



Comparative Study on Bearing Capacity Improvement of Clay Soil Using Polypropylene Geogrid and Acrylic Reinforcement

Praveenraj A¹, Kumar M²

Department of Civil Engineering, Government College of Technology, Coimbatore, Tamil Nadu, India

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Abstract

Weak clayey soils often exhibit low bearing capacity and excessive settlement, resulting in unsafe and uneconomical foundation systems. Soil reinforcement using geosynthetics such as polypropylene (PP) geogrids has become a widely accepted ground improvement technique. However, acrylic reinforcement materials possess higher stiffness and improved load transfer characteristics, which may provide better settlement control and bearing resistance. This study presents a comparative investigation on the bearing capacity improvement of clay soil reinforced with polypropylene geogrid and acrylic sheet reinforcement using laboratory model plate load tests. Experimental tests were conducted on unreinforced soil, single-layer reinforced soil, and double-layer reinforced soil configurations. The performance was evaluated based on ultimate load carrying capacity and settlement behavior. Results indicated that acrylic double-layer reinforcement exhibited the highest improvement, increasing the ultimate load from 14 kN to 17.8 kN while reducing settlement from 14.8 mm to 8.6 mm. Polypropylene geogrid reinforcement also enhanced soil performance, but acrylic reinforcement demonstrated superior stiffness and confinement characteristics. The study confirms that acrylic reinforcement can serve as an effective alternative reinforcement material for foundation applications in weak clay soils.

Keywords: Clay soil, Polypropylene geogrid, Acrylic reinforcement, Bearing capacity, Settlement, Plate load test.

1. Introduction

Weak and highly compressible clay soils pose serious challenges in geotechnical engineering due to their low shear strength, excessive compressibility, and poor load-bearing characteristics. Structures constructed on such soils often experience excessive settlement, differential deformation, and reduced foundation stability. These issues become more critical in highway embankments, retaining structures, shallow foundations, and industrial structures where soil deformation directly influences structural safety and serviceability. Polypropylene (PP) geogrids are widely used as reinforcement materials due to their tensile strength, flexibility, lightweight nature, and resistance to chemical degradation. The primary mechanism of geogrid reinforcement involves interlocking between soil particles and the grid apertures, resulting in improved confinement and redistribution of stresses beneath the footing. However, polypropylene geogrids exhibit certain limitations such as creep deformation under long-term loading, moderate stiffness, and sensitivity to ultraviolet exposure.



The study also investigates the influence of reinforcement layer arrangement and spacing on foundation performance. The findings from this work are expected to contribute toward identifying alternative reinforcement materials for improving weak subgrade soils in practical geotechnical applications.

1.1 Problem Statement

Clayey soils with high plasticity generally exhibit excessive settlement and low bearing resistance under structural loading. Conventional reinforcement systems such as polypropylene geogrids improve soil performance; however, the influence of stiffer acrylic reinforcement materials under shallow foundation loading conditions remains insufficiently explored. Therefore, a detailed comparative study is required to evaluate the effectiveness of acrylic reinforcement against conventional geogrid systems.

1.2 Research Objectives

The major objectives of the study are as follows:

- To determine the bearing capacity improvement of clay soil using polypropylene geogrid and acrylic reinforcement.
- To evaluate settlement reduction characteristics under different reinforcement configurations.
- To identify the optimum reinforcement arrangement for improved load carrying capacity.
- To evaluate the suitability of acrylic reinforcement as an alternative to polypropylene geogrid.

1.3 Scope of the Study

The present study is limited to laboratory model plate load testing on clay soil under static loading conditions. Only polypropylene geogrid and acrylic sheet reinforcements were considered. The study focuses on shallow foundation behavior and evaluates the improvement in bearing capacity and settlement characteristics through experimental investigation.

2. Literature Review

Soil reinforcement has become an effective technique for improving weak soil behavior in geotechnical engineering applications. Numerous studies have investigated the influence of geosynthetics and polymer-based materials on bearing capacity improvement, settlement reduction, and stress distribution.

Ghasemzadeh (2022) examined acrylic polymer-stabilized kaolinite clay and observed substantial improvement in compressive strength due to enhanced particle bonding and load transfer mechanisms. The results demonstrated the effectiveness of acrylic polymers in increasing stiffness characteristics of fine-grained soils.

Debbarma and Dey (2023) analyzed the effect of vinyl acrylic polymers on fine-grained soils. The researchers observed improved strength, stiffness, and durability characteristics due to polymer treatment. Long-term performance enhancement was also reported.

Park et al. (2021) evaluated polymer-treated soils using CBR and unconfined compression tests. The inclusion of acrylic-based polymers significantly increased penetration resistance and stiffness properties of the soil mass.

Rao and Reddy (2020) studied the load-settlement behavior of polymer-stabilized weak soils. Their investigation showed that higher stiffness polymers effectively reduced settlement under loading conditions and improved foundation stability.



Singh and Kumar (2024) investigated the penetration resistance of geosynthetic-reinforced soils through CBR testing. The study reported that reinforcement stiffness, layer spacing, and placement depth strongly influence the load carrying performance of reinforced soil systems.

2.1 Identified Research Gap

Based on the literature review, the following research gaps were identified:

1. Most previous studies focused on acrylic polymers as stabilizing agents rather than reinforcement layers.
2. Comparative evaluation between polypropylene geogrid and acrylic reinforcement under identical conditions is limited.
3. The influence of acrylic reinforcement stiffness on load-settlement behavior is not fully understood.
4. Limited experimental data are available regarding double-layer acrylic reinforcement beneath shallow foundations.
5. Optimum reinforcement depth and spacing for acrylic reinforcement require further investigation.

3. Materials and Methods

3.1 Soil Sample Collection and Preparation

The clay soil used in this study was collected from Chinnamettupalayam near Idikarai, Coimbatore, Tamil Nadu, India. The location coordinates were approximately 11.103477° N latitude and 76.973347° E longitude. The collected soil exhibited black coloration and plastic behavior, indicating the presence of fine-grained clay minerals. The soil samples were excavated manually from shallow depth and transported to the geotechnical laboratory in airtight bags to minimize moisture loss. The collected soil was air-dried for 24 hours and pulverized using wooden mallets to break down large lumps. The processed soil was then sieved to remove oversized particles and ensure uniformity during testing. The prepared soil was stored in sealed containers until further laboratory investigation.

Table 1. Soil Parameters

PROPERTY	VALUES
Specific gravity (Gs)	2.73
Moisture content	23.5 %
Grain size distribution	12% sand, 28% silt, 60% clay
Liquid limit (W _L)	48 %
Plastic limit (W _P)	25 %
Plasticity index (PI)	27%
Soil Classification Type	Intermediate Compressibility Clay
Optimum moisture content (OMC)	17%
Maximum dry density (MDD)	1.72 g/cc
Unconfined compressive strength (qu)	48 kN/m ²



Cohesion (c)	24 kN/m ²
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3.2 Reinforcement Materials

Two different reinforcement materials were considered in this investigation:

1. Polypropylene geogrid
2. Acrylic sheet reinforcement

3.2.1 Polypropylene Geogrid

The polypropylene geogrid used in this study was a biaxial geogrid possessing high tensile strength and adequate stiffness. The geogrid was selected because of its common use in geotechnical reinforcement applications.

The important engineering properties of the geogrid are presented below.

Property	Value
Tensile Strength at 5% Strain	76 kN/m
Poisson's Ratio	0.31
Thickness	3.1 mm
Mass per Unit Area	73 g/m ²
Elongation at Yield Point	22%
Axial Stiffness	787 kN/m
Density	920 kg/m ³
Young's Modulus	1300–1800 N/mm ²

Table 2. Property of Geogrid

3.2.2 Acrylic Sheet Reinforcement

The acrylic reinforcement material used in the study consisted of thin rigid acrylic sheets placed beneath the footing zone. Acrylic material was selected due to its higher rigidity, improved stiffness, and potential for better load transfer compared to flexible geogrid systems. The acrylic sheets acted as rigid confinement layers and redistributed stresses over a larger area beneath the footing.

3.3 Experimental Setup

The laboratory model plate load test setup consisted of a steel tank with dimensions of 50 cm × 50 cm × 75 cm. The tank dimensions were selected to minimize boundary effects during loading. A square steel loading plate of dimensions 10 cm × 10 cm and thickness 25 mm was used to transfer vertical load to the soil surface. Load was applied gradually through a loading frame and hydraulic jack arrangement. Settlement measurements were recorded using a dial gauge mounted above the loading plate.



3.4 Preparation of Reinforced Soil Bed

The soil bed was prepared in layers at optimum moisture content and compacted uniformly to achieve the desired dry density. For reinforced cases, reinforcement layers were placed at predetermined depths within the soil bed. The reinforcement configurations adopted in the study were:

- Unreinforced soil
- Polypropylene single-layer reinforcement
- Polypropylene double-layer reinforcement
- Acrylic single-layer reinforcement
- Acrylic double-layer reinforcement

3.5 Reinforcement Placement Configuration

The reinforcement layers were positioned within the shear failure zone beneath the footing to maximize soil-reinforcement interaction. The footing width (B) was maintained as 10 cm. Reinforcement placement depths were selected based on the expected stress distribution zone beneath the footing.

Reinforcement Configuration	Layer Position	Depth Ratio	Depth
Single Layer	Layer 1	0.5B	5 cm
Double Layer Trial 1	Layer 1	0.5B	5 cm
	Layer 2	1B	10 cm
Double Layer Trial 2	Layer 1	0.5B	5 cm
	Layer 2	1.5B	15 cm

Table 3. Reinforcement Depth Configuration

The reinforcement depth ratios were selected because maximum stress concentration beneath shallow foundations generally occurs within 0.3B to 0.6B depth.

4. Results and Discussion

4.1 General

The experimental investigation was carried out to evaluate the effectiveness of polypropylene geogrid and acrylic reinforcement in improving the load carrying capacity and settlement characteristics of clay soil. The behavior of reinforced and unreinforced soil beds was analyzed through load-settlement relationships obtained from laboratory model plate load tests.

The performance of the reinforced systems was evaluated based on:

- Ultimate load carrying capacity
- Settlement reduction characteristics
- Stiffness improvement
- Load transfer mechanism



- Confinement effect
- Influence of reinforcement layer configuration

The experimental observations clearly demonstrated that reinforcement inclusion significantly enhanced the engineering behavior of clay soil.

4.2 Stress Distribution Beneath Footing

When a shallow footing is subjected to vertical loading, stresses are transferred into the underlying soil mass. In unreinforced soil, these stresses are concentrated directly beneath the footing, resulting in excessive vertical compression and lateral displacement. The inclusion of reinforcement layers modifies the stress distribution pattern beneath the footing. Reinforcement materials intercept the stress transfer path and distribute the applied load over a wider area. This mechanism reduces stress concentration and minimizes settlement.

The effectiveness of reinforcement depends on several factors such as:

- Reinforcement stiffness
- Tensile resistance
- Depth of placement
- Number of reinforcement layers
- Soil-reinforcement interaction
- Interfacial friction characteristics

The acrylic reinforcement exhibited better stress redistribution due to its rigid sheet action and higher stiffness compared to polypropylene geogrid.

4.3 Load–Settlement Characteristics

The load-settlement response obtained from laboratory testing showed nonlinear behavior for all reinforcement configurations. Settlement increased gradually with load application until the ultimate load condition was approached.

4.3.1 Unreinforced Soil

The unreinforced clay soil exhibited the highest settlement among all cases investigated. The soil failed primarily due to excessive compression and shear deformation beneath the footing. At lower load levels, the settlement increased gradually. However, beyond the elastic limit, rapid deformation was observed due to insufficient confinement and low shear resistance. The ultimate load carrying capacity was observed as 14 kN with a corresponding settlement of 14.8 mm. The larger settlement values indicate poor stiffness characteristics and low resistance against deformation.

4.3.2 Polypropylene Geogrid Reinforcement

The inclusion of polypropylene geogrid significantly improved the load-settlement response of clay soil.

The geogrid reinforcement acted through:

- Tensile membrane action
- Soil-geogrid interlocking
- Improved confinement



- Restriction of lateral displacement
- Redistribution of applied stresses

The polypropylene single-layer system increased the ultimate load carrying capacity to 15.5 kN and reduced settlement to 11.6 mm.

The double-layer polypropylene system further improved the soil behavior by distributing stresses within a larger reinforced zone. The ultimate load carrying capacity increased to 16.8 kN, while settlement reduced to 9.8 mm. The improved performance observed in double-layer reinforcement indicates that additional reinforcement layers enhance stress transfer efficiency and reduce deformation.

4.3.3 Acrylic Reinforcement

Acrylic reinforcement exhibited superior performance due to its higher rigidity and stiffness characteristics. Unlike flexible geogrid systems, acrylic sheets acted as rigid reinforcement layers capable of distributing applied stresses over a larger area beneath the footing.

The acrylic reinforcement mechanism involved:

- Rigid confinement action
- Reduction of stress concentration
- Increased stiffness within the reinforced zone
- Prevention of localized shear failure
- Improved load transfer mechanism

The acrylic single-layer system increased the ultimate load carrying capacity to 16.2 kN while reducing settlement to 10.8 mm. The acrylic double-layer system showed the highest performance among all reinforcement configurations tested. The ultimate load carrying capacity increased to 17.8 kN with settlement reduced to 8.6 mm.

4.4 Improvement in Bearing Capacity

The percentage improvement in ultimate load carrying capacity was calculated using the following equation:

$$\text{Bearing Capacity Improvement (\%)} = [(Q_u(\text{reinforced}) - Q_u(\text{unreinforced})) / Q_u(\text{unreinforced})] \times 100$$

Where:

- $Q_u(\text{reinforced})$ = Ultimate load capacity of reinforced soil
- $Q_u(\text{unreinforced})$ = Ultimate load capacity of unreinforced soil

The calculated improvement values are presented below.

Reinforcement Configuration	Ultimate Load (kN)	Bearing Capacity Improvement (%)
Unreinforced Soil	14.0	-
PP Single Layer	15.5	10.71
PP Double Layer	16.8	20.00
Acrylic Single Layer	16.2	15.71



Acrylic Double Layer	17.8	27.14
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Table 4. Ultimate Load Vs Settlement

The results indicate that acrylic double-layer reinforcement achieved the highest improvement in load carrying capacity.

4.5 Settlement Reduction Analysis

Settlement reduction percentage was calculated using the following equation:

$$\text{Settlement Reduction (\%)} = [(S(\text{unreinforced}) - S(\text{reinforced})) / S(\text{unreinforced})] \times 100$$

Where:

- $S(\text{unreinforced})$ = Settlement of unreinforced soil
- $S(\text{reinforced})$ = Settlement of reinforced soil

Reinforcement Configuration	Settlement (mm)	Settlement Reduction (%)
Unreinforced Soil	14.8	-
PP Single Layer	11.6	21.62
PP Double Layer	9.8	33.78
Acrylic Single Layer	10.8	27.03
Acrylic Double Layer	8.6	41.89

The maximum settlement reduction of approximately 41.89% was achieved in acrylic double-layer reinforcement. This significant reduction in settlement demonstrates the effectiveness of rigid reinforcement in minimizing vertical deformation beneath shallow foundations.

4.6 Effect of Reinforcement Depth

The reinforcement depth significantly affects the performance of reinforced foundations. The reinforcement layers were placed at depth ratios of 0.5B, 1B, and 1.5B beneath the footing. These depths were selected because the maximum stress concentration beneath shallow foundations generally occurs within this region. Reinforcement placed near the footing effectively intercepts stress transfer and provides immediate confinement.

4.7 Comparative Performance of Reinforcement Materials

The comparative analysis clearly demonstrates that acrylic reinforcement performed better than polypropylene geogrid in terms of both load carrying capacity and settlement reduction. The superior performance of acrylic reinforcement can be attributed to:

1. Higher stiffness characteristics
2. Better stress distribution capability
3. Increased rigidity beneath footing
4. Reduced lateral deformation
5. Improved confinement effect



6. Enhanced resistance against shear failure

Polypropylene geogrid improved the engineering behavior primarily through tensile membrane action and interlocking mechanisms, whereas acrylic sheets acted as rigid load-distributing layers.

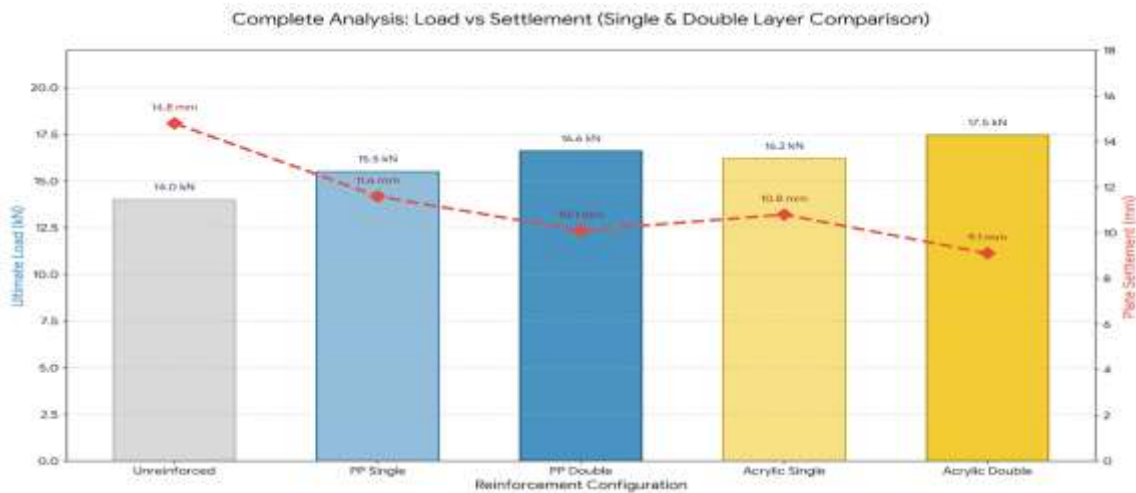


Fig Comparative Analysis Load vs Settlements (Single & Double Layer)

4.9 Limitations of the Study

Although the present investigation provided valuable insights into reinforcement behavior, certain limitations exist:

1. The study was limited to laboratory-scale model testing.
2. Only static loading conditions were considered.
3. Long-term creep behavior was not investigated.
4. Environmental effects such as temperature and moisture variation were not considered.
5. Numerical modeling validation was not included in the present phase.

Future investigations can focus on field-scale studies and numerical simulations for better understanding of reinforced soil behavior.

4.10 Future Scope

Based on the present investigation, the following future research areas are recommended:

- Numerical analysis using PLAXIS 3D
- Cyclic and repeated loading studies
- Long-term durability assessment
- Optimization of reinforcement spacing and thickness
- Three-layer and multi-layer reinforcement systems
- Large-scale field investigations
- Dynamic loading analysis
- Reinforcement behavior under saturated conditions



5. Conclusions

Weak clayey soils are characterized by low shear strength, high compressibility, and excessive settlement under structural loading. These characteristics significantly affect the stability and serviceability of shallow foundations. To overcome these challenges, soil reinforcement techniques using geosynthetics have been widely adopted in geotechnical engineering.

Polypropylene geogrids are commonly used due to their tensile strength, flexibility, and ability to improve load distribution. Nevertheless, their long-term performance may be influenced by creep deformation and moderate stiffness characteristics. Recently, polymer-based materials with higher rigidity have attracted attention for their potential to improve bearing capacity and settlement control.

Acrylic materials possess higher stiffness and improved bonding characteristics compared to conventional geogrids. Although acrylic polymers have been extensively studied as stabilizing agents in soil improvement, limited studies are available regarding their use as reinforcement materials under footing loads. Therefore, this study focuses on comparing the performance of polypropylene geogrid and acrylic sheet reinforcement through laboratory plate load testing.

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