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Creep in Dense Sands

by

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Introduction

Creep is defined as time dependent deformation under stress. The ability to deform with time is inherent in many substances, from colloidal systems and polymers to metals, and from suspensions to rocks. Although all real bodies, in principle creep, this property can be observed only if, in addition to a certain load and temperature, a reasonable interval of time is available. As far as creep in soils is concerned, it is observed that a lot of work has been done to study the creep behaviour of clays (Christensen and Wu, 1964; Mitchell, 1964; Murayama and Shibata, 1958, 1961 & 1964) but little has been done to study the creep behaviour of sands. This may be due to their inconspicuous time dependency. Dhahran, a city in eastern province of Saudi Arabia, where this study was conducted had dune sand deposits with silica as the predominant mineral component. Settlement in residential buildings in this region is observed due to creep in sands. So, it was decided to explore the creep behaviour of sands, not only from the point of view of its practical applications but also for basic insight on their time dependent behaviour.

This study is an attempt to understand the behaviour of saturated dense silica sand under different stress levels. Volumetric strain has been monitored as a function of time. Effect of precompression stress and mean effective pressure on creep behaviour can be expressed by mathematical relationships. Also, additional informations were derived on critical stresses.

Experimental Program

Material

Silica sand obtained from local dunes in Dhahran, Saudi Arabia was the main source for this study. The grain size distribution of this sand is shown in Fig.1. The properties of the sand were as follows:

Effective diameter (D_{10})	=	0.15 mm
Medium grain size (D_{50})	=	0.25 mm

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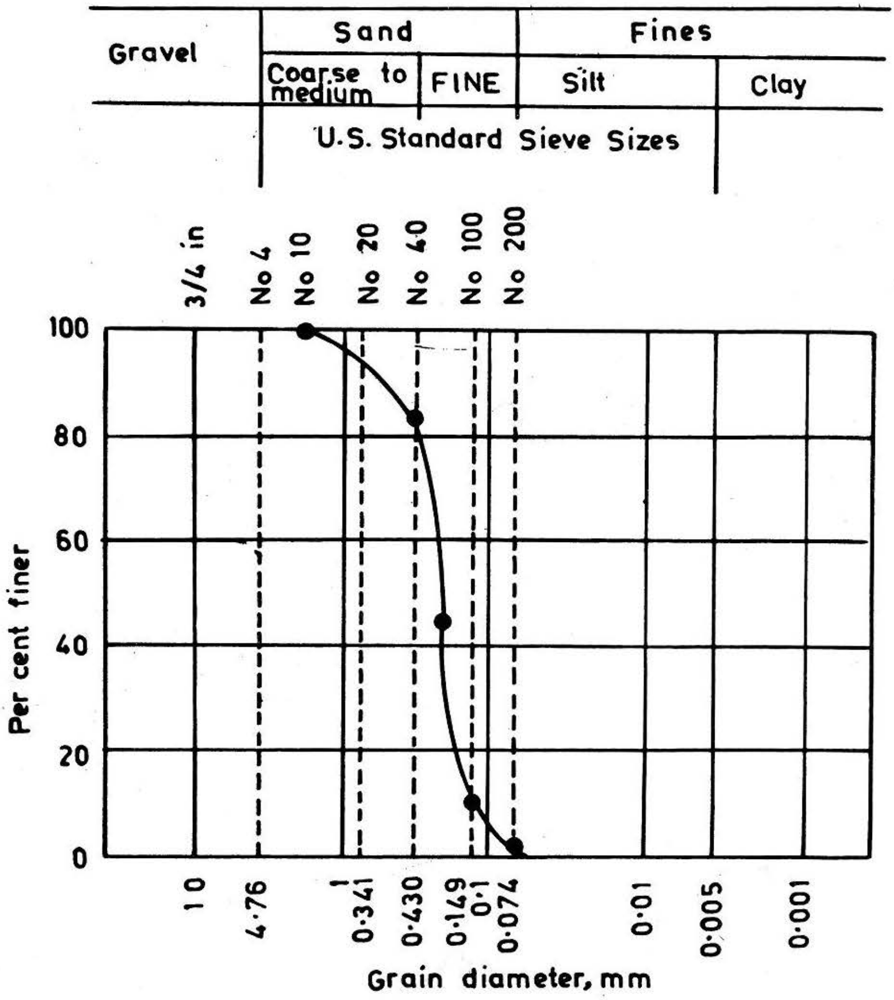

FIGURE 1 Grain Size Distribution Curve

Uniformity coefficient (C_u) = 3.00, and

Coefficient of Curvature (C_c) = 0.42

The specific gravity of this sand is 2.87. The maximum and minimum densities were determined by ASTMSTP no. 5213 (1973) and found to be 18.3 KN/m^3 and 15.6 KN/m^3 .

Sample Preparation

Pluviation technique is considered to approximate a natural deposition process. Both the nature of anistropy and soil fabric obtained by pluviation method have been found to duplicate those observed in a natural alluvial environment (Oda *et al.*, 1978). Hence this technique of preparation of laboratory samples allows a convenient study of mechanical response of natural sands (Vaid and Negussey, 1984).

Dune sand specimens for drained creep test were prepared by pluviation compaction through air technique (Mulilis *et al.*, 1975), so that all specimen could attain a relative density of 85 ± 2 percent. Triaxial specimens were prepared by usual laboratory procedures. Confining pressure, applied using pressured water, was gradually introduced to the cell with the slow removal of vacuum applied during sample preparation. A back pressure of 310 KPa was applied from bottom drainage line of the triaxial cell, matched equally by a confining pressure on the outside of the specimen, preventing any differential stress, in order to ensure full saturation condition of the test specimen. The back pressure was maintained on sample until Skempton's pore pressure parameter B was 95%, or more. After ensuring high B-value, the sample was allowed to consolidate under the selected confining pressure for about one hour by opening the top drainage line.

Experimental Setup

The creep testing system (CTS) developed for this research has the capability of performing simultaneously two completely independent triaxial creep tests. The creep testing system (CTS) consists of two table top consolidation devices converted to accommodate a 70 mm triaxial cell. A lever arm ratio of ten to one permits application of larger loads using relatively small dead weight with no "shock" loading on sample. The loading frame was equipped with a screw control to maintain the lever arm horizontal and to position the arm at the beginning of each test. Loads were transmitted from the lever arm to the sample by means of a vertical hanger that bears on the loading piston.

Cell pressure (σ_3) was measured by a pressure gauge of precision 0.68 KPa. The volumetric change of the specimen was measured by the volume change of water drained into a burette with 20 mm^3 graduation. In low stress tests, axial strain was measured by 0.002 mm deformation gauge. However, for high pressure tests, a transducer model LDP-10B (Make: Tokyo Sokki Kenkyuji Co. Ltd, Japan) with a precision of 0.001 mm and a 10-channel data-longer were used to record creep strain.

Creep tests were performed on saturated sand specimens. In these tests, in order to analyze the creep behaviour due to principal stress difference (σ'), the mean principal stress (σ'_m), was kept constant for all tests of the same test series, where:

$$\sigma'_m = (1/3)\ (\sigma'_1 + 2\sigma'_3) \quad (1)$$

and

$$\sigma' = \sigma'_1 - \sigma'_3 \quad (2)$$

The maximum shearing strain (γ) was calculated using the following formula:

$$\gamma = \varepsilon_1 - \varepsilon_3 \qquad (3)$$

Where

$\varepsilon_3 = (1/2)\ (\varepsilon_\nu - \varepsilon_1)$

ε_1 = Axial strain

ε_ν = Volumetric strain

ε_3 = Radial strain

Experimental Results and Discussion

In most practical cases, where saturated cohesionless soils are involved in stability problems, the rate of application of disturbing forces is so slow that any change in pore water pressure induced by the loads are dissipated as the loading progresses with time. Thus, the strength characteristics of interest are those developed under drained conditions in the laboratory (Fukushima and Tatsuoka, 1984).

Drained triaxial creep tests were performed under different constant mean effective principal stress (σ'_m) for a period ranging from few minutes to several days depending upon the stress level, as given in Table-1. In these tests, samples were consolidated under a constant confining pressure referred to here as precompression stress (σ'_{pc}) and then tested at constant mean effective pressure (σ'_m) keeping confining pressure as constant during the test.

The relationships between shearing strain (γ) and time t_o under various intensities of principal stress difference (σ') and mean effective principal stress (σ'_m) of 128 KPa, keeping confining pressure constant are shown in Fig. 2. Similar relationships are obtained at mean effective stress (σ'_m) of 148 KPa and 197 KPa, as shown in Figs. 3 & 4 respectively. Figs. 5, 6 & 7 show the same relationships replotted on a semi-log scale after regressing the experimental data using SAS package. It is evident from these graphs that the shearing strain (γ) increases linearly with the log of time, to approximately over a range of 100 minutes as long as the applied stress difference is less than a critical stress. This relationship can be expressed approximately by the following equation at constant deviatoric stress as long as the applied stress difference is less that a certain critical stress

$$\gamma = A + B \log t_o \qquad (4)$$

where A & B are intercept and slope of equation (4) respectively. Values of A and B are constant for a particular deviatoric stress but will vary with

TABLE 1
List of Tests Performed at Relative Density of 85%

Test No.	Mean Effective Stress σ'_m KPa	Deviatoric Stress σ' KPa	Axial Stress σ'_1 KPa	Confining Stress σ'_3 KPa
1	128	99	194	95
2		123	211	87
3		148	227	79
4		160	235	75
5		168	240	72
6		177	247	70
7		181	249	68
8		187	253	66
9	148	57	186	129
10		84	204	120
11		118	227	109
12		217	292	75
13		222	296	74
14		242	309	67
15		247	313	66
16	197	59	237	178
17		118	276	158
18		128	283	155
19		207	335	128
20		232	352	120
21		247	362	115
22		261	371	110
23		266	375	109

the variation *i* deviatoric stress.

The slight deviation from the linear behaviour observed after elapsed time of 100 minutes (Figs. 2, 3 & 4) may be due to dilatency of sand and will be discussed later. At a stress level higher than the critical stress, some curves appear to increase concave upward, leading to creep failure.

The variation of creep strain rate with time under various levels of stress is shown in Figs. 8, 9 and 10 for mean effective stress (σ'_m) of 128, 148 and 197 KPa respectively. It is observed from these Figs. that $\log(d\gamma/dt_o) - \log t_o$ relationships at stress below a specific level are expressed by descending curves in a concave downward manner. The uppermost curve of Figs. 8 to 10 have a distinct points of minimum creep strain rate and

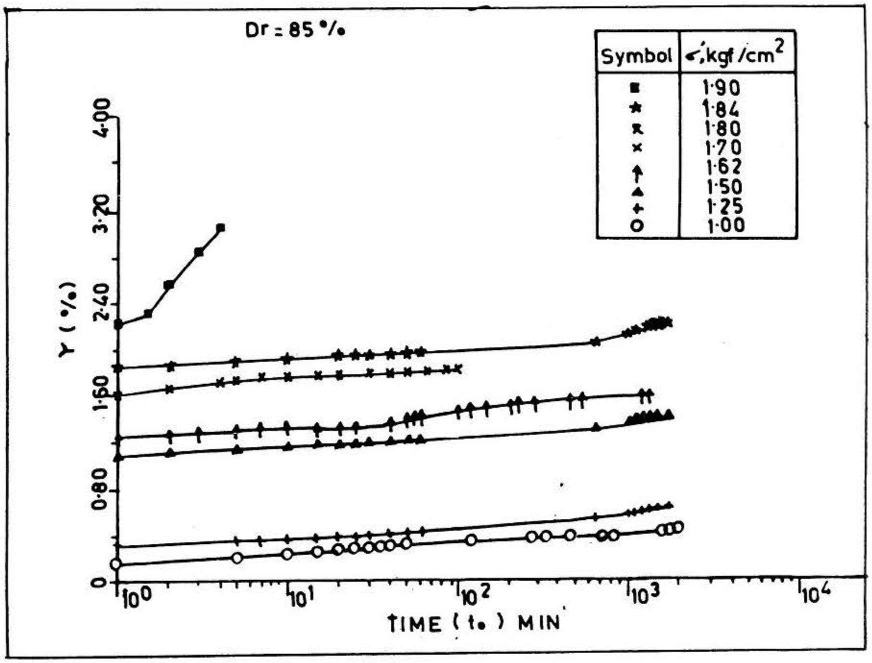

FIGURE 2 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 128 KPa).

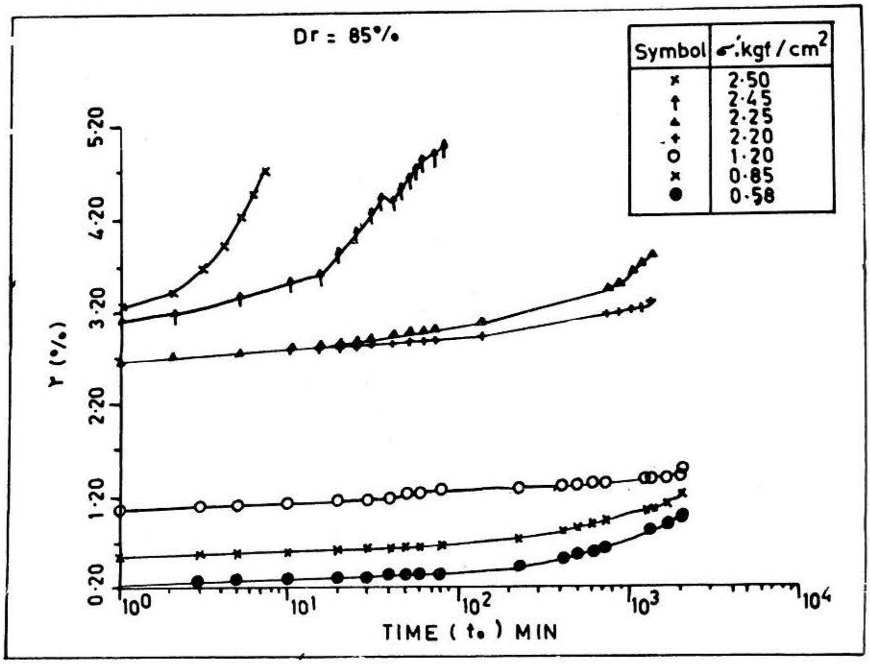

FIGURE 3 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 148 KPa).

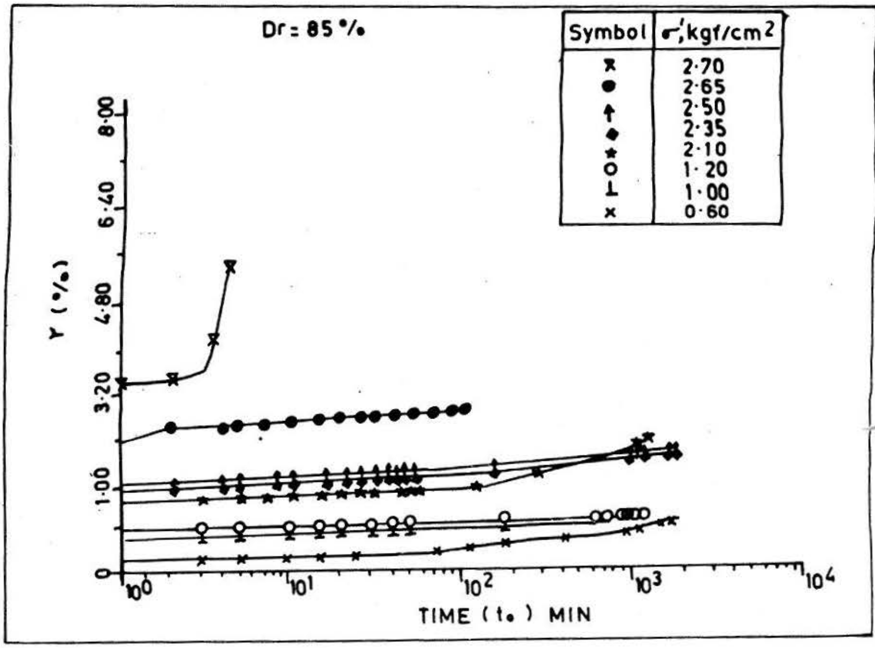

FIGURE 4 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 197 KPa).

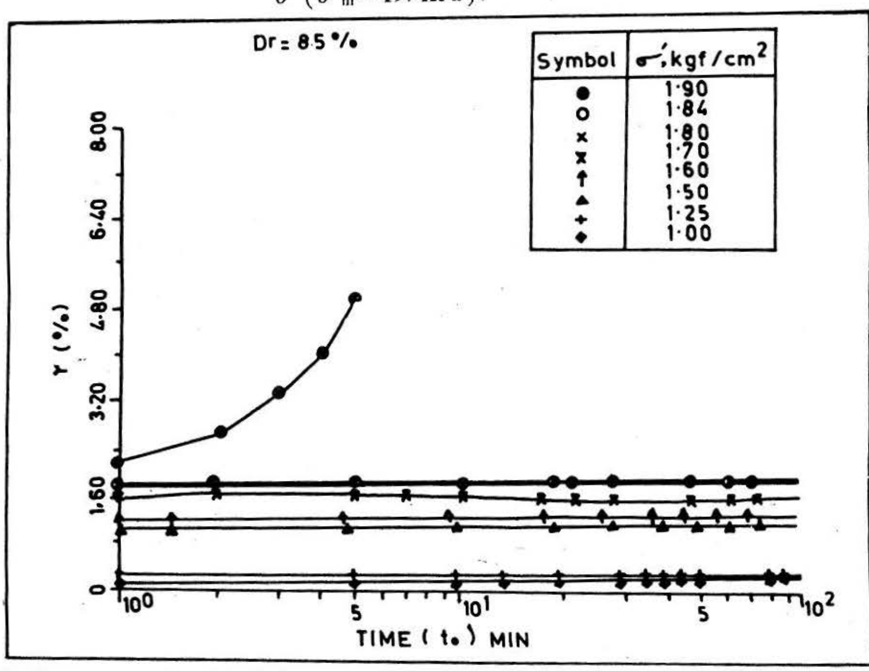

FIGURE 5 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 128 KPa).

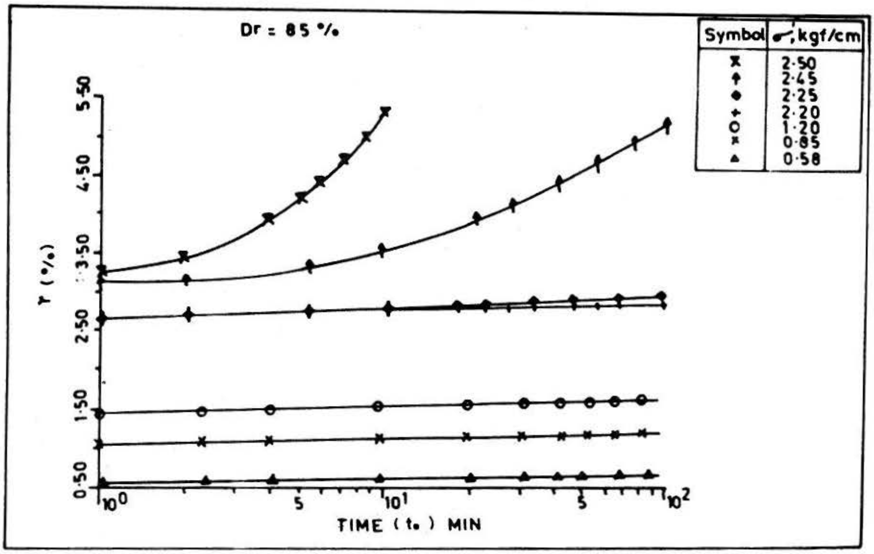

FIGURE 6 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 128 KPa) – Regressed Data.

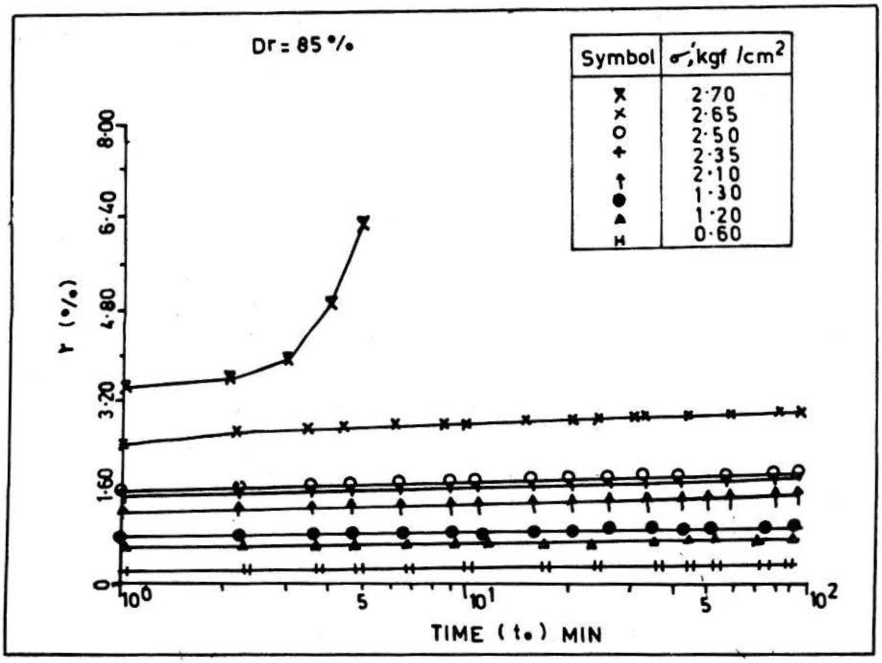

FIGURE 7 γ – log t_0 Relationship Under Various Levels of Stress Difference σ' (σ'_m = 197 KPa) – Regressed Data.

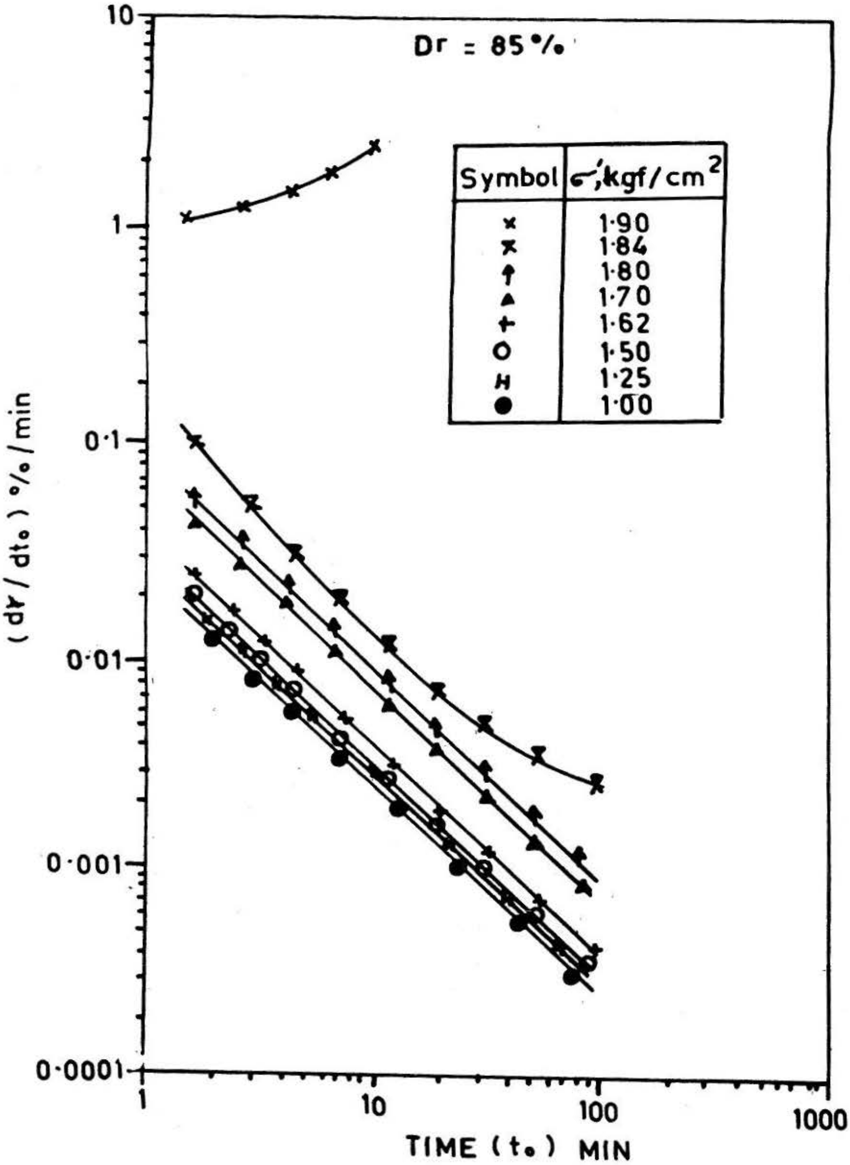

FIGURE 8 Log (dγ/dt₀) – Log t₀ Relationship at Mean Effective Stress (σ'_m = 128 KPa).

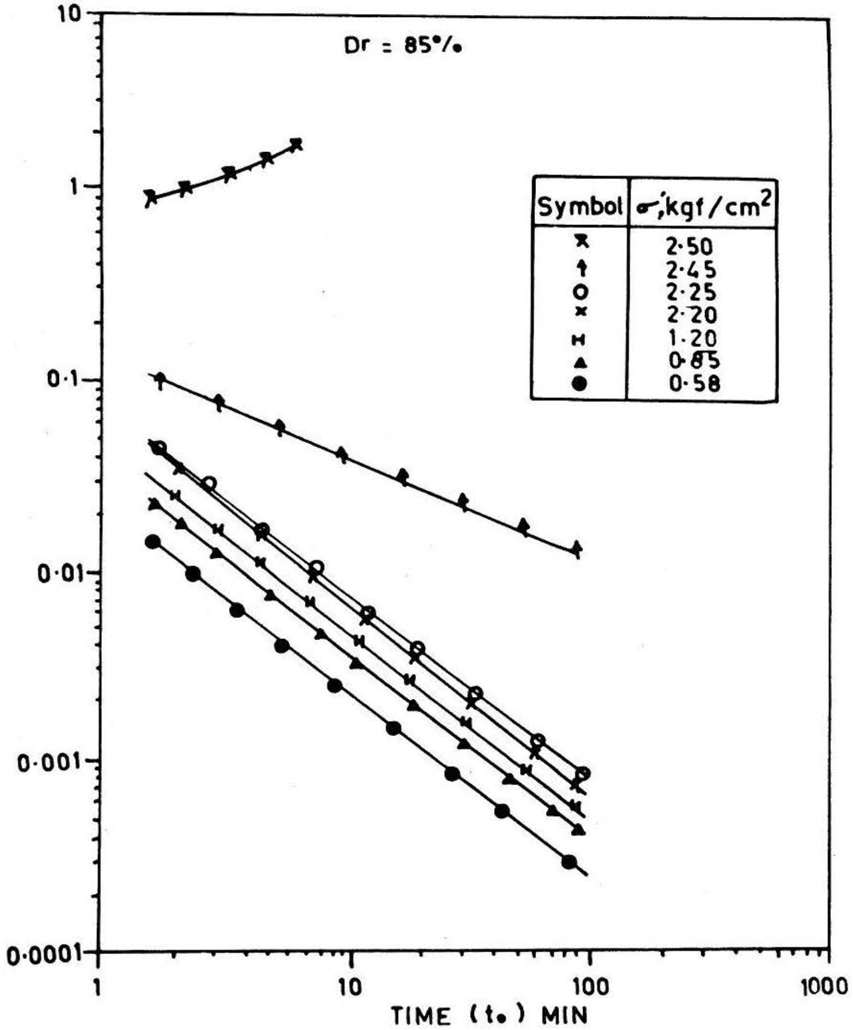

FIGURE 9 **Log (dγ/dt₀) – Log t₀ Relationship at Mean Effective Stress (σ'm = 148 KPa).**

after passing the minimum points, they rise at an accelerating rate towards creep failure.

Volumetric Change of Specimen

Figures 11, 12 and 13 show relationship between volumetric strain (ε_v) and elapsed time (t_o) obtained from drained triaxial creep tests under constant mean effective stress (σ'_m) of 128, 148 and 197 KPa respectively. It is evident from these figures that measured volumetric strain exhibits linear behaviour upto about 100 minutes and beyond this time, changes drastically where volumetric strain (ε_v) versus time t_0 relationship appears as concave upward

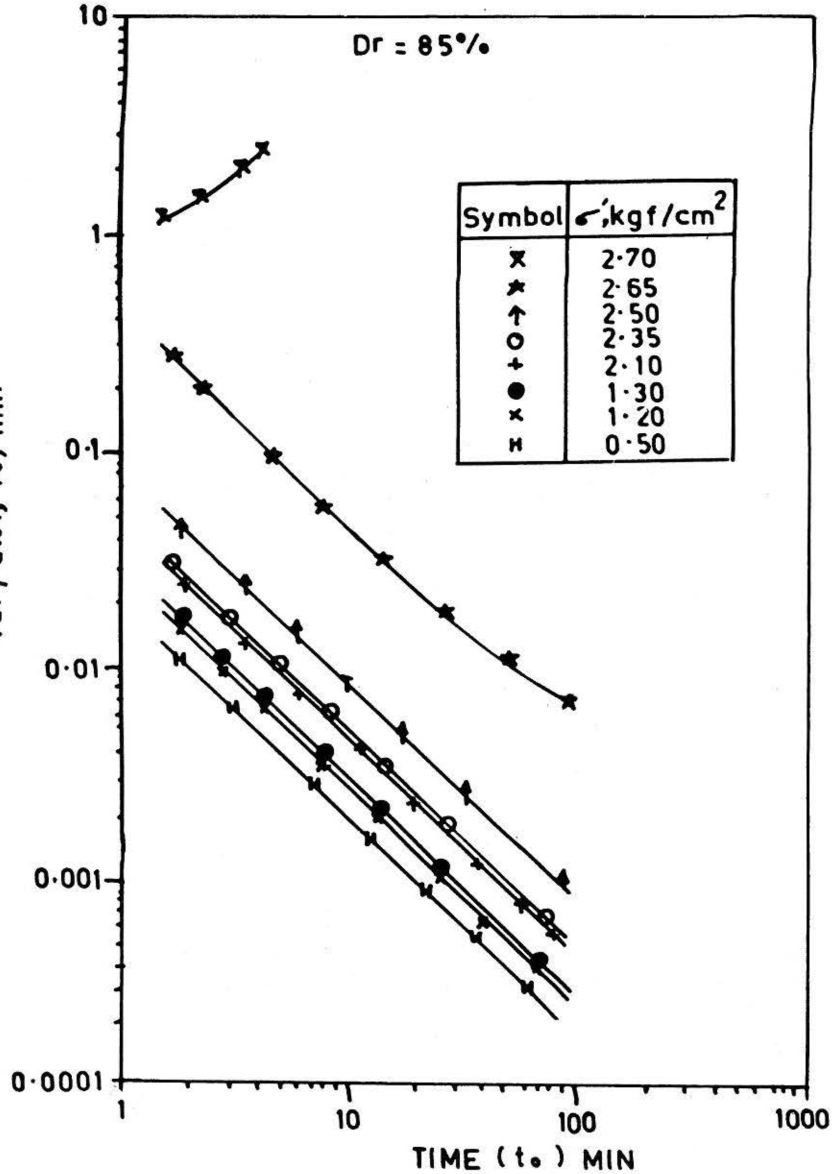

FIGURE 10 Log(dγ/dt₀) – Log t₀ Relationship at Mean Effective Stress (σ'_m = 197 KPa).

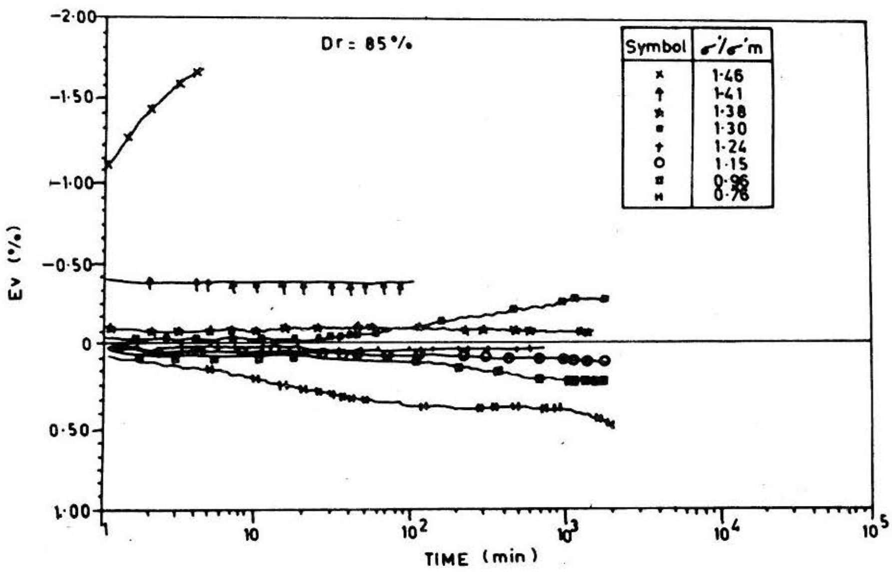

FIGURE 11 Relationship Between Volumetric Strain (ε_v) and Elapsed time t_0 (σ'_m = 128 KPa)

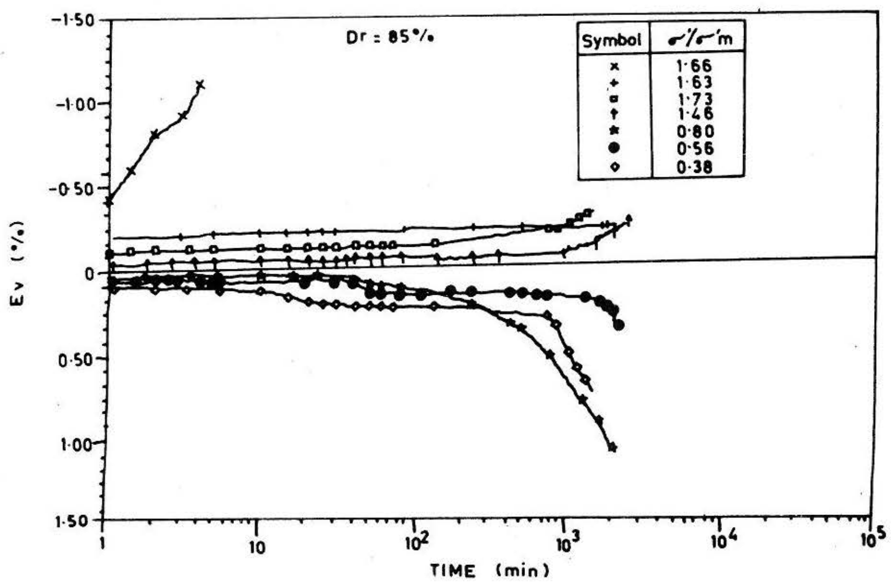

FIGURE 12 Relationship Between Volumetric Strain (ε_v) and Elapsed time t_0 (σ'_m = 148 KPa)

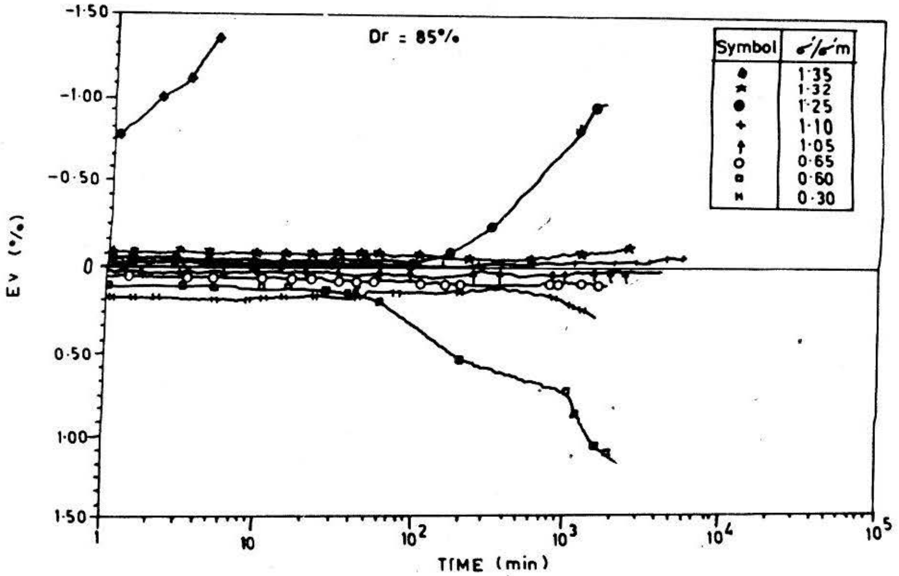

FIGURE 13 Relationship Between Volumetric Strain (ε_v) and Elapsed time t_0 (σ'_m = 197 KPa)

upward or downward, depending whether volumetric strain (ε_v) increases or decreases as a function of time. Also, at high confining pressure, a concave upward trend is observed.

Past studies on behaviour of sand (Murayama and Shibata 1964) show that the volumetric strain (ε_v) due to dilatency may be expressed by the following relation:

$$\varepsilon_v = D\ (\sigma'/\sigma'_m) \tag{5}$$

where D is a coefficient depending on dilatency and initial void ratio. Furthermore, D seems to be a constant within a certain limit of stress ratio (σ'/σ'_m). In our case mean effective stress (σ'_m) is different in value before the start of creep as compared to its value after the start of creep ($\sigma'_m = \sigma'_{PC}$) and as a consequence, a change in volumetric strain is observed.

Elastic Limit Stress

Elastic limit stress, known as critical limit stress, is defined as the stress upto which sand behaves elastically. The lower yield stress (σ_0), defined as the apparent internal friction of soil has been theoretically and experimentally proven to be absent in the case of sand (Murayama, 1983).

Figure 14 shows relationship between strain rate ($d\gamma/dt_0$) versus deviatoric stress (σ') at selected elapsed times of 1.5, 2.5 and 3.6 minutes for mean

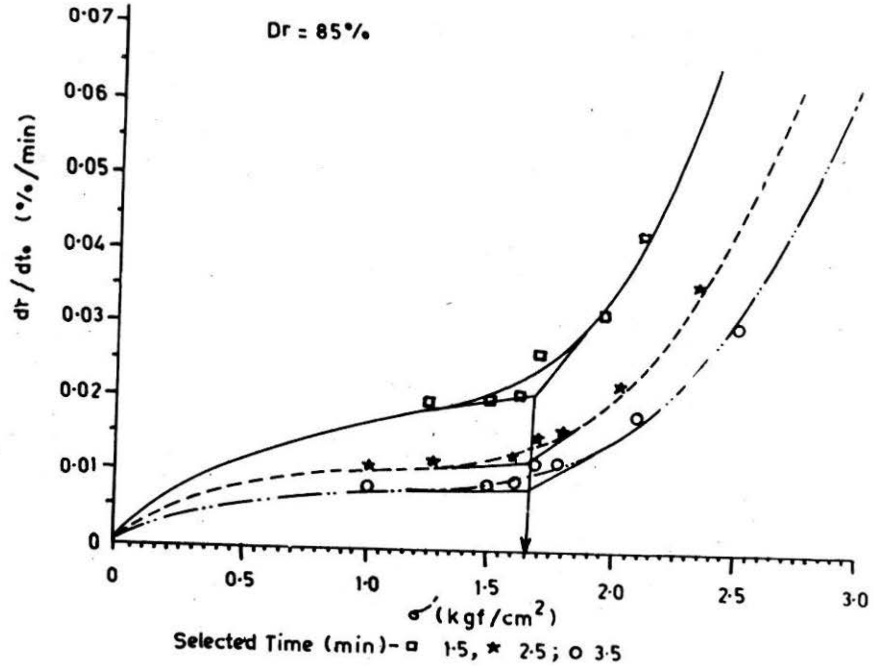

FIGURE 14 Relationship Between Strain Rate ($d\gamma / dt_0$) and Stress difference (σ') at σ'_m = 128 KPa

effective stress (σ'_m), of 128 KPa, considering lower yield stress (σ_0) is absent. It is observed that there is an inflection point at a stress of 165 KPa. Beyond this stress level, curve rises in concave upward direction. The inflection point of Fig. 14 is equal to elastic limit stress (σ_{e1}), which is found to be 165 KPa. Similarly, Figs. 15 and 16 show the same relationship for mean effective stress (σ'_m) of 148 and 197 KPa respectively. It is evident from Figs. 15 and 16 that the elastic limit stress (σ_{e1}) is 165 KPa. Also, from Figs. 14 to 16 , it is observed that each curve is almost linear within the stress range *upto 165 KPa. Beyond this stress range, all curves* rise sharply in a concave upward direction.

Conclusions

From the results of drained triaxial creep tests on dense sand, the following conclusions can be drawn:

1. Creep behaviuor of tested dune sand may be expressed by a linear relationship

$$\gamma = A + B \log t_o$$

The intercept (A) and slope (B) of this relationship are constant for a particular deviatoric stress. However it will vary with variation in deviatoric

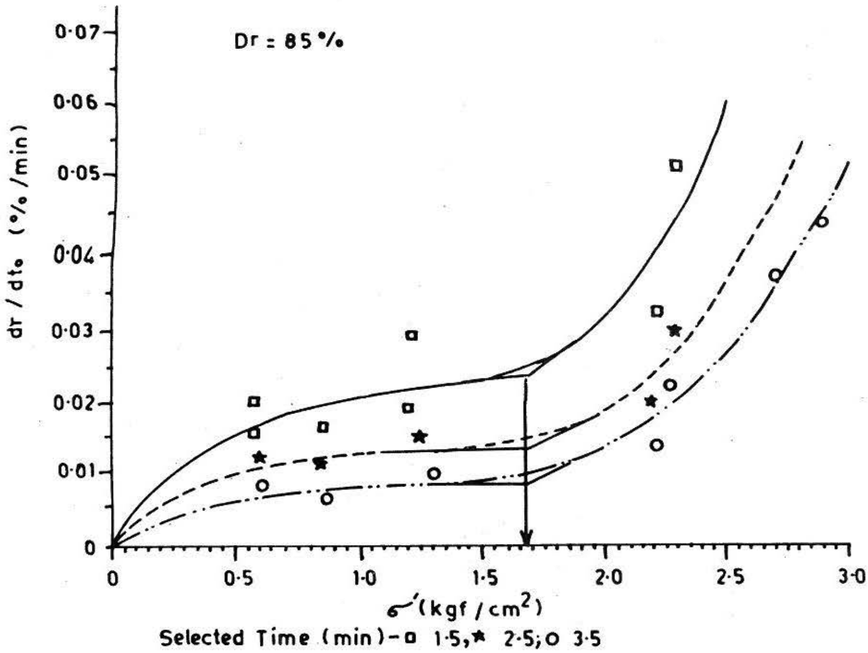

FIGURE 15 Relationship Between Strain Rate ($d\gamma / dt_0$) and Stress difference (σ') at σ'_m = 148 KPa

stress.

2. The creep strain-time relationship, depending of stress level applied, may be depicted by a straight line between creep strain versus log of time at lower stresses. However, at higher stress levels, it can be represented by a polynomial relationship between creep strain and log of time.

3. The increase *n* volumetric strain appears negligible upto elapsed time of about 100 minutes for all samples tested. However, the volumetric strain increases rapidly with time after an elapsed time of 100 minutes due to dilatency.

4. Based on test data, it is found that the elastic limit stress is a constant for a particular density.

Acknowledgements

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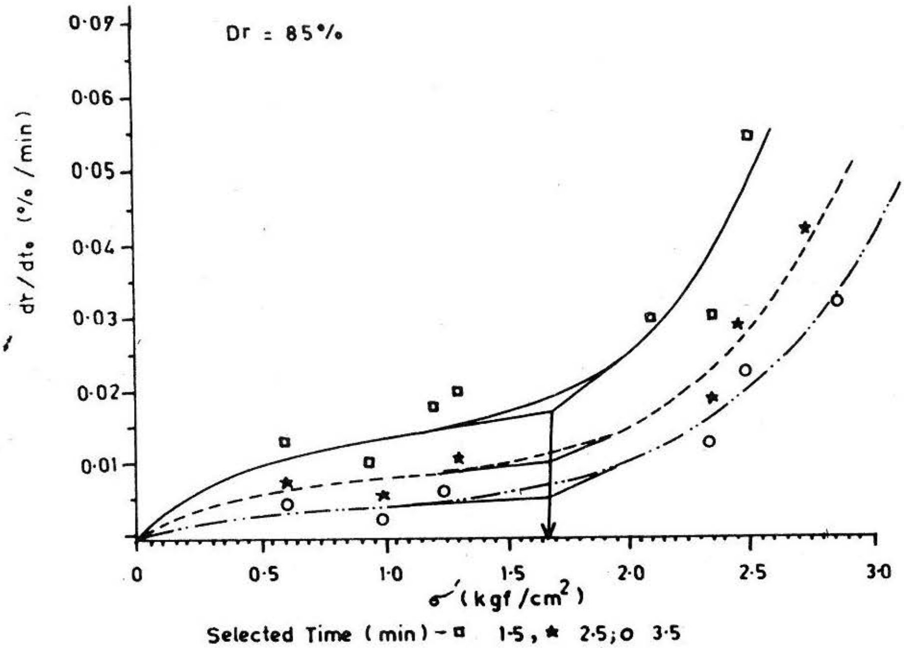

FIGURE 16 Relationship Between Strain Rate ($d\gamma / dt_0$) and Stress difference (σ') at σ'_m = 197 KPa

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