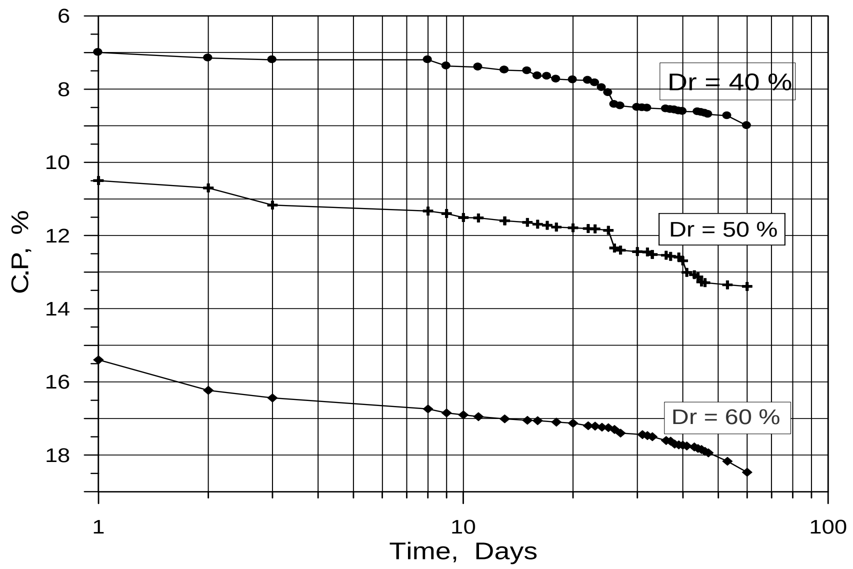


Fig. (10) : Collapse potential-log time relationships at different relative densities, (N1 soil).

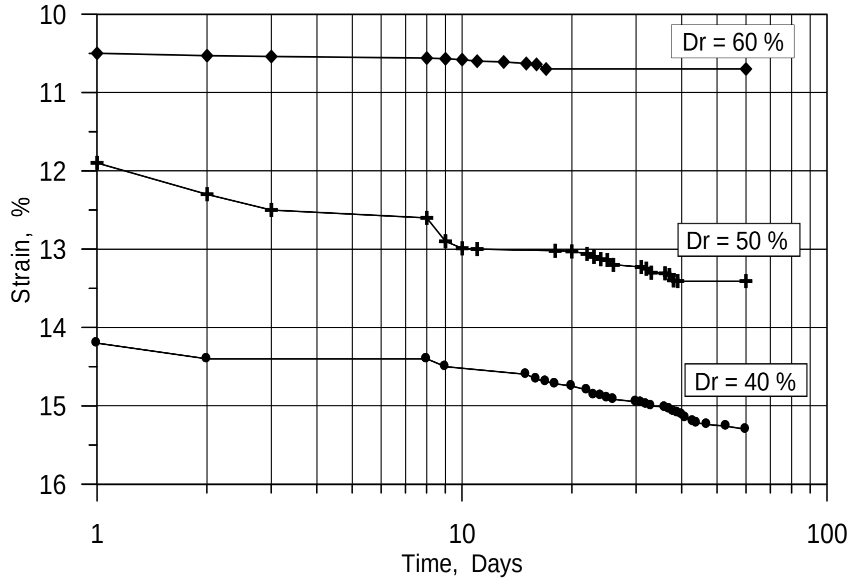


Fig. (11) : Effect of relative density on creep for dry samples, (N1 soil).

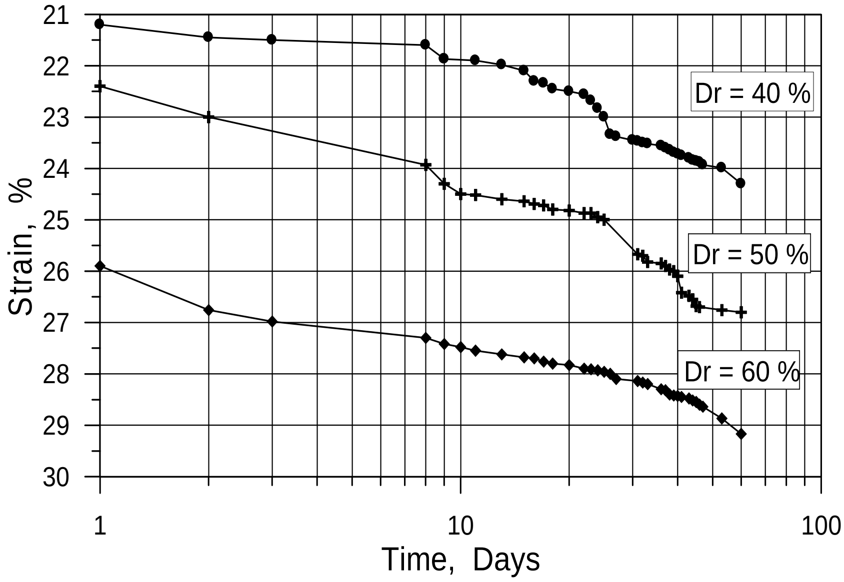


Fig. (12) : Effect of relative density on creep for soaked samples, (N1 soil).

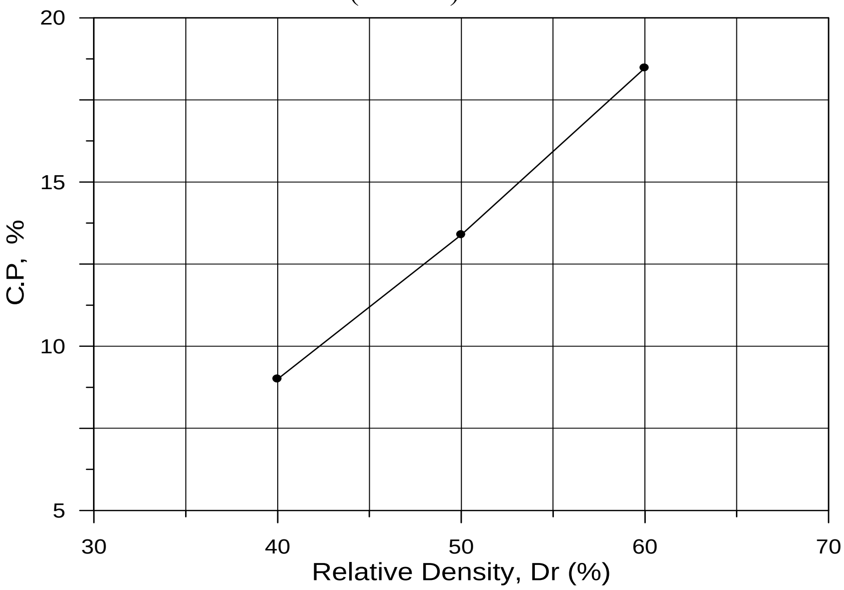


Fig. (13) : The relationship between the collapse potential and relative density for DOT (soil N1).