Radial Consolidation of Soft Kaolinitic Clay Using Vertical Jute Geo-Drain

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ABSTRACT

The need to utilize the poor soil for foundation support and earth work construction increases day by day, amongst the various ground improvement technique the radial consolidation of soft clays by vertical geo-drain is one of the ground improvement technique. Under this technique the rate of settlement is alternated by vertical prefabricated geo-drain because consolidation time varies as square of drainage path length and also most deposits have greater permeability in horizontal direction then in vertical direction. The installation of vertical geo-drains intercepts horizontally flowing pore water and reduces the drainage path thus increasing the rate of consolidation manifold. Installation of drains is either round or flat band drains. The aim of the present investigation is to explore the fabrication of an efficient geo-drain for accelerating the consolidation settlement of clayey soils. A pre-fabricated vertical jute geo-drain is developed by encasing polyamide bonded with polyester filter fabric. The hydraulically pressurized Oedometer with central geo-drain is employed in present investigation and C_{vr} value is determined using both the settlement and pore pressure reading. The value of Tvr_{50} for n = 12.09 is used for determination of C_{vr} from settlement readings. The experimental isochrones using the pore pressure readings at radial co-ordinates are drawn and compared with theoretical ones. The gain in strength of clay because of consolidation is also examined. The geo-drain employed in present investigation has increased the effective rate of pore pressure dissipation and thus allowed easily consolidation for a particular construction loading which signifies its use in field application, where the rate of construction is required to be compatible with time schedule available. The use of jute makes it possible in saving the cost over the other available geo-drain. Encasement of polyamide bonded with polyester filter helps in increasing the durability of jute

Keywords: Vertical Geo-drain, Radial Consolidation, Prefabricated Jute Drain, Pore Pressure Dissipation

INTRODUCTION

Prefabricated Vertical Drains (PVDs) have evolved significantly over the decades to meet the growing demands of sustainable ground improvement. Initially, sand drains were introduced by Karl Terzaghi in 1936, but due to their limitations, the first syn-thetic PVD was developed by Kjellman in 1977 in Sweden. This drain used a plastic core wrapped in geotextile and became widely adopted in the 1980s for large infra-structure projects. Over time, enhancements such as grooved cores and advanced filter fabrics were introduced to improve efficiency and prevent clogging. As environmental concerns grew, particularly around plastic waste and carbon emissions, researchers began exploring eco-friendly alternatives. From 2010 onwards, natural materials like jute and coir gained attention as biodegradable substitutes for synthetic components. Studies by researchers such as S.S. Gandhi, A. Latha, and S. Murugesan contributed to this shift. Recent innovations include hybrid PVDs combining jute cores with polyamide-polyester geosynthetics, offering a balance of sustainability and performance. These eco-friendly PVDs are now promoted for green infrastructure and climate-conscious construction, marking a new era in geotechnical engineering.

Objective:

The primary objective of this investigation is to evaluate the effectiveness of a cost-effective, eco-friendly **JPPG (Jute wrapped with Polyamide Polyester Geosynthetics)** drain on the strength and consolidation behavior of soft clayey soils through radial drainage. Using a modified Rowe-type hydraulically pressurized oedometer, the study measures settlement and pore pressure dissipation under applied pressures of 20, 40, 80, 160, and 320 kPa. Pore pressures are recorded at radial distances of r/re = 0.2, 0.56, and 0.87 to analyze radial consolidation behavior. The objective of the current research is:

1. To evaluate the effectiveness of a hybrid JPPG drain in accelerating radial consolidation of soft Kaolinitic clay.

2. To determine and compare coefficients of vertical (C_v) and radial consolidation (C_{vr}).

3. To assess permeability variation under different consolidation pressures.

4. To examine compressibility characteristics and validate compression index (C_c).

5. To discuss sustainability aspects and practical implications.

Laboratory Investigations:

The soil used for this investigation was clay mineral Kaolinite obtained commercially in the form of powder. To ensure full saturation of the sample the clay was mixed to form slurry with twice the liquid limit using de-aired distilled water. The tested clay is Kaolinite with a specific gravity of 2.456, liquid limit of 59.6%, plastic limit of 33.33%, and plasticity index of 26.27%, classifying it as CH (high plasticity clay) on the Casagrande chart. Its coefficient of permeability measured is 0.6×10^{-6} cm/sec.

Properties of PVD drain material:

The newly developed jute drain wrapped with polyamide polyester has an apparent opening size (A.O.S. 095) of less than 75 micrometers and a permeability of 1.1×10^{-1} cm/sec. These properties ensure efficient filtration and rapid water flow in geotechnical applications. The jute geotextile has a mass of 388 gm/m², tensile strength of 250–350 N, grab tensile strength of 800–900 N, and 5% elongation at break. It shows a permeability of 3×10^{-2} cm/sec, fiber length ranging from 10–200 mm, and thickness of 1.08 mm (single layer) and 2.06 mm (double layer).

Experimental Set up

The experimental setup includes a hydraulic pressure system, Rowe-type oedometer with central geodrain, and systems for measuring pore pressure and settlement. Consolidation (Cvr) values are determined using both settlement and pore pressure data, with pore pressure measured via the conventional Bishop's setup.

Fig.1. Rowe Type Oedometer and self-compensating Mercury

Experimental Procedure and Preparation of Clay Sample:

Commercially available Kaolinite clay was mixed with de-aired distilled water at twice its liquid limit to form a slurry, which was poured into a silicon-greased oedometer cell and vibrated to remove air bubbles. The sample was then preconsolidated under incremental static loads, with measurements taken for initial water content, shear strength, and height to ensure uniform strain during testing.

Preparation of Drain :

A modified Colbond prefabricated vertical drain with a 3D polyester/polyamide core and nonwoven polyester filter was shaped circularly (height-to-diameter ratio 2.5) and filled with jute fibers. This jute-intermixed Colbond drain was tested for vertical and horizontal permeability as well as flexibility under stress.
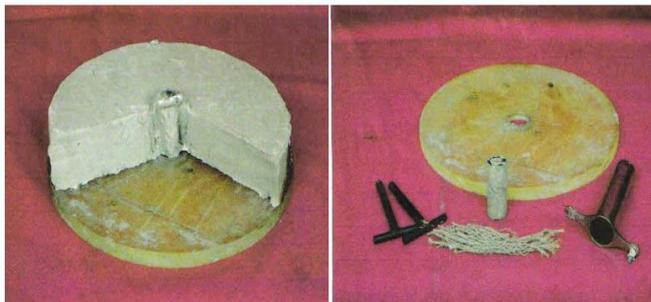

Fig.2. Sample of JPPG before and after Experiment

1   Method of Analysis :

The investigation focused on evaluating the performance of circular vertical jute geo-drains bonded with polyamide-polyester filter material in the radial consolidation of Kaolinite soil using a 254 mm diameter oedometer.

Parameters Measured:

1. Time–settlement measurements during vertical and radial consolidation.

These experimental data were analyzed to determine the coefficient of vertical consolidation (C_v) and coefficient of radial consolidation (C_{vr}) using Terzaghi's theory and Barron's equation, respectively.

Vertical Consolidation

It is calculated using Terzaghi's one-dimensional consolidation theory. A plot of dial gauge reading vs. log t is used to obtain t_{50} via Casagrande's method. The formula used is:

$$Cv = \frac{T_{50} \cdot d^2}{t_{50}}$$

Where: $T_{50}=0.197$ is the   (time factor), $d = \frac{H_{i+}H_f}{2}$ is the (drainage path)

H_i and H_f are initial and final specimen heights.

Radial Consolidation

Barron's equal vertical strain theory with no smear and no well resistance has been used to carry out the analysis for co- efficient of radial consolidation. Radial consolidation co-efficient is calculated using the following equation:

$$C_{vr} = T_{vr\ 50}\ re^2/t_{50}$$

Where, T_{vr} values are calculated from the equation $T_{vr} = \ln(1-Ur)/-4.542$,

re = diameter of oedometer/2

The analysis assumes no smear and negligible well resistance, appropriate for controlled laboratory conditions. However, in field installations, disturbance-induced smear may reduce effective horizontal permeability and slightly modify performance.

Result Analysis

Presentation of results for 254 mm diameter oedometer (n=12.09)

A. Consolidation due to Vertical drainage:

(i) <u>Co-efficient of vertical consolidation</u> – figure3 shows the plots of dial gauge reading versus logarithm of time. The coefficient of consolidation is calculated by casagrandae logarithm method. The time required for 50% consolidation at 100kPa is the 560 minutes which reduces to 230 minutes at 400 kPa. This time will reduce with increase in pressure resulting into an increase in the value of coefficient of consolidation.
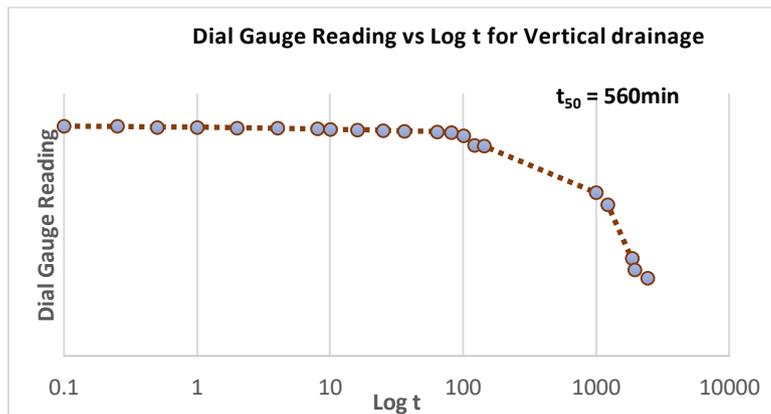

Fig. 3. Dial Gauge Reading vs Log t for Vertical drainage

(ii) Co-efficient of consolidation versus consolidation pressure:

The figure indicates that there is minimal variation in the value of **coefficient of consolidation (c_v)** beyond a pressure of 50 kPa Up to this pressure, the change in c_v reflects the initial structural resistance present in the clay-water structure of Kaolinitic clay. The average value of c_v is approximately **2.55×10^{-4} cm²/sec**.

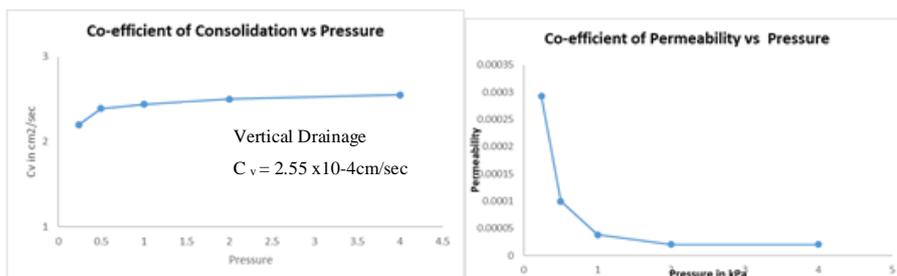

Fig. 4. (a) Cvr vs Pressure and Fig.4. (b) K vs P for Vertical Drainage

(iii) Vertical permeability versus consolidation pressure:

The figure 4(b) indicates that permeability decreases from 2.934×10^{-4} cm/sec at a pressure of 25 kPa to 3.81×10^{-5} cm/sec at 15 kPa and then stabilizes, maintaining a nearly constant value of 2.07×10^{-5} cm/sec.

(iv) Void ratio versus log of consolidation pressure:

The figure presents a characteristic curve of normally consolidated soil, where the compression index (Cc) is determined to be 0.487. This is higher than the value of 0.371 obtained using the well-known empirical formula: $Cc = 0.007(w_L - 10)$.
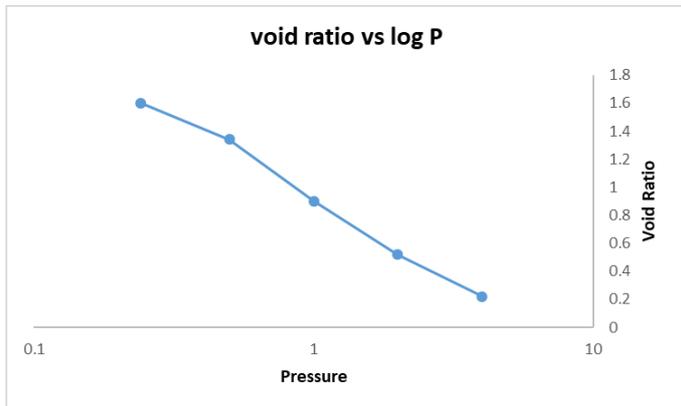

Fig. 5. Void Ratio Versus Consolidation Pressure for vertical drainage

The experimentally obtained compression index (Cc = 0.487) is approximately **31% higher** than the empirical estimate (Cc = 0.371). This deviation suggests that the tested Kaolinite exhibits higher compressibility than predicted by generalized empirical correlations.

B. Consolidation due to radial drainage

(i) Coefficient of radial consolidation (C_{vr}):

The figure shows plots of dial gauge readings versus the logarithm of time, used to determine the coefficient of consolidation through the Casagrande method. At a pressure of 12 kPa the time required to achieve 50% consolidation is 500 minutes. When the pressure is increased to 400 kPa, this time decreases significantly to 160 minutes. This reduction in consolidation time with increasing pressure indicates a corresponding increase in the coefficient of consolidation. In radial consolidation, the use of prefabricated vertical drains and the naturally higher permeability in the radial direction further accelerates the consolidation process.
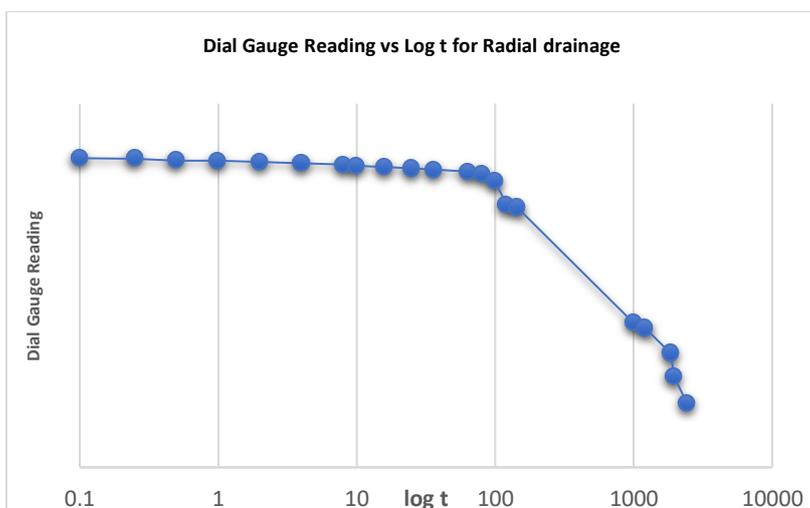

Fig. 6. Dial Gauge Reading vs Log t for Radial drainage

(ii) Coefficient of radial consolidation against consolidation pressure

Figure shows that there is no much variation in the value of C_{vr} after pressure of 100 kPa . Upto pressure of 100 kPa, the C_{vr} increases with increases of pressure. The average C_{vr} value is found to be 1.33 x 10-3 cm^2/sec.
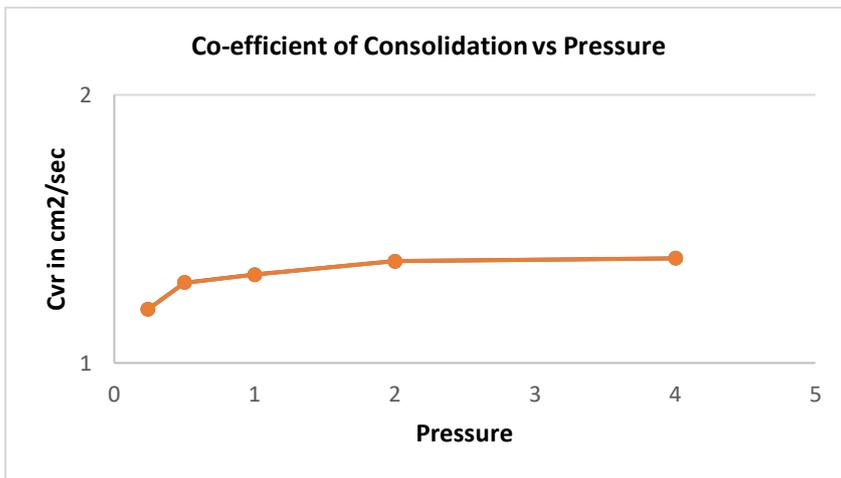
Fig. 7. Co-efficient of Consolidation vs Pressure

(iii) Horizontal permeability versus consolidation pressure: The horizontal permeability decrease with increase in pressure from 3.90×10^{-4} cm/sec at 24kPa to 0.6×10^{-4} at 400 kPa and then remains more or less constant giving the value of 0.5×10^{-4} cm/sec.
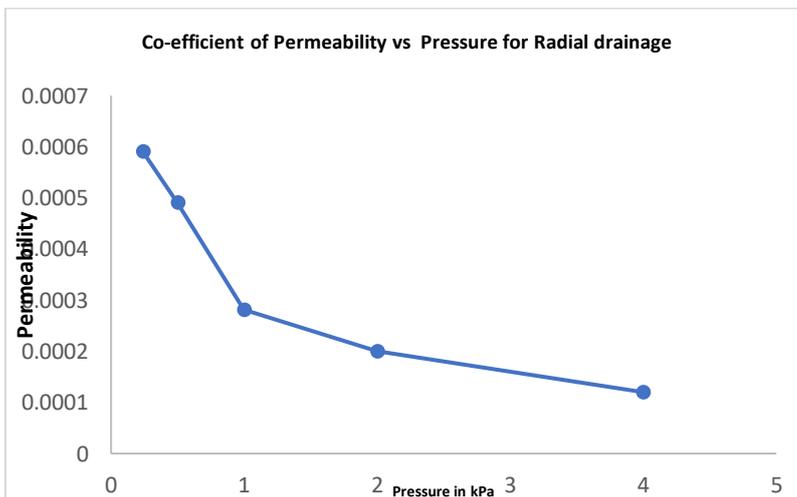

Fig. 8. Co-efficient of Permeability vs Pressure for Radial drainage

(iv) Void ratio versus log of consolidation pressure:
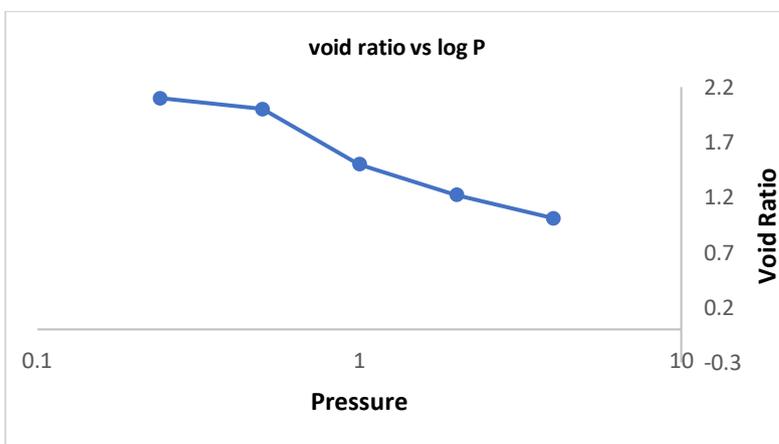

Fig. 9. Void ratio vs log P

The value of Cc calculated from the straight line portion of this curve gives value of 0.60.

CONCLUSION

Comparison of Radial Drainage and Vertical Drainage

Consolidation without PVD is a slow process, often taking months or years for excess pore water pressure to dissipate naturally. It leads to prolonged construction timelines and delayed strength gain in soft clayey soils. With PVDs, radial drainage paths are introduced, significantly accelerating consolidation. This results in faster pore pressure dissipation, quicker settlement, and early improvement in shear strength.

Overall, PVDs reduce construction time and enhance soil stability, making them highly efficient for soft ground improvement.

a) The settlement curves for radial drainage lie below those of vertical drainage, indicating a higher rate of consolidation. At a pressure of 200 kPa the time required to achieve 50% consolidation is approximately **170 minutes** for radial drainage, compared to **390 minutes** for vertical drainage.
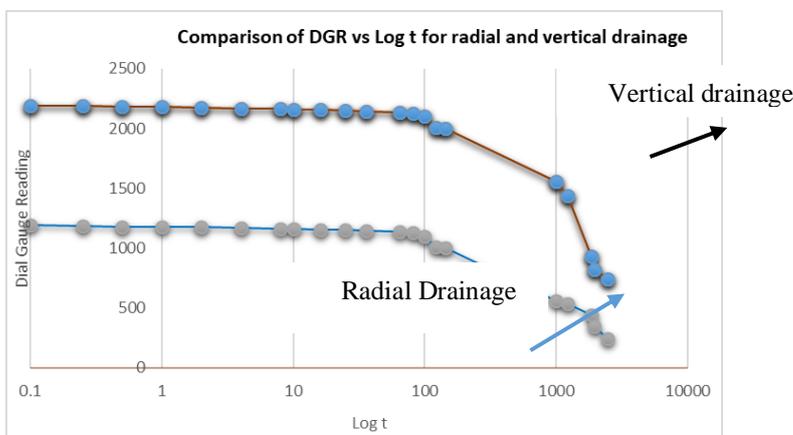

Fig. 10. Comparison of DGR vs logt for radial and vertical drainage at 80 kPA

b) The average horizontal permeability in radial drainage is about **seven times** greater than the vertical permeability, demonstrating enhanced pore water dissipation in the horizontal direction.

c) The coefficient of radial consolidation is found to be 1.99×10^{-3} **cm²/sec**, in contrast to the vertical coefficient of consolidation which is 2.55×10^{-4} **cm²/sec** at the same pressure of 200 kPa. Consolidation without PVD is a time-consuming process, often requiring months to years for pore water pressure to dissipate. In soft clayey soils, this leads to delayed settlement and slower strength gain. The natural vertical drainage path is long and inefficient. As a result, construction timelines are extended, and bearing capacity improves gradually. Introducing Prefabricated Vertical Drains (PVDs) changes this scenario significantly.

d) The higher experimental compression index (Cc = 0.487) compared to the empirical estimate may be attributed to the remolded slurry preparation of the clay at high water content, which resulted in a dispersed structure and higher initial void ratio. Complete saturation and particle rearrangement during consolidation further increased compressibility. Additionally, the tested soil is high-plasticity Kaolinite (CH), for which generalized empirical correlations often underestimate Cc. Since empirical formulas are derived from broad soil databases, they may not accurately represent laboratory-prepared, fully remolded clay systems.

Cost Effective

Type of PVD	Approx. Cost (INR/m)	Remarks
Jute + Polyamide-Polyester Geosynthetic PVD	25 – 35	Low-cost, eco-friendly, biodegradable core with synthetic wrap

Conventional Synthetic PVD (Polypropylene + Geotextile)	45 – 60	Industry standard, high durability and performance
Spiral Core PVD (Advanced flow design)	60 – 75	High discharge rate, used in heavy-duty consolidation projects
Smart PVD (Sensor-embedded with MEMS/Fiber Optics)	200 – 400+	Allows real-time monitoring of pore pressure and settlement
Biodegradable PVD (Pure jute/coir + degradable wrap)	20 – 30	Fully biodegradable, best for temporary or green infrastructure

REFERENCES

1. R.P.Shrivastava, Dr. A.V.Shroff (2022) , "Experimental Study on Performance of Prefabricated Vertical Drain on Kaolinite With various drain material".
2. R.P.Shrivastava, Dr. A.V.Shroff (2021) , "Chapter in the Springer Book Titled "Dynamics of Soil and Modelling of Geotechnical Problems – Proceedings of Indian Geotechnical Conference 2020 Volume 5"
3. R.P.Shrivastava, Dr. A.V.Shroff (2020) , "Theoretical Simulation Of Experimental Results With Barron's Theory For Consolidation Of Soft Clay By Radial Flow Using PVD"
4. S.S. Gandhi & A. Latha, "Natural Geosynthetics in Ground Improvement: Performance Evaluation of Coir and Jute Drains in Soft Clay Soils"
5. S. Murugesan, "Application of Biodegradable Prefabricated Vertical Drains for Sustainable Consolidation of Soft Clays"
6. Kjellman, "Development of Synthetic Vertical Drains for Accelerated Soil Consolidation"