Accelerated Consolidation of Coir Reinforced Lateritic Soils with Vertical Sand Drains for Pavement Foundations

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Abstract:

It is found that sub-grade soils of lateritic origin encountered in the construction of highway embankments in various regions of India, often comprise intrusions of clayey soils that result in large settlements during constructions, and differential settlements at later stages. This necessitates the use of appropriate soil improvement techniques to improve the load-carrying capacity of pavements. This work deals with the accelerated consolidation of un-reinforced and coir-reinforced lateritic soils, provided with three vertical sand drains. The load-settlement characteristics were studied for various preloads ranging from 50kg (0.0013 N/mm^2) to 500kg (0.013N/mm^2). Studies were performed using circular ferro-cement moulds. It was observed that at lower preloads up to 300kg, the relative increase in consolidation (Cr) for randomly reinforced soil with vertical drains was significantly higher than that of un-reinforced soil without vertical drains. Also, the Cr for un-reinforced soil with vertical drains was quite higher than that of un-reinforced soil without vertical drains, with values above 40.61%.

However, in the case of higher preloads of 450kg and 500kg, the Cr for randomly reinforced soil with vertical drains was insignificant, and the Cr for un-reinforced soil with vertical drains remained slightly higher at around 6.23% for similar comparisons. The aspect-ratio of coir fibers used was 1: 275.

Keywords: *vertical sand drains, accelerated consolidation, coir reinforcement, laterite.*

Introduction

It is a challenging task to design pavement structures for various types of soil conditions. Clayey and silty soils have lower permeability, and due to this reason, the settlement and consolidation take longer durations to occur. The time taken for settlement is thus a crucial factor that can influence the construction of embankments and sub-grades for roadways and rail-tracks.

In this connection, the use of natural fibers in soil stabilization, and in providing vertical sand drains is expected to play a vital role in highway embankment constructions. Additionally, it is observed that vast tracts of areas in coastal regions are either water-logged, or exhibit the prevalence of soft-clay or silty sub-grades.

Natural geo-textiles are made of natural fibers of coir, jute, and of similar materials, while synthetic geo-textiles are made of polymers and petrochemical derivatives. It is found that natural fibers of coir made from processed husk of coconuts can be used effectively in the improvement of sub grade strength mainly due to enhanced consolidation as a result of accelerated drainage of moisture due to presence of coir fibers.

The use of natural fibers such as coir, in providing vertical sand drains and in providing soil-reinforcement, is expected to accelerate the process of consolidation by permitting pore-water pressures to dissipate easily when subjected to overburden pressures.

Francis Buchanan

First gave the name *laterite,* to describe "ferruginous, vesicular, un-stratified, and porous soil with yellow ochre's due to high iron content, occurring in Malabar, India". Laterite soil can be found to occur above underlying shedi soil (or fine silty soil) in almost all parts of Dakshina Kannada and Udupi districts. Laterite soil is comparatively stronger than shedi soil.

2.0 Scope and objectives of the present study

In well drained soils, a large amount of consolidation takes place during the construction stage. However, soft soils must be further strengthened by applying loads in stages such that the bearing capacity of the soil improves. In the case of consolidation of weak soils especially as in the construction of embankments for highways, pore-water pressure builds up under the overburden pressure and surcharge loads.

The use of vertical drains will shorten the length of the horizontal drainage paths. When the water particles come under the influence of vertical drains accelerates the consolidation process. The enhanced dissipation of pore-water due to the presence of natural fiber reinforcements and the overburden pressures imposed by road construction machinery will result in further acceleration of the consolidation process in soil sub-grades of embankments. The subsequent decay of natural fibers after two to three years will not affect the strength and stability of soil sub-grades of highway embankments, since consolidation of the soil layers has already been achieved.

From a literature review, it is found that most of the previous investigations concentrated on the study of the strength and the stiffness of soils reinforced with coir, under the influence of surcharge loads, while a few studies examined the effect of the use of vertical drains.

The objectives of the present study include the following:

- To perform basic laboratory investigations such as grain size analysis, consistency limits, CBR tests, tests for standard and modified compaction tests for lateritic soil samples as specified by Indian Standard (IS) codes.

- To measure the load-settlement properties and consolidation of fully saturated confined and un-reinforced lateritic soil without the use of vertical drains for soil samples drained at the top and bottom.
- To measure the load-settlement properties and consolidation of fully saturated confined and un-reinforced lateritic soil with the use of 3 vertical drains.
- To measure the load-settlement properties and consolidation of fully saturated confined randomly reinforced lateritic soil provided with 3 vertical drains
- Further analysis, interpretation, and comparison of results.

3.0 Literature Review

Lee et al (1989) conducted tests using vertical drains made of natural fiber such as jute and coir for soil improvement simulating field conditions, where it was observed that the axial and filter permeability of fiber drains was higher than 10^{-5} m/sec for consolidation pressures upto 400 kN/m^2.

Some of the investigations in the field of application of coir-fibers **(Mandal et al, 1989; Charan et al, 1995)** highlighted the significant impact that natural fibers could make in providing temporary stabilization for embankments for highways and railways through the use of fiber-reinforced vertical drains.

Stapelfeldt (2006) observed that preloading, and the use of vertical drains, increased the shear strength of the soil, reduced the soil compressibility, reduced the permeability of the soil prior to construction, and prevented large-scale differential settlements. See **Fig.1**, and **Fig.2**.

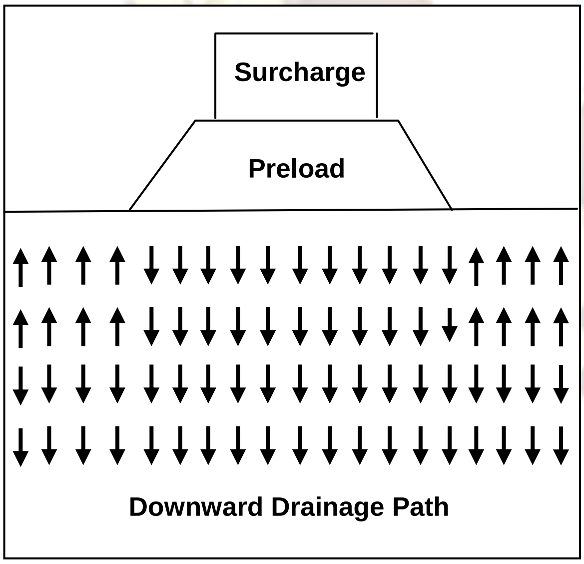

Fig.1 Preloading without vertical drains

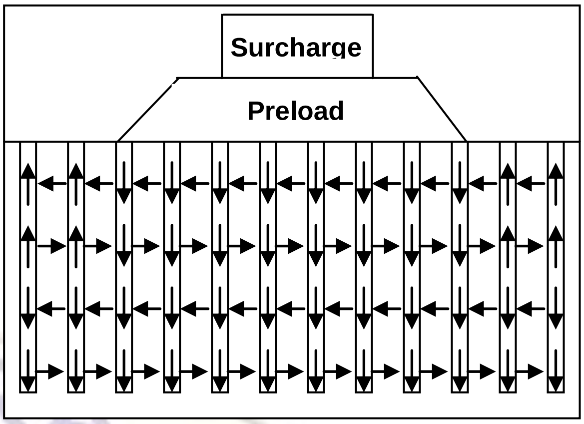

Fig.2 Preloading with Vertical Drains

Terzaghi (1923) provides the basic theory for such one-dimensional consolidation for saturated conditions and also provides the strain formulation**.** The relationship between the final settlement (S_f) and the settlement (S_t) at time t was be expressed as (**Terzaghi, 1923**)

$S_t = U_v \cdot S_f$ (Eq. 1)

The expression for U_v, the average degree of consolidation at depth z at any instant t was given by **Terzaghi (1943**) as,

$U_v = 1 - \sum_{m=0}^{\infty} (2/M^2) \exp(-M^2 T_v)$ (Eq.2)

where Tv = time factor (non dimensional) = $(C_v t)/H^2$; C_v = coefficient of vertical consolidation (m^2/s) = k/ ($\gamma_w m_v$); k = permeability coefficient; m_v = coefficient of volume compressibility = $a_v/(1+e_0)$; e_o = initial void ratio; a_v = coefficient of compressibility = Δ_e/Δ_p; t = time in seconds; H = total distance of drainage path which is equal to the thickness of the layer (in m.) for soil subjected to top drainage, and is equal to half the thickness of the layer (in m.) for soils drained at the top and the bottom; and $M = \pi (2m+1)/2$ for m = 0, 1, 2…α.

From the above formulation, it is evident that consolidation is dependent on the permeability of the medium. Therefore, it is expected that the use of vertical drains will have a profound effect on accelerating the consolidation process.

4.0 Materials Used & Tests Conducted

The materials used for the tests include the lateritic soil, sand and coir. The lateritic soil obtained from the field was tested in the laboratory for the basic properties like specific gravity, grain size distribution, consistency limits, and compaction, CBR and permeability tests. The results are tabulated in the **table 1.** The sand used for the present study was the locally available river-sand passing through 4.75 mm IS sieve with a coefficient of curvature (C_c) of 0.82, and a uniformity coefficient (C_u) of 1.7, was used for the preparation of vertical drains. The sand selected satisfies the general requirements of permeability and piping.The properties of sand are shown in **table 2**. All the tests were performed as per IS specifications.

Table: 1 Geotechnical properties of lateritic soil

Sl No.	Property	Values
1	**Specific gravity**	2.68
2	**Grain size distribution**	
	a) Gravel %	32.66
	b) Sand %	48.82
	c) Silt %	16.52
	d) Clay %	2.00 %
3	**Consistency Limits**	
	Liquid limit %	34.80
	Plastic limit %	26.71
	Plasticity index %	8.09
	Shrinkage Limit %	22.55
4	**Engineering Properties**	
	I.S Light Compaction	
	a) Max dry density, $\gamma_d$max (gm/cc)	1.99
	b) O.M.C %	13.20
	I.S Heavy Compaction	
	a) Max dry density, $\gamma_d$max (gm/cc)	2.02
	b) O.M.C %	12.99
5	**CBR %**	
	I.S Light Compaction a) OMC condition % b) Soaked condition %	 39.0 6.0
	I.S Heavy Compaction a) OMC condition % b) Soaked condition %	 17.0 14.0
6	**Un confined compression test**	
	I.S Light Compaction (MPa) I.S Heavy Compaction (MPa)	0.034 0.036
7	**Co-efficient of permeability**	
	I.S Heavy Compaction (cm/sec)	1.55×10^{-7}

Table 2 Properties of sand used in this study

Property	Result
Coefficient of curvature, Cc	0.82
Coefficient of uniformity, Cu	1.97
D 15,mm	0.35

5.0 Determination of Optimal Fiber Content for Soil Samples Using CBR Tests

CBR tests were conducted as per IS 2720: Part VII (1983) with various percentages of coir fiber content randomly reinforced with 0.25 %,0.5 %, 0.75 %, 1.0 %, and 1.25 % of coir, and the CBR values at 2.5 mm and 5 mm penetrations were noted for soaked and un-soaked soil samples. The CBR values were determined for the soil sample, and the optimum fiber contents are reported as in **Table 3**

Table 3 Optimum fiber contents (OFC)

Sl. no	Soil	OMC (%)	OFC (%)
1	Laterite	15.94	1.00

6.0 Tests for Consolidation

The test for accelerated consolidation involves several stages such as, preparation of the soil sample, soaking of specimens, loading, and installation of vertical drains and preloading of soil samples. The soil sample to be tested was prepared as mentioned above, and the water contents required to prepare soil beds at 80% MDD were determined from the compaction curves. It was decided to perform tests at moisture content lesser than the OMC in order to study the load-settlement characteristics effectively.

7.0 Experimental set up and methodology

Investigations were conducted for reinforced and un-reinforced soil specimens, with and without installation of vertical drains. These tests were conducted in order to evaluate the improvement in the bearing capacity due to the accelerated consolidation.

7.1 Tests for consolidation of Un-Reinforced soil without using Vertical Drains

In order to study the compressibility and consolidation of soil sample, a ferro-cement cylindrical test mould was used, as shown in **Fig. 3**, of 740 mm internal diameter, 850 mm height, and 30 mm wall thickness. The test mould was provided with an inlet pipe at the top and an outlet pipe at the bottom, both of 20mm diameters, to permit soaking of the soil sample, and drainage of water. The test mould was placed on leveled ground.

Fig 3 Ferro-cement cylindrical test mould

A sand layer of 100 mm thickness was provided at the bottom of the Ferro-cement tank to act as a permeable layer, and was compacted to a density of 1.53 g/cc. Above this layer, a jute textile was provided to act as a separator. Over this, three layers of the soil sample, each of 200 mm thickness, were placed and compacted to 80% of the MDD. The soil and the sand layers were compacted to the desired thickness, and respective densities using a steel rammer (of 885 mm height, 140 mm diameter, and 11.5 kg weight) and a wooden rammer (of 870 mm height, 40 mm diameter, and 1.17 kg weight). On top of the three layers of compacted soil sample, a layer of jute textile was placed. A layer of sand of 100mm thickness compacted to a density of 1.53 g/cc was provided at the top, to act as level-surface for the application of preloads.

The soil sample in the cylindrical test mould possesses the same characteristics as mentioned in the sections above. A flat surface made of treated perforated plywood (of 730 mm diameter, and 12 mm thickness) was provided above the sand layer. A schematic diagram of the test set up is shown in **Fig 4**. The details of the components used in this experiment are listed below:

1. Cylindrical Ferro-cement mould
2. Bottom layer of sand of 100 mm thickness
3. Bottom layer of jute-textile as a separator
4. Three layers of soil, each of 200 mm thickness
5. Top layer of jute-textile as a separator
6. Top layer of sand of 100 mm thickness
7. Loading platform of treated plywood
8. Standard steel weights
9. Dial gauges of 0.01 mm least count
10. Water inlet
11. Water outlet

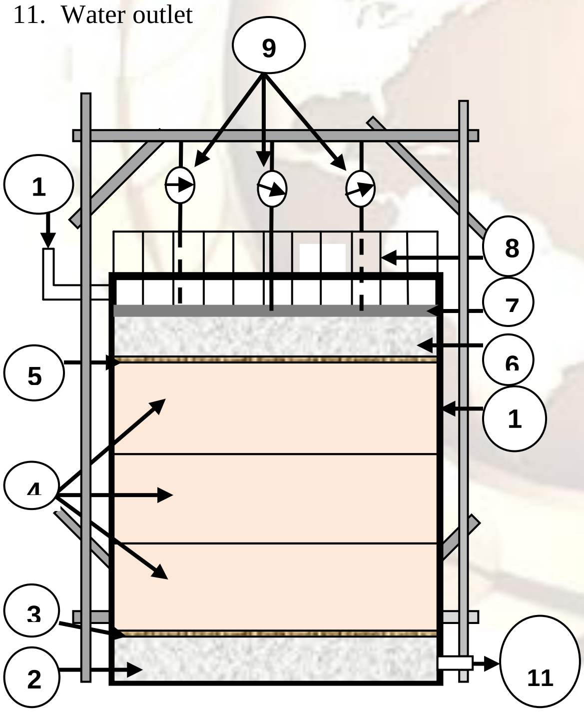

Fig. 4 Schematic diagram of the test setup without vertical drains

7.2 Tests on consolidation of Un-Reinforced soil using three vertical drains

The test set up and procedure for test on consolidation of un-reinforced soil sample is the same as that explained above. A Ferro-cement cylindrical test mould with vertical drains of 100 mm diameter and 600 mm height are installed in a triangular pattern such that the center to center distance between the adjacent drains is 350 mm. This arrangement is considered to be more effective as it is expected to result in uniform consolidation between the drains due to uniform center to center distances, when compared to vertical drains installed in a square pattern The radius of influence (R) of a vertical drain depends upon the spacing (S) between drains. In the case of cylindrical drains installed in triangular pattern the radius of influence (R) can be computed from the empirical formula.

$$R = 0.546 \times S \quad \text{(Eq. 4)}$$

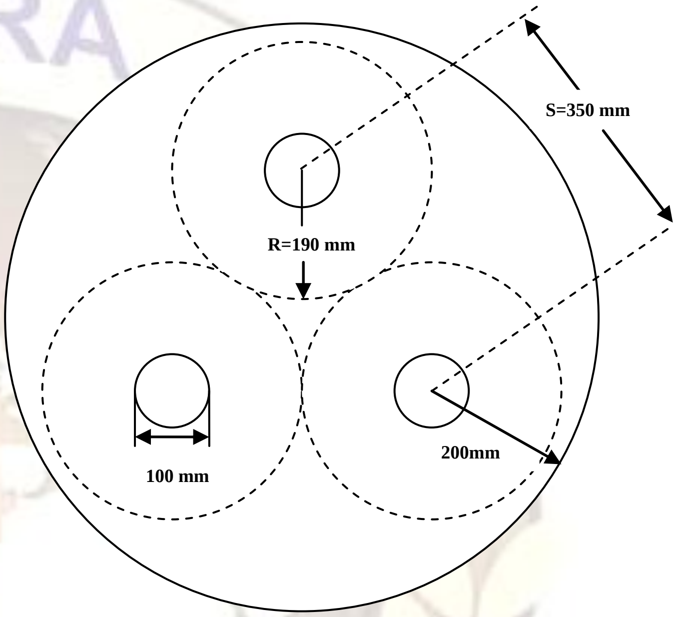

Fig. 5 Influence zone for triangular pattern of drains

Thus for vertical drains of 100 mm diameter and center to center spacing of 350 mm between the drains, the radius of influence can be obtained as 190 mm based on **Eq. 4**. The vertical drains of 600 mm height were installed with the help of sampling tubes of 100 mm diameter inserted into sleeves made of jute fabric. See **Fig. 5**. **Fig.6a** and **Fig.6b** provide a clear view of the installation of vertical drains.

The sampling tube enclosed in the jute sleeves, were then filled in two layers with sand randomly mixed with 1% of coir fibers by weight of sand for a height of 200 mm by compacting with a wooden tamping tool with 15 blows per layer to obtain a compacted density of 1.08 g/cc. The tubes were gradually withdrawn when each layer of soil sample of 100 mm was compacted. Smears developed due to the disturbance to the soil while installing vertical drains, can result in reduced soil permeability around the smear zone, restricting the rate of consolidation. However, in this investigation, since the vertical drains were installed in a simultaneous build-up procedure, the smear effects are assumed to be negligible.

Fig.6a Installation of vertical drains

Fig.6b Removal of casing for the third vertical drain

7.3 Tests on Consolidation of Randomly Reinforced soil using Three Vertical Drains

In this part of the experiment, the soil used in the test mould was randomly reinforced using coir. The optimum fiber content of 1% by weight of soil was adopted in these tests. The overall experimental set up remains the same as explained above.

8.0 Results

The load-settlement details are discussed below for un-reinforced soil samples without vertical drains (UR), un-reinforced soil samples with vertical drains (UR-VD), and reinforced soil samples with vertical drains (RR-VD).

8.1 Settlement characteristics: *UR soils*

Fig.7a provides details on the load-settlement characteristics for un-reinforced lateritic soils. Also, **Table 4a** provides details on the coefficient of consolidation (C_v) for various preloads for the soil sample tested. It can be observed that during the initial stages of loading using preloads of 50kg, 100kg, 150kg, and 200kg, the compaction of soil is considered to have taken place. This can be visualized from the corresponding increase in the rate of compaction in the above table. Thereafter, the rate of compaction for preloads of 250kg to 500kg shows a decreasing trend, indicating the commencement of the consolidation process.

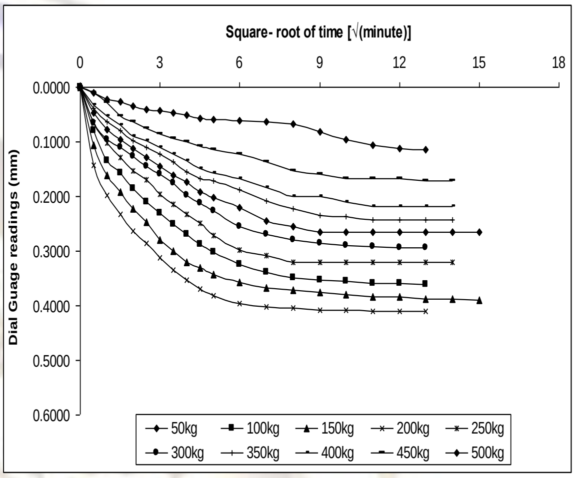

Fig. 7a Load-settlement: *UR* soils

8.2 Settlement characteristics: *UR-VD*

Fig.7b provides details on the load-settlement characteristics for un-reinforced vertically drained lateritic soils. **Table 4b** provides details on the coefficient of consolidation (C_v) for various preloads for the soil sample tested. In this case, it can be seen that during the initial stages of loading, as in the case of preloads of 50kg, 100kg, and 150kg, the compaction of soil is considered to have taken place. Thereafter, the rate of compaction for preloads of 200kg to 500kg shows a decreasing trend, indicating the commencement of the consolidation process.

Table 4a C_v values: *UR soils*

Co-efficient of consolidation C_v	
Preload (kg)	C_v
50	1.6190
100	1.9398
150	2.0165
200	2.0825
250	1.8687
300	1.7408
350	1.4694
400	1.4202
450	1.3819
500	1.3527

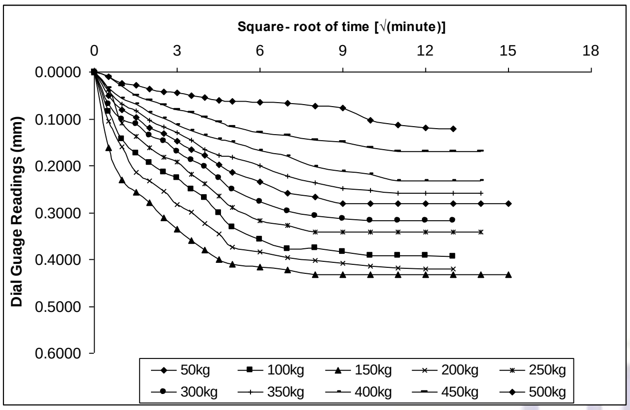

Fig.7b Load-Settlement: *UR-VD* soils

Table 4b C_v values: *UR-VD soils*

Co-efficient of consolidation C_v	
Preload (kg)	C_v
50	1.7174
100	2.0327
150	2.2683
200	2.1902
250	1.9107
300	1.8153
350	1.6399
400	1.5132
450	1.4529
500	1.4050

8.3 Settlement characteristics: *RR-VD soil*

Fig.7c illustrates details on the load-settlement characteristics for randomly-reinforced vertically drained soils comprising 100% Laterite. **Table 4c** gives details on the coefficient of consolidation (C_v) for various preloads. It can be observed that in the initial stages of loading, the behavior of the soil is almost the same as observed in the case of ***UR-VD*** *soil*. The rate of compaction for preloads of 200kg to 500kg shows a decreasing trend, indicating the commencement of the consolidation process. .

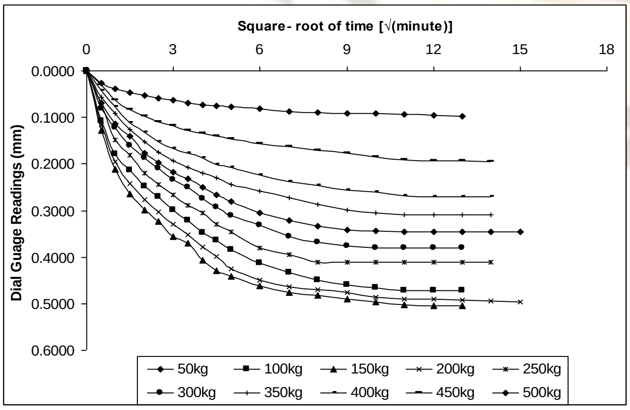

Fig.7c Load-Settlement: *RR-VD soils*

Table 4c C_v values: *RR-VD* soils

Co-efficient of consolidation C_v	
Preload (kg)	C_v
50	1.7287
100	2.0652
150	2.2882
200	2.2281
250	1.9395
300	1.8280
350	1.6397
400	1.5130
450	1.4528
500	1.4051

9.0 Discussion on comparisons of *UR* with *UR-VD*, and *RR-VD* soils

Fig.9 provides details of the load-settlement trends for a preload of 50kg for UR, UR-VD, and RR-VD test conditions for lateritic soils. Similar figures can be obtained and studied for preloads of 100kg, 150kg, 200kg, 250kg, 300kg, 350kg, 400kg, 450kg, and 500kg.

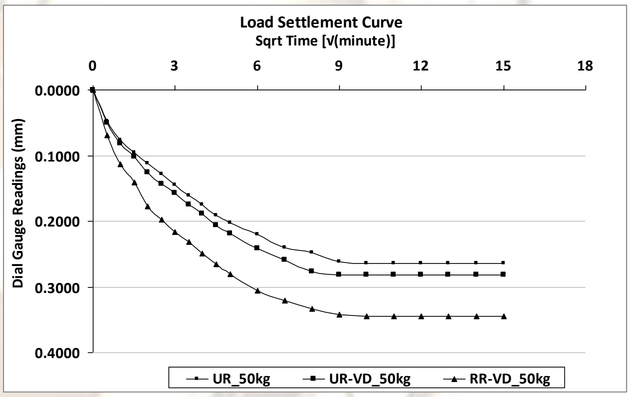

Fig.9 Load-Settlement trend for preload of 50kg

On observation of the load-settlement trends for various pre-loads, it was found that the 121st minute could be taken as a reference for comparison, since the soil was found to attain stability at this instance. In other words, the soil can be assumed to have been consolidated at this point in time.

The *relative increase in consolidation* achieved by un-reinforced soil samples provided with vertical drains, when compared to un-reinforced soil samples without vertical drains is expressed using the percentage of the increase in settlement of the soil sample provided with vertical drains, to the settlement of the un-reinforced soil without vertical drains. This is denoted as, *Cr (UR v/s UR-VD)*.

Similarly, the *relative increase in consolidation* achieved by randomly reinforced soil samples provided with vertical drains, when compared to un-reinforced soil samples without vertical drains is expressed using the percentage of the increase in settlement of the randomly reinforced soil sample provided with vertical drains, to the settlement of the un-reinforced soil without vertical drains. This is denoted as, *Cr (UR v/s RR-VD)*.

Table 5 provides details on the relative increase in consolidation at different preloads at the 121st minute of the load settlements for *UR v/s UR-VD*, and *UR v/s RR-VD* observations. In this table, it is observed that at lower preloads of 50kg, 100kg, 150kg, 200kg, 250kg and 300kg, the *Cr (UR v/s RR-VD)* is significantly higher when compared to *Cr (UR v/s UR-VD)*. It is seen that within this range of preloads, the *Cr (UR v/s RR-VD)* varies between 29.00% and 28.47%, while the *Cr (UR v/s UR-VD)* varies from 6.38% to 8.47%.

Table 5 Relative increase in consolidation at different preloads at the 121st minute of L-S

Preload (kg)	*Cr (UR vs UR-VD)* (%)	*Cr (UR vs RR-VD)* (%)
50	06.38	29.00
100	09.36	29.36
150	12.66	28.92
200	08.23	18.68
250	06.38	26.38
300	08.47	28.47
350	06.38	26.38
400	06.38	21.97
450	09.59	16.80
500	09.58	22.08

At medium level preloads of 350kg and 400kg the relative advantages of providing vertical drains and random reinforcements to the soil layer are found to be moderate. The *Cr (UR v/s RR-VD)* is found to range between 26.38 and 21.97%, while the *Cr (UR v/s UR-VD)* remains constant at around 6.38%.

However, at higher preloads of 450kg and 500kg the relative advantages of providing vertical drains and random reinforcements to the soil layer are not significant. The *Cr (UR v/s RR-VD)* is found to range between 16.80% and 22.08%, while the *Cr (UR v/s UR-VD)* remains constant at around 9.59%.

Thus it can be concluded from observations on higher preloads that for lateritic soils, the effect of reinforcing soils randomly with fibers is not effective when compared to the use of vertical drains.

10.0 CONCLUSIONS

The above sections focused on examining the rate of consolidation for lateritic soil for various test conditions using vertical drains. The observations made as part of this work will have an important bearing on the construction of road and railway embankments on expansive soil sub-grades.

Also, natural fibers of coir can be effectively used in further accelerating consolidation since the fibers allow pore-water pressures to dissipate easily when subjected to overburden pressures. Also, coir being a natural fiber undergoes decomposition once the soil attains sufficient strength through consolidation.

Laboratory investigations were performed in this study, for soil compacted in cylindrical moulds of 70cm dia and 85 cm internal height for laterite soil. Tests on drained soil samples were performed by providing 3 vertical sand drains reinforced with 1% coir fiber. The following are the conclusions drawn from this study.

From **Sections 8.0** and **9.0**, and **Table 5**, it is seen that the soil attained stability at around the 121st minute after application of the preloads. Using this as a datum, it was observed that on application of preloads higher than 450 kg, the effect of reinforcing soils randomly with fibers was not significant. The relative increase in consolidation for *UR v/s RR-VD* (denoted as *Cr (UR v/s RR-VD)*), was found to range between 16.80% and 22.08%, while the *Cr (UR v/s UR-VD)* values remained constant at around 9.59%. There seems to be an additional increase in the rate of consolidation by around 10% considering the average values. However, is relative advantage not significant considering the time and effort consumed in preparing randomly reinforced soil-layers?

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