Pneumatic Radial Loading To Ease Preloading – An Innovative Technique

V. Ramana Murty
Associate Professor, Department of civil engineering
National Institute of Technology,
Warangal, India
vrm_nitw@yahoo.com

P. Hari Krishna
Associate Professor, Department of civil engineering
National Institute of Technology,
Warangal, India
phknitw@gmail.com

Abstract— Soft ground improvement gained prominence all over the world in view of ever growing engineering activities for various purposes. In view of serious problems during and after construction in these deposits, vertical drains method using preloading is being frequently applied to improve these soil beds. However, in view of the difficulties associated with this technique, an alternative vacuum preloading technique was developed. But vacuum preloading is also limited to the available atmospheric pressure with inevitable technical difficulties. The present paper discusses an innovative technique of applying radial pneumatic pressure with the help of inflatable balloons/tubes. The drainage is facilitated along the surface of inflatable tubes by providing fabric strips/the traditional strip drains. The laboratory experimentation in test tank indicated that this technique has the potential for practical applications.

***Index Terms*— Pneumatic Radial Loading, Soft clays, Inflating Baloons, Strip drains.**

I. INTRODUCTION

Soft clays are characterized by high water content, high compressibility and low shear strength [1, 2]. These soils cover large portions of the world along the coast lines and estuaries [3]. Such deposits pose huge problems during construction and also after construction. Depending upon the in-situ condition of such deposits, different modification/ treatment techniques such as electro-osmosis, granular piles, deep chemical alteration and pre-loading were developed to promote the engineering activity in such deposits [4, 5, 6, 7]. Among the treatment alternatives, preloading with vertical drains has been widely used across the world to improve these soils so that the post construction settlements can be controlled [8, 9].

Preloading suffers from the difficulty of placement of large surcharge loading and its removal after the process of consolidation [10]. At several work sites, finding such loading material in large quantities is reported to be difficult and any erroneous placement of it leads to the shear failure of the ground. In the recent years, the atmospheric pressure is being used as a pre-load by spreading a geomembrane over the entire area to be treated which is referred to as vacuum preloading. However, such a loading can be a maximum of 10 t /m^2, equal to the atmospheric pressure; though in practice, it is reported to be limited to 8 t/m^2 withthe associated technical difficulties and higher costs[11]. Still efforts are being made to simplify the loading process in preloading technique.

In the present investigation, an attempt is made to insert inflatable balloons/ tubes in the simulated soft clay bed and gradually inflate them so that the consolidation is effected under radial pressure. The cotton fabric strips are attached to the surface of balloons to facilitate vertical drainage under inflation pressure. This experimental work is carried out in a test tank in the laboratory. The time period for 90% consolidation was calculated using the design chart for conventional sand drains and it is compared with that obtained from PLAXIS 3D software.

II. EXPERIMENTAL WORK

MATERIALS USED

A. Soil

Locally available clay is used to prepare the soft clay bed in a test tank. The properties of soil are determined as per relevant codes of practice (Table.1).

B. Inflatable Rubber Balloons

Tough inflatable rubber balloons are used to exert radial pressure in the drainage holes formed in the prepared clay bed. Balloons are placed inside the PVC pipes that are used to install balloons in the clay bed. 6 mm diameter rubber tubes are inserted through the inlet for balloons and tied them tightly with a thread. A cycle tube valve is attached at the outer end of the 6 mm rubber tube through which air is filled in the balloons using an air pump. The applied pneumatic pressure is recorded by a pressure gauge.

Table 1: Soil Properties

S. No	Property	Value
1	Specific gravity	2.7
2	Grain size distribution	
	Gravel (%)	0
	Sand (%)	26
	Silt (%)	43
	Clay (%)	31

IJSMS

3	Atterberg limits	
	Liquid Limit	58
	Plastic Limit	23
	Shrinkage Limit	13
4	I S Classification	CH
5	Compaction Properties	
	Optimum Moisture Content (OMC) (%)	19
	Maximum Dry Density (MDD) (g/cc)	1.75
6	Consolidation Properties	
	Compression Index	0.37
	Coefficient of consolidation (cm^2/s)	4.50×10^{-4}

C. Cotton Fabric Strips

The cotton fabric strips are attached to the surface of balloons in order to facilitate vertical drainage under a radial pneumatic pressure.

D. Test Tank

A steel test tank of 31 cm inner diameter and 30 cm height is used for the experimental work.

E. Procedure

The preliminary tests are carried out to check the tolerable inflation pressure of balloons used and also to get an idea of the feasibility of the proposed technique. The clay is dried and pulverized to pass through 4.75 mm sieve. This soil is compacted indry state in the test tank to a dry density of 1.3 g/cc simulating the soft clay density after providing a drainage layer of 2 cm thick sand at the bottom. On top of the clay bed, a layer of filter paper is kept, above which an 8cm thick sand layer is placed in order to provide drainage and also to prevent heaving of clay bed in vertical direction during the application of inflation pressure. Before compacting soil in the test tank, three PVC pipes of 12 mm inside diameter are held vertically, in triangular pattern at 13 cm centre to centre, with balloons inside them. Cotton strips are provided along the length of balloons and tied them at the top and bottom of balloons to facilitate vertical drainage. After each layer is compacted to the required density (Fig.1(a)), the PVC pipes are gradually raised by rotating them, leaving the balloons behind. The compacted soil bed with balloon system is flooded with water to saturate it(Fig.1(b)).



Fig. 1(A): Preparation of Clay Bed (B) Flooding the System For Saturation

After saturating the clay bed by flooding for 20 days, the balloons are inflated under radial pressures of 0.25, 0.5, 1.0 and 1.5 kg/cm^2, and these pressures are maintained for a time period required for 90% consolidation of the clay bed. The time for 90% consolidation is calculated using radial consolidation theory (Fig.2).

The time period for 90% consolidation is found to be about 0.35 days from radial consolidation theory. At the end of this time period, the surface water is drained and soil samples are collected at different depths to determine their density and water content. The clay bed is prepared afresh for each subsequent pressure increment to be applied.Laboratory oedometer test is conducted on the specimen subjected to 1.5 kg/cm^2 radial pressure to determine the preconsolidation pressure.

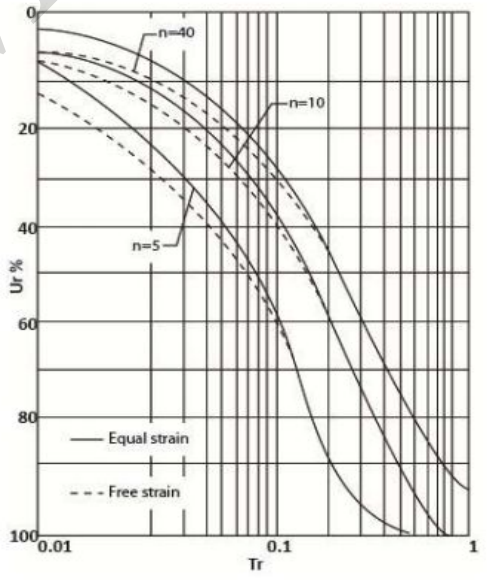


Fig. 2: Variation of degree of consolidation U_r with time factor T_r[12].

One more oedometer test is conducted on clay sample at a density of 1.3 g/cc, equal to the density in test tank, to determine the consolidation properties of the simulated soft clay bed.

IJSMS

F. Plaxis 3D Modelling

A model simulating the laboratory experiment with 20 cm thick clay bed and 2 cm thick bottom sand layer and 18 cm thick top sand layer is created in the PLAXIS 3D software to get the time required for 90% consolidation. The built-in soft clay model is used for the clay layer and hardening soil model is used for sand. Line drains in triangular pattern at a distance of 13 cm centre to centre are used in the model to simulate vertical drains. Vertical load equivalent to radial inflation pressure in the balloons is given as surface load above the clay layer in desired increments.

III. DISCUSSION ON TEST RESULTS

The test results obtained during the investigation and also the observations made in this study are presented and discussed below.

A. Vertical Drainage and Lateral Displacement

Upon the application of pneumatic pressure, air bubbles are observed around the inflated balloons along with mild flow of water through the cotton fabrics. At the end of consolidation process, the balloons are deflated and sand is observed to fill the holes formed around the balloons confirming lateral displacement of soil under radial pneumatic pressure (Fig.3).



Fig.3: Sand Filled In the Drain Holes

B. Density Variation

After the 90% consolidation period for each pressure increment, UD samples are taken at different depths to determine their density and water content (Table. 2)

Table 2: Density and Water Content Values of Clay Bed Corresponding To Pressure Increments

Pressure increment (kg/cm^2)	Dry density (g/cm^3)	Water content (%)
0.5	1.397	34
1.0	1.528	28
1.5	1.569	27

Oedometer test is conducted in the laboratory with initial dry density of 1.3 g/cc. The dry densities corresponding to the pressure increments used in oedometer test are calculated and compared with those obtained from the test tank. (Table.3)

From Table 3, it can be observed that the dry densities corresponding to each pressure increment in test tank and oedometer are close to each other, though the values from test tank are a little lower. The lower values in the test tank may be attributed to the presence of free surface at the topwhich is likely to allow a small volume change as against the closed oedometer system.

Table 3: Comparison of Dry Densities in the Test Tank and Oedometer Corresponding To Pressure Increments

Pressure increment (kg/cm^2)	Dry density(g/cc)	
	Test tank	Oedometer
0.5	1.397	1.432
1.0	1.528	1.551
1.5	1.569	1.588

At the end of pneumatic consolidation in the test tank under 1.5 kg/cm^2, the clay specimen extracted from test tank is further subjected to consolidation test in an oedometer and the preconsolidation pressure is determined. Figure. 4 shows the determination of preconsolidation pressure from the e - log p curve plotted after oedometer test.

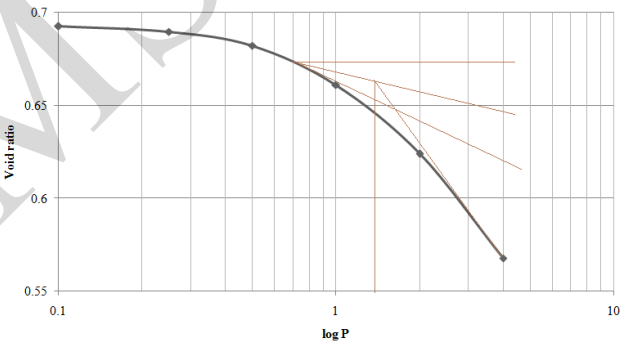


Fig.4: Preconsolidation pressure from e – log P curve

From the plot, it can be seen that the preconsolidation pressure is about 1.4 kg/cm^2, which is observed to be close to the applied pneumatic pressure (1.5 kg/cm^2), which indicates that the pneumatic pressure applied is almost entirely taken by the clay bed for its improvement. The compression index during the initial stage of consolidation is 0.37 and it is reduced to 0.15 after pneumatic consolidation which indicates that further settlements would be small.

C. PLAXIS 3D Analysis

A model study is done using PLAXIS 3D software by applying an equivalent vertical load corresponding to the applied pneumatic pressure. The time for 90% consolidation is found for each load increment from the plot showing the variation of excess pore pressure with time (Fig.5).

IJSMS

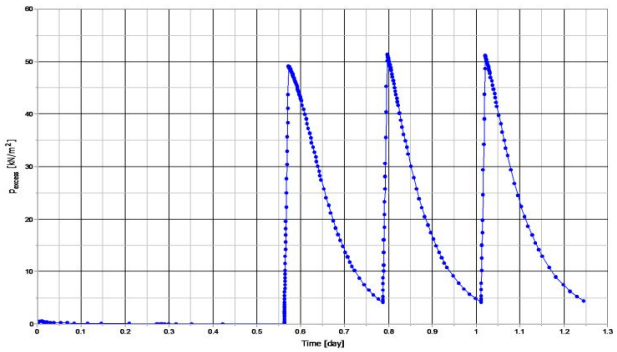


Fig. 5: Excess pore pressure versus time plot from PLAXIS 3D analysis

The time for 90% consolidation is about 0.25 day which is almost matching with the time calculated for 90% consolidation using sand drain design chart.

IV. CONCLUSIONS

The following conclusions are drawn based on thetest results and observations made during this study.

1. Upon inflation of balloons with cotton fabric strips on their surface, gradual draining of water and formation of air bubbles are observed at the surface, indicating the effectiveness of pneumatic radial consolidation process.
2. The calculation of time for 90% consolidation based on the charts used for sand drain design isclosely matched with that observed from PLAXIS 3D model.
3. The degree of improvement in terms of dry densities during the process of consolidation under pneumatic pressure is close to that observed from conventional oedometer test on clay specimens with similar initial dry density under each pressure increment.
4. The calculated preconsolidation pressure from oedometer test on a sample collected from test tank after pneumatic consolidation is close to the inflation pressure, which indicates the system response to the proposed technique.

The present investigation indicates that the use of radial pneumatic pressure could be a potential alternative to the conventional preloading methods in view of its simplicity without any need for surcharge loading which is considered to be a cumbersome process.

Further testing using tougher inflatable tubes would be useful in demonstrating the viability of the technique for prototype applications. The system can be further improved with a central hollow pipe having expandable tube around it in order to facilitate backfilling of the formed holes.

ACKNOWLEDGMENT

The authors appreciate the efforts of Miss. S. Soumya and P.R.T. Pranav, PG Students for conducting the experimental work.

REFERENCES

[1] Indraratna, B., Rujikiatkamjorn, C., Wijeyakulasuriya, V.,Shahin, M. A. and Christie, D. (2007), Soft soil stabilisation with special reference to road and railway embankments, Proc. of Soft Soil Engineering – Chan & Law (eds),Taylor & Francis Group, London, 35-55

[2] Frans, B. J. (2011),Introduction to Soft Soil Geotechnique: Content, Context And Application, Technical University Delft/ Deltares.

[3] Kitazume, M. (2007), Design, Execution and Quality Control of Ground Improvement in Land Reclamation, 13th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Volume II, 135-149

[4] Pilot, G. (1981), Methods of Improving The Engineering Properties of Soft Clay, Developments In Geotechnical Engineering 20, Soft ClayEngineering Elsevier Scientific Publishing Company, Amsterdam.

[5] Puppala, A. J. and Porbaha, A. (2004),International perspectives on quality assessment of deep mixing,Geosupport 2004 on Drilled Shafts, Micropiling, Deep Mixing, Remedial Methods, And Specialty Foundation Systems, ASCE, Orlando, Florida.

[6] Indraratna, B., Rujikiatkamjorn C. and Sathananthan, I. (2005), Analytical and numerical solutions for a single vertical drain including the effects of vacuum preloading, Can. Geotech. J., 42(4), 994-1014.

[7] Estabragh, A. R., Naseh, M. and Javadi, A.A. (2014), Improvement of clay soil by electro-osmosis technique, Applied Clay Science, 95, 32–36.

[8] Shen, S., Chai, J.C., Hong, Z. and Cai, F. (2005), Analysis of field performance of embankments onsoft clay deposit with and without PVD-improvement,Geotextiles and Geomembranes, 23, 463–485.

[9] Cascone, E. and Biondi, G. (2013), A case study on soil settlements induced by preloading and vertical drains,Geotextiles and Geomembranes, 38, 51-67.

[10] Hausmann, M.R. (1990), Engineering Principles of Ground Modification, Mc. Graw Hill Publishing Co.

[11] Chu, J., Yan, S and Indraratna, B. (2008), Vacuum Preloading Techniques – Recent Developments and Applications,GeoCongress 2008, New Orleans, Geosustainability and Geohazard Mitigation GPS 178, Reddy, KR, Khire, MV, Alshawabkeh, AN (eds), 2008, 586-595.

[12] Richart, F. E.(1959) Areview of Theories of Sand Drains, Trans. ASCE, 124, 709-739.

IJSMS