International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 49, no. 3, June, 2025 pp. 321-330
Journal homepage: http://iieta.org/journals/acsm

Comparison of Geosynthetic Reinforcement Performance on Clay Soil: An Experimental Study of Variations in Placement Distance and Material Type

Lusi Dwi Putri[1,2], Abdul Hakam[1*], Rendy Thamrin[1], Yossyafra[1]

[1] Civil Engineering Department, Andalas University, Padang 25163, Indonesia
[2] Civil Engineering Department, Lancang Kuning University, Pekanbaru 28265, Indonesia

Corresponding Author Email: ahakam@eng.unand.ac.id

https://doi.org/10.18280/acsm.490312

Received: 18 May 2025
Revised: 19 June 2025
Accepted: 24 June 2025
Available online: 30 June 2025

Keywords:
geosynthetics, clay soil, reinforcement, geogrid, woven geotextile, non-woven geotextile, placement distance, bearing capacity

ABSTRACT

This study evaluates the performance of various geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—under maximum load (P_{max}), geosynthetic strain (τ), and maximum displacement on clay soil, with variations in placement depth (5 cm, 10 cm, and a combination of 5 cm & 10 cm). Clay soil samples were compacted, and geosynthetics were placed at specified depths within the soil. Load tests were performed to measure P_{max}, while geosynthetic strain (τ) and maximum displacement (Max Displacement) were recorded to assess the geosynthetic performance. The results showed that geosynthetics significantly enhance soil performance. The woven geotextile exhibited the highest P_{max} (240.695 kg at a combined depth of 5 cm & 10 cm), followed by the non-woven geotextile (230.230 kg at the same depth), and the geogrid (197.340 kg at the same depth). For geosynthetic strain (τ), the highest values were recorded in the woven geotextile (1,605.553 N/cm² at a combined depth of 5 cm & 10 cm), followed by the non-woven geotextile (1,513.158 N/cm²) and the geogrid (1,471.710 N/cm²). Regarding maximum displacement, the geogrid showed the most significant displacement (3.0 cm at a depth of 5 cm). The woven geotextile had the least minor displacement (1.4 cm at a combined depth of 5 cm & 10 cm), followed by the non-woven geotextile (2.7 cm at 5 cm). The study concludes that the woven geotextile performs best regarding P_{max}, geosynthetic strain, and minimal displacement. At the same time, the geogrid shows the most significant displacement and the least favorable performance. These findings suggest that the two materials are effective for different applications. Further research should focus on the long-term performance and environmental impacts of geosynthetics.

1. INTRODUCTION

The availability of safe and comfortable buildings, roads, and infrastructure is a key factor in providing suitable housing and urban development. However, as settlements grow and land prices rise, construction on soft soils, particularly clay, becomes inevitable. Clay soil poses significant geotechnical challenges due to its problematic characteristics. Common issues include low bearing capacity, high compressibility, drainage limitations, and shrink-swell behavior [1-8]. Clay soil is one type of soil that often causes problems in geotechnical construction due to its unique but problematic properties. Some of the main challenges to be overcome in this study include; (1) Low Soil Bearing Capacity, (2) Compressibility and Excessive Settlement, (3) Low Permeability and Drainage Problems, (4) Shrink-Swell Behavior. The Importance of Overcoming These Challenges in the Context of Geotechnical Engineering. These problems are very crucial because they threaten the stability of structures (buildings, roads, embankments, dams, etc.), increase construction and maintenance costs due to premature damage or decreased function of the structure and affect the service life of various civil infrastructures.

These challenges are particularly substantial in geotechnical engineering, as they directly affect the stability and longevity of infrastructure, particularly roads and buildings, which are critical for urban development. Vertical deformation due to load application is related to the vertical stress distribution transferred to the soil sample [9-10]. Roads built on this type of soil often deteriorate before their lifespan and require frequent maintenance, necessitating special attention [5, 11]. Key variables influencing road durability include subgrade The primary factors predicting the lifespan of reinforced roads are the subgrade bearing capacity, loading effects, testing type, compaction methods, environmental variables (such as moisture, temperature, and aging), and pavement design parameters. The subgrade soil significantly affects road construction costs, as the subgrade's bearing capacity determines the pavement layer's thickness [12].

The soil in Riau Province is predominantly clay, making it crucial to pay particular attention when planning roads or buildings. Clay is a soil with micron-sized to sub-micron-sized particles resulting from weathering the chemical elements that make up rocks. Clay soil becomes very hard when dry and have very low permeability, making it highly plastic. The low shear strength and high compressibility of clay soils lead to significant challenges in providing adequate infrastructure support, requiring specific attention from geotechnical engineers. Developing clay soils is challenging due to their low shear strength and high compressibility [13]. The low shear strength of clay soils significantly limits the load they can bear with adequate safety in the short term. The condition of the subgrade, with many layers of different soil types, will lead to varying load distributions, especially in unstable soils [8]. Therefore, it is essential to study clay soil's physical and mechanical properties to determine its bearing capacity. This is important for ensuring the immediate stability of infrastructure and designing long-lasting solutions that minimize the need for future repairs.

These soil data can also be used for numerical modeling by finite element analysis to predict potential failure [14]. The numerical models used depend on the characteristics of the soil layers. An optical flow-based image processing analysis can also measure lateral displacement and estimate shear strain. Finite element numerical analysis using software applications can be used to address issues in clay soils. Rapid maintenance of clay subgrades is one of the main ways to solve problems related to road construction [12].

There are several ways to address these problems. Clay soil is first stabilized before any construction is done in such conditions. Another solution is to add reinforcement materials, such as geosynthetics [11, 15]. The stress transfer mechanism from the soil due to loading to the reinforcement is friction between the soil and the reinforcement.

Geosynthetics are known for their lightweight nature and high tensile strength, making them suitable for reinforcement applications in soft ground conditions [16]. Theoretically, settlement will still occur due to the low supporting capacity and vertical stress added by shallow foundations covered with geosynthetics, but the extent of the settlement can be reduced. Furthermore, geosynthetics also function as filters, holding fine particles in place to prevent them from being carried away by seepage water, separating two layers between soil and soil or soil and water to avoid mixing.

Several studies have investigated using geosynthetics to improve the performance of soils, particularly in enhancing the bearing capacity of soft soils like clay. Research has demonstrated that geosynthetics, such as geotextiles and geogrids, effectively distribute loads more evenly, reduce vertical deformation, and improve soil stability [11, 13]. These studies underscore the importance of using geosynthetics as a reinforcement material, particularly for soils with low shear strength and high compressibility, such as clay.

In addition to geosynthetics, much of the literature on clay soil stabilization has focused on various methods to improve the shear strength and reduce the compressibility of clay. Techniques such as chemical stabilization, compaction methods, and the addition of reinforcement materials like geosynthetics have been widely studied [11].

However, despite the wealth of studies on geosynthetics and soil stabilization, there is still a lack of comprehensive research examining the combined effect of different geosynthetics and their placement depth on soil reinforcement. Studies by Moayed et al. [9], Kamalzare and Ziaie-Moayed [10], and Zhan [12] have explored the effects of geosynthetics in shallow foundations but have not fully addressed how varying the placement depth of geosynthetics influences their performance. This study aims to fill this gap by comparing the effectiveness of different geosynthetics placed at various depths (5 cm, 10 cm, and a combination of 5 cm and 10 cm).

Recent findings by Yang et al. [15] emphasize the use of geotextiles in structures built over soft clay, such as embankments and dykes, providing additional motivation for this study. In addition, geosynthetics' capacity for both reinforcement and filtration makes them suitable for environments with low permeability and high water retention.

The primary objective of this study is to evaluate the performance of different geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—in reinforcing clay soil, with a focus on their ability to support maximum load (P_{max}), resist geosynthetic strain (τ), and minimize maximum displacement under varying placement depths (5 cm, 10 cm, and combined 5 cm & 10 cm). The parameters of maximum load, geosynthetic strain, and maximum displacement are important indicators to assess the effectiveness of geosynthetics in soil reinforcement because all three directly describe the mechanical performance and stability of the reinforced soil system. If the maximum load value increases significantly compared to unreinforced soil, it can be concluded that the geosynthetic is effective in increasing soil strength. The higher the maximum load value, the better the reinforcement so that the soil is better able to withstand external loads. The optimum strain indicates that the geosynthetic is able to absorb deformation energy and function as reinforcement efficiently without failure. The smaller maximum displacement compared to unreinforced soil indicates that the geosynthetic is able to control deformation, increase stability, and prevent failure.

2. MATERIAL AND METHOD

This study evaluates the performance of various geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—under maximum load (P_{max}), geosynthetic strain (τ), and maximum displacement on clay soil, with variations in placement depth (5 cm, 10 cm, and a combination of both 5 cm and 10 cm). The study aims to investigate how these geosynthetic materials, when placed at varying depths, affect the mechanical properties of clay soil under load conditions.

2.1 Experimental setup

The experimental setup was designed to evaluate the performance of three geosynthetic materials:

•Woven geotextile (G. Woven): Known for its high tensile strength and ability to distribute loads effectively.

•Non-woven geotextile (G. Non-woven): Selected for its flexibility and filtration properties.

•Geogrid: Chosen for its capacity to distribute loads and reinforce soil stability.

Testing of soil loading with reinforcement as follows: (1) clay soil that has been tested for its properties is inserted in such a way that it matches the height of the reinforcement material placement into the test box (80 cm × 40 cm × 10 cm), (2) Install the reinforcement material on the ground, (3) Cover the reinforcement material with soil then saturate it, (4) Testing by providing a uniform load in the form of an iron plate (10 cm × 9.5 cm × 0.3 cm) on the ground surface and observing the strain readings that occur and the load readings given for each decrease up to a limit of 1 inch. The strain and load readings that occur are recorded.

The geosynthetics were placed at varying depths to observe how depth affects their reinforcing ability. The placement depths used were: 5 cm, 10 cm and combination of 5 cm and 10 cm as shown in Figure 1.

These depths were chosen to examine the influence of different geosynthetic placement depths on the performance of clay soil under various loading conditions.

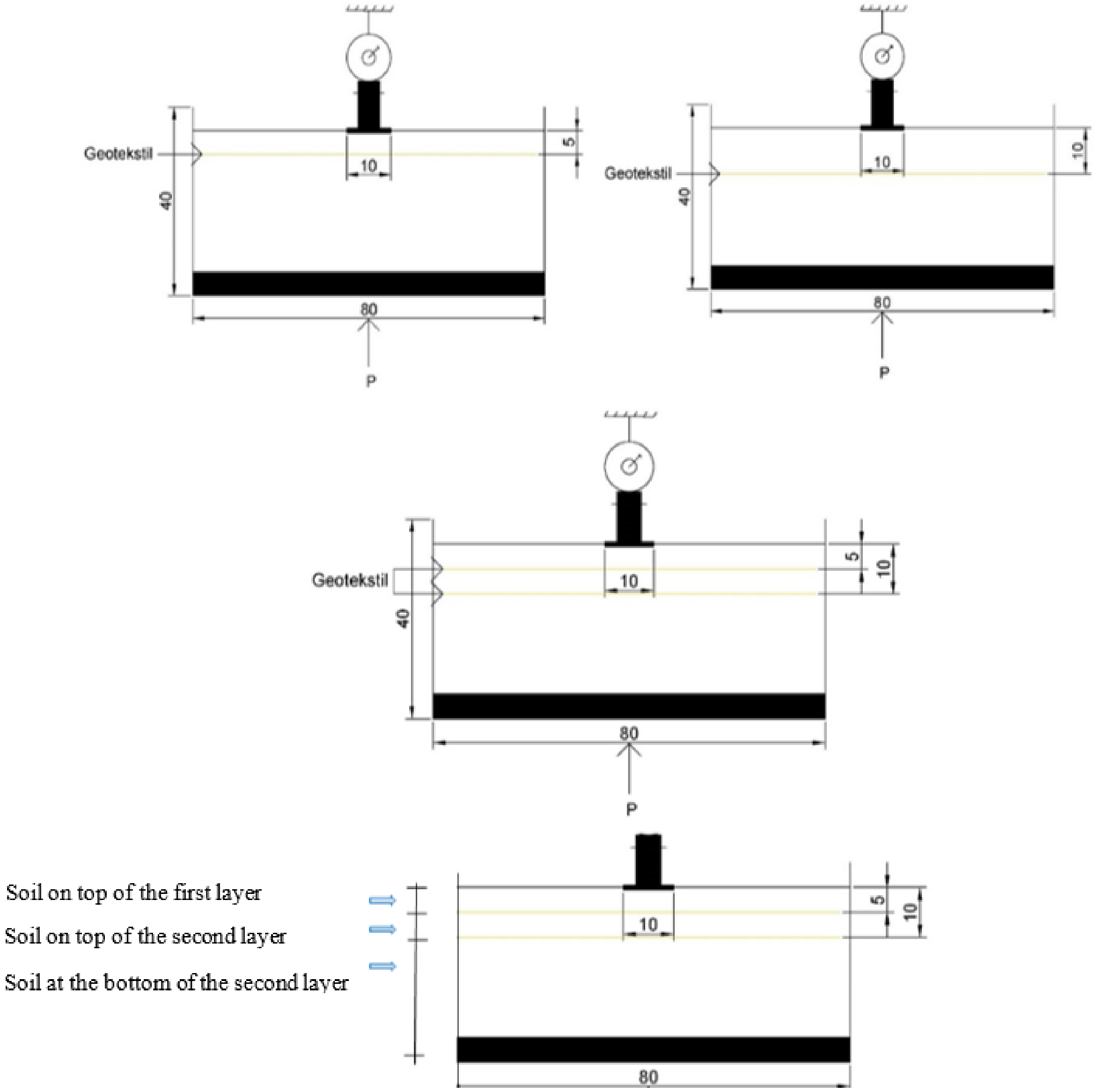

Figure 1. Test setup, including the soil specimens and the geosynthetics arrangement

The soil used in this study was clay soil, which passed through a sieve with a number. 100 and was sourced from Pekanbaru City, Riau Province as shown in Figure 2. The soil was classified as CL (Clay with Low Plasticity) according to the Unified Soil Classification System (USCS). The clay soil had a water content of 26.25%, an Atterberg limit of 41.54% for liquid limit, and a plasticity index of 20.00%. This specific soil was selected to reflect typical conditions in soft soil areas.

Figure 2. Soil clay

2.2 Data collection

2.2.1 Load tests

Incremental load was applied to each soil specimen, and the corresponding displacement was measured. These tests were performed to determine the maximum load (P_{max}) the soil could withstand and assess how well the geosynthetic materials reinforced the soil. The data from these tests were used to construct load-displacement curves, which helped determine the material's ability to resist load and minimize deformation.

2.2.2 Geosynthetic strain (τ)

The geosynthetic strain (τ) was measured to assess how much stress each material experienced under load. Strain is essential in understanding how well geosynthetics resist deformation under loading conditions. The stress on the geosynthetics is then calculated based on Construction and

Building Guidelines No. 003/BM/2009 of the Department of Public Works, Directorate General of Highways, Directorate of Engineering Development, concerning Planning and Implementation of Soil Reinforcement with Geosynthetics.

2.2.3 Maximum displacement (Max Displacement)

The data collected from the load tests, strain measurements, and maximum displacement observations were analyzed to evaluate the performance of the geosynthetic materials. The study compared the following parameters:

•Maximum load (P_{max}): The ability of the material to withstand applied loads.

•Geosynthetic strain (τ): The internal stress experienced by the material under load.

•Maximum displacement: The amount of deformation the soil experienced under the applied load.

2.3 Geosynthetic material specifications

PT Geoforce Indonesia provided the geosynthetics used in the experiment. The woven geotextiles are made from polyester (PET), with a structure that enhances tensile strength and load distribution as shown in Figure 3. The non-woven geotextiles are made from polypropylene (PP) and polyester (PET), offering high hydraulic and mechanical properties, including high tensile strength (15 kN/m) and permeability of 10^{-3} cm/sec. The non-woven geotextiles are particularly effective in enhancing drainage due to their permeability and filtration capabilities. The geogrids used were made from polyethylene (PE), offering high tensile strength (30 kN/m) and are known for their ability to reinforce soil and distribute loads effectively.

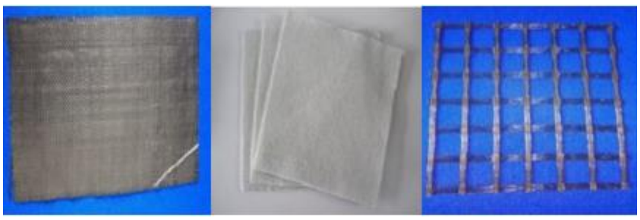

Figure 3. Geosynthetic

2.4 Soil compaction and container details

Testing of soil loading with reinforcement as follows: (1) clay soil that has been tested for its properties is inserted in such a way that it matches the height of the reinforcement material placement into the test box (80 cm × 40 cm × 10 cm), (2) Install the reinforcement material on the ground, (3) Cover the reinforcement material with soil then saturate it, (4) Testing by providing a uniform load in the form of an iron plate (10 cm × 9.5 cm × 0.3 cm) on the ground surface and observing the strain readings that occur and the load readings given for each decrease up to a limit of 1 inch. The strain and load readings that occur are recorded and recorded.

The soil used in this study was clay soil, which passed through sieve no. 40 and was sourced from Pekanbaru City, Riau Province. The soil was classified as CL (Clay with Low Plasticity) according to the Unified Soil Classification System (USCS). The clay soil had a water content of 26.25%, an Atterberg limit of 41.54% for liquid limit, and a plasticity index of 20.00%. This specific soil was selected to reflect typical conditions found in soft soil areas.

2.5 Clarification of geosynthetic strain measurement

The stress that occurs in geosynthetics is calculated by referring to the Construction and Building Guidelines No. 003/BM/2009 issued by the Department of Public Works, Directorate General of Highways, Directorate of Engineering Development, regarding Planning and Implementation of Soil Reinforcement with Geosynthetics. This guideline provides a technical reference in calculating the tensile stress that works on geosynthetic materials as part of a soil reinforcement system.

3. RESULT

3.1 Original soil test

Original soil data and direct shear test data of soil with geosynthetics are shown in Tables 1 and 2. Table 1 presents the characteristics of the native soil based on laboratory tests, identifying it as CL (Clay with Low Plasticity), water content 26.250%, Specific Gravity 2.653, LL 41.54%, PL 21.54%, PI 20%, Gravel 0%, Sand 21.133%, Clay 78.867%, cohesion c 0.421 Kg/cm^2 and friction angle φ 2.66°.

The results of the Direct Shear test between soil and three types of geosynthetics are shown in Table 2.

The data shown in Table 2 calculates the stress on geosynthetics. Based on the data above, the stress on the geosynthetics is then calculated based on Construction and Building Guidelines No. 003/BM/2009 of the Department of Public Works, Directorate General of Highways, Directorate of Engineering Development, concerning Planning and Implementation of Soil Reinforcement with Geosynthetics which is shown in Table 3.

Table 1. Original soil test results

No	Tests Performed	Parameter		Unit
1	Water Content	w	26.250	%
2	Specific Gravity	Gs	2.653	
3	Atterberg Limit	LL	41.540	%
4	Atterberg Limit	PL	21.540	%
5	Atterberg Limit	PI	20.000	%
6	Sieve Analysis	Gravel	0.000	%
7	Sieve Analysis	Sand	21.133	%
8	Sieve Analysis	Clay	78.867	%
9	Triaxial	c	0.421	Kg/cm^2
10	Triaxial	φ	2.66	°

Table 2. Recapitulation of contact area cohesion values (c_a) and contact area friction angle ($Ø_a$) from direct shear test results

Geosynthetics	Contact Field Cohesion (c_a) N/cm^2	Contact Area Friction Angle ($Ø_a$)°
G. Woven	1.28	30.786
G. Non-Woven	4.25	37.26
Geogrid	5.82	44.30

Table 3. Summary of data, showing the maximum load (P_{max}), geosynthetic strain (τ), and maximum displacement (Max Displacement) for each material and placement depth

No	Geosynthetic Model	Distance (cm)	Max Load (P_{max}) kg	Geosynthetic Strain (τ) N/cm²	Max Displacement (cm)
1	G. Woven	5	201.83	1,591.24	1.8
2	G. Woven	10	210.80	3,366.08	1.6
3	G. Woven	5 & 10	240.70	1,605.55 & 3,249.5	1.8 & 1.4
4	G. Non-woven	5	194.35	1,512.77	2.7
5	G. Non-woven	10	195.85	3,242.14	2.1
6	G. Non-woven	5 & 10	230.23	1,513,16 &3,143.31	2.7 & 1.9
7	Geogrid	5	173.42	1,458.37	3.0
8	Geogrid	10	185.38	3,206.32	2.5
9	Geogrid	5 & 10	197.34	1,471.710 & 3,104.13	3.0 & 2.2
10	No. Geo	-	167.440	-	-

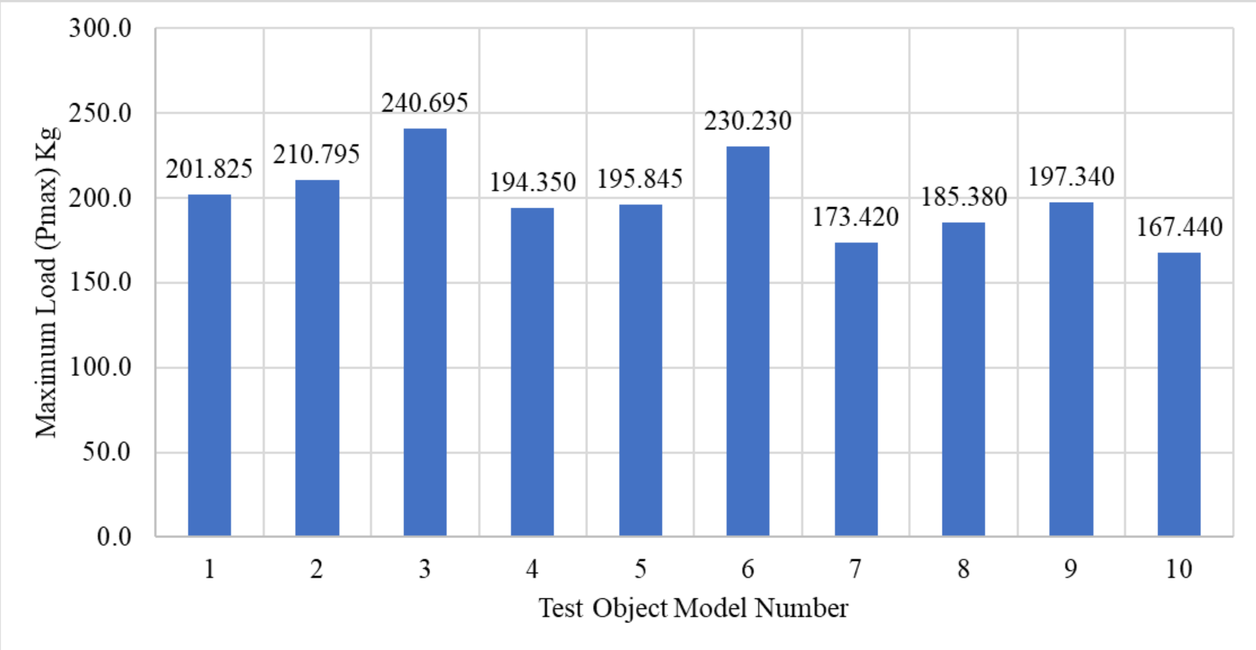

Figure 4. Maximum load (P_{max}) comparison for each geosynthetic material and placement depth

3.2 Maximum load (P_{max})

One of the primary objectives of this study was to assess how well each geosynthetic material could improve the load-bearing capacity of clay soil. Maximum load (P_{max}) represents the highest load the soil, reinforced with geosynthetics, could withstand before failure.

Figure 2 presents the P_{max} results for each geosynthetic material at the three different placement depths (5 cm, 10 cm, and combined 5 cm & 10 cm). The data show that woven geotextile consistently exhibited the highest P_{max} across all placement depths.

Specifically:

•At 5 cm depth, the woven geotextile supported a load of 201.825 kg.

•At 10 cm depth, the woven geotextile increased its capacity to 210.795 kg.

•The highest P_{max} (240.695 kg) was recorded at the combined depth of 5 cm & 10 cm for woven geotextile, outperforming both non-woven geotextile (230.230 kg at 5 cm & 10 cm) and geogrid (197.340 kg at 5 cm & 10 cm).

The graph of the maximum load that three types of geosynthetics can support is shown in Figure 4.

As shown in Figure 4, the woven geotextile demonstrated the highest load-bearing capacity, particularly at the combined 5 cm & 10 cm depth, which suggests that the combination of depths enhances the material's performance. On the other hand, the geogrid showed the lowest P_{max} across all placement depths, which could indicate its limitation in applications where vertical load-bearing capacity is crucial.

3.3 Geosynthetic strain (τ)

Geosynthetic strain (τ) refers to the internal stress experienced by the material under load, which is critical for understanding how well a geosynthetic resists deformation. Figure 5-7 shows the strain measurements for each material at 5 cm, 10 cm, and combined 5 cm & 10 cm depths.

The results indicated that woven geotextile experienced the highest strain values, suggesting it is better suited to handle high stress loads.

Specifically:

•At 5 cm depth, the woven geotextile exhibited a strain of 1,591.239 N/cm².

•At 10 cm depth, this value increased to 3,366.076 N/cm², showing that woven geotextile can effectively resist higher stresses at greater depths.

•For the combined 5 cm & 10 cm depth, the woven geotextile showed strain values of 1,605.553 N/cm² in the upper layer and 3,249.5 N/cm² in the lower layer.

Non-woven geotextile and geogrid recorded lower strain values:

•Non-woven geotextile: 1,512.765 N/cm² at 5 cm depth, 3,242.135 N/cm² at 10 cm depth, and 1,513,158 N/cm² (upper layer) and 3,143.305 N/cm² (lower layer) at 5 cm & 10 cm depth.

•Geogrid: 1,458.371 N/cm² at 5 cm depth, 3,206.320 N/cm² at 10 cm depth, and 1,471.710 N/cm² (upper layer) and 3,104.130 N/cm² (lower layer) at 5 cm & 10 cm depth.

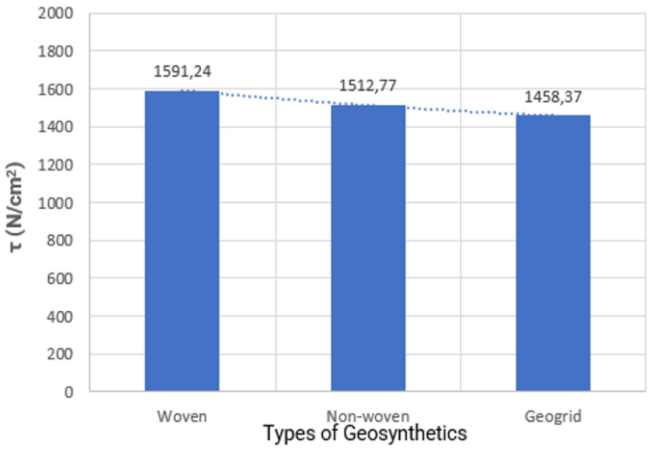

Figure 5. Compares geosynthetic strain for 5 cm reinforcement spacing

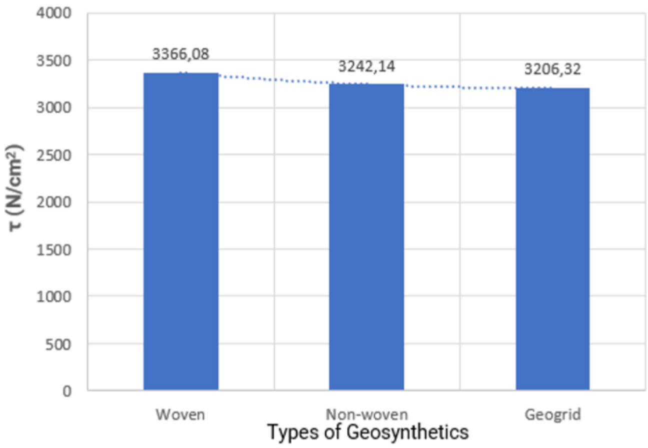

Figure 6. Compares geosynthetic strain for 10 cm reinforcement spacing

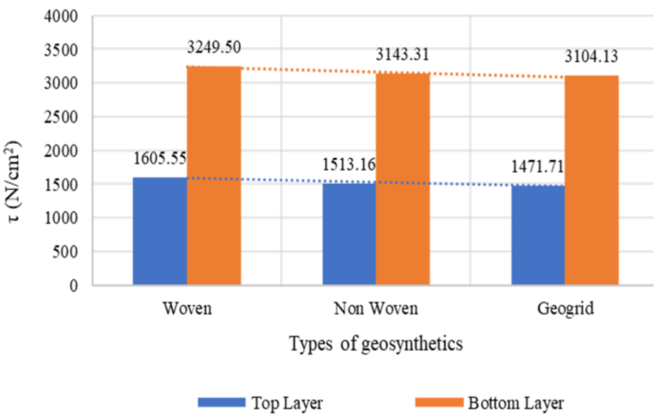

Figure 7. Compares geosynthetic strain for combined 5 cm & 10 cm reinforcement spacing

Figures 5-7 data demonstrate that woven geotextile experiences the highest strain, particularly in the deeper placements (10 cm and combined 5 cm & 10 cm). This indicates that woven geotextile has superior tensile strength and ability to resist deformation compared to non-woven geotextile and geogrid, making it the most resilient material under high-stress conditions.

3.4 Maximum displacement (Max Displacement)

Maximum displacement (Max Displacement) was used to assess how much the soil deforms under the applied load. Displacement is essential for understanding soil stability, as excessive displacement can lead to structural settlement issues.

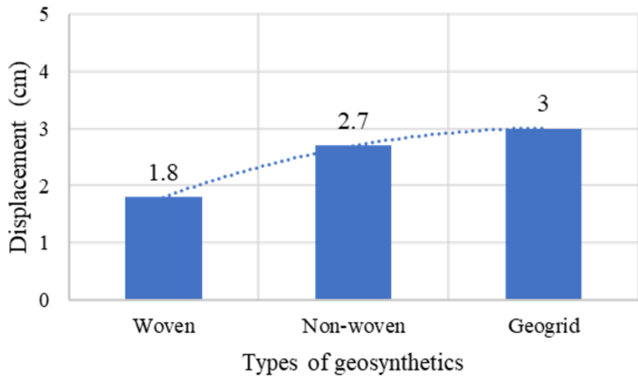

Figure 8. Compare displacement for 5 cm reinforcement spacing

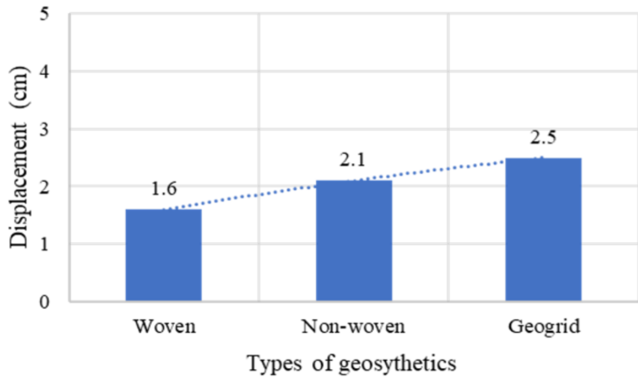

Figure 9. Compare displacement for 10 cm reinforcement spacing

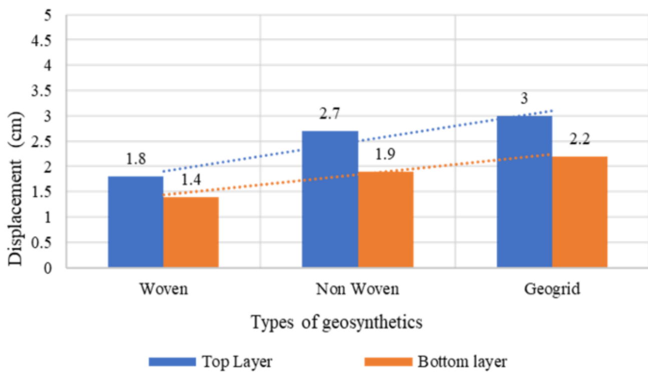

Figure 10. Compare displacement for combined 5 cm & 10 cm reinforcement spacing

Comparison of three types of geosynthetics (1) woven, (2) non-woven, and (3) single layer geogrid with a distance of 5 cm and 10 cm and a distance of 2 layers concerning geosynthetic settlement can be seen in Figures 8-10. Figure 10 compares the displacement for each material at different depths.

These graphs illustrate how displacement varies with different materials and placement depths, allowing us to observe the geosynthetic material's ability to minimize soil deformation.

The results show that woven geotextile performed the best in minimizing soil displacement:

•At 5 cm depth, the displacement for woven geotextile was 1.8 cm.

•At 10 cm depth, it was 1.6 cm.

•The smallest displacement (1.4 cm) was observed at the combined 5 cm & 10 cm depth.

In contrast, non-woven geotextile and geogrid exhibited greater displacement:

•Non-woven geotextile: 2.7 cm at 5 cm, 2.1 cm at 10 cm, and 1.9 cm at 5 cm & 10 cm.

•Geogrid: 3.0 cm at 5 cm, 2.5 cm at 10 cm, and 2.2 cm at 5 cm & 10 cm.

Figure 8-10 clearly illustrates that woven geotextile resulted in the least displacement, suggesting its effectiveness in maintaining soil stability under load. On the other hand, geogrid demonstrated the most significant displacement, particularly at the 5 cm depth, highlighting its relatively lower efficiency in preventing vertical settlement than woven geotextile.

4. DISCUSSION

Woven geotextile with a combined 5 cm & 10 cm placement depth was the most effective geosynthetic material for reinforcing clay soil based on the maximum load, geosynthetic strain, and maximum displacement results. It showed the highest load-bearing capacity, the most significant strain resistance, and the smallest displacement, making it the optimal material for improving soil stability and reducing deformation under load. The findings from this study highlight the importance of addressing the challenges of soft soils like clay, which often lead to significant settlement issues under load [14]. These challenges are crucial for improving infrastructure projects' overall stability and durability.

The experimental results provide valuable insights into the performance of three geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—used to reinforce clay soil. These materials were tested under conditions involving maximum load (P_{max}), geosynthetic strain (τ), and maximum displacement (Max Displacement), with variations in placement depth (5 cm, 10 cm, and a combination of 5 cm and 10 cm). These results not only validate the findings of previous studies but also emphasize the gap in knowledge regarding the long-term effectiveness of these materials in real-world conditions.

This study aimed to evaluate the performance of three geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—under conditions of maximum load (P_{max}), geosynthetic strain (τ), and maximum displacement, with variations in placement depth (5 cm, 10 cm, and a combination of both 5 cm & 10 cm). The key findings from this investigation are consistent with previous studies in the field of geosynthetics, confirming that woven geotextile is the most effective material for enhancing the load-bearing capacity and minimizing soil deformation, particularly in clay soils. These studies primarily focused on short-term effects, and while this research corroborates their findings, it also suggests the need for further exploration into the long-term performance of these materials under environmental stressors.

From an industrial perspective, using woven geotextile in construction can result in longer-lasting infrastructure, reducing the need for frequent repairs and maintenance, especially for roadway applications where geotextiles improve pavement structure [15]. This is particularly valuable for projects where settlement and deformation are of significant concern. Moreover, applying woven geotextile could help reduce construction costs over time by preventing structural damage caused by soil movement and providing a more durable solution.

Yang et al. [15] highlighted the use of geotextile-reinforced structures in soft subsoil conditions, especially for embankments and dykes, which reinforces this study's relevance. Woven geotextile demonstrated the highest P_{max} values (240.695 kg at a combined depth of 5 cm & 10 cm), and the lowest displacement (1.4 cm), confirming its superior load-bearing and settlement resistance properties.

Akene and Okoto [16] further emphasized the benefits of geotextile applications in pavement design, particularly in soft subgrade scenarios. Their findings support the suitability of woven geotextile in vertical reinforcement scenarios, aligning with this study's experimental results.

Murakami et al. [17] indicated that while geogrids are effective for lateral soil stabilization, they are less efficient in preventing vertical deformation, particularly in soft soils. In our study, geogrid exhibited the most significant displacement (3.0 cm at 5 cm depth), which aligns with previous research suggesting that geogrids are more suited to applications where lateral stability is crucial than vertical reinforcement. This highlights the importance of selecting appropriate materials based on the specific reinforcement needs, further reinforcing the contribution of this study in clarifying material suitability for various applications.

Installation-related mechanical stresses can compromise the effectiveness of geosynthetics. Koerner et al. [18] and Kukreja [19] found that stresses from aggregates or improper installation can reduce geosynthetic performance, indicating the need for improved field application practices.

Additionally, non-woven geotextiles showed superior performance in drainage and filtration due to their permeability [20]. These properties make them ideal for conditions where moisture management is critical, though they are less optimal for vertical load support compared to woven geotextiles.

Environmental durability must also be considered. Beaumier et al. [21] found that UV exposure prior to installation can degrade geotextile performance. Though this study was conducted in controlled laboratory settings, future research should evaluate long-term environmental impacts, including exposure to sunlight, moisture variations, and mechanical fatigue.

While this study's results offer valuable insights, it is essential to acknowledge its limitations. The experiments were conducted in controlled laboratory settings, where factors such as moisture content, temperature, and soil heterogeneity were not varied. These environmental factors play a critical role in the performance of geosynthetics in real-world conditions. Future studies should investigate the long-term performance of woven geotextile, non-woven geotextile, and geogrid under variable field conditions, including changes in soil moisture and environmental stressors. The lack of environmental variability in this study's conditions highlights the need for future research to explore the real-world effectiveness of these materials.

Additionally, this study has not considered the environmental impact of geosynthetics, particularly in terms of material degradation, leaching, and potential contamination. As geosynthetics are widely used in construction projects involving sensitive ecosystems, further research should focus on assessing their sustainability and long-term environmental impact. This gap in research on the ecological impact of geosynthetics is a critical contribution this study calls for, as it is essential for evaluating the full lifecycle of these materials in construction.

The findings from this study have significant implications for the practical application of geosynthetics in geotechnical engineering. Woven geotextile, with its superior performance in load-bearing capacity, strain resistance, and soil displacement minimization, should be considered the material of choice for applications requiring vertical reinforcement, such as road construction, embankments, and foundation works. Its ability to significantly reduce settlement in soft soils makes it ideal for reinforcing clayey soils, which are often problematic in infrastructure projects. The results of this study provide a clear pathway for selecting the optimal geosynthetic material, filling the gap in material selection guidelines for soil reinforcement.

While geogrid and non-woven geotextile also demonstrated effective performance in some contexts, their primary utility lies in lateral stabilization and filtration. Non-woven geotextile, for instance, may be more cost-effective for applications that do not require high load-bearing capacity but still benefit from improved soil drainage and reinforcement. On the other hand, geogrid should be considered for applications where lateral soil reinforcement is more critical, such as slope stabilization, rather than vertical reinforcement. This finding emphasizes the need for engineers to carefully assess the specific requirements of each project before selecting a geosynthetic material.

This study confirms the effectiveness of woven geotextile in reinforcing clay soils, highlighting its superior performance in load-bearing, minimizing displacement, and resisting strain. These findings suggest that woven geotextile is the most suitable material for addressing vertical deformation concerns in soft soils. The results contribute significantly to the field of soil reinforcement by offering clear guidance on the best materials for vertical soil reinforcement applications. Future research should continue to explore the long-term behavior of these materials, particularly their durability under varying environmental conditions and their environmental impact. This continued research is necessary to address the remaining gaps in our understanding of geosynthetic materials' long-term sustainability and their effect on the environment.

The results of this study contribute to the growing body of knowledge on the use of geosynthetics in soil reinforcement, particularly in clayey soils. By providing a deeper understanding of the material performance and their respective applications, this study aids in the informed selection of geosynthetic materials in engineering practice, ensuring that infrastructure projects benefit from sustainable, cost-effective, and durable reinforcement solutions. This research significantly contributes to closing the gaps identified in previous studies, offering valuable insights for future developments in geotechnical engineering.

5. CONCLUSIONS

The primary objective of this study was to evaluate the performance of different geosynthetic materials—woven geotextile, non-woven geotextile, and geogrid—in reinforcing clay soils, with a particular focus on their ability to support maximum load (P_{max}), resist geosynthetic strain (τ), and minimize maximum displacement under varying placement depths (5 cm, 10 cm, and a combination of both 5 cm & 10 cm). The results demonstrated that woven geotextile outperformed non-woven geotextile and geogrid across all measured parameters. These findings address the knowledge gap identified in previous studies, particularly regarding these materials' long-term performance and effectiveness under various loading conditions.

Woven geotextile consistently showed the highest P_{max}, with a maximum load of 240.695 kg at the combined depth of 5 cm & 10 cm, surpassing the performance of non-woven geotextile (230.230 kg) and geogrid (197.340 kg). In addition, woven geotextile exhibited the lowest maximum displacement (1.4 cm), highlighting its effectiveness in minimizing soil settlement compared to non-woven geotextile (2.7 cm) and geogrid (3.0 cm). This underscores the superiority of woven geotextile in vertical reinforcement and load distribution, which directly addresses the challenge of vertical settlement and deformation commonly encountered in clay soils, as noted in prior research.

The results of this study are significant for practical applications in civil engineering, particularly in projects involving soft or clayey soils. Given the findings of this study, woven geotextile can be recommended as the most reliable material for reinforcing such soils, making it an ideal choice for road construction, embankments, and foundation stabilization applications. It offers an optimal balance between load-bearing capacity, strain resistance, and displacement control, thereby improving soil stability and ensuring the durability of civil infrastructure. This contribution to understanding the material's suitability for vertical reinforcement in clay soils fills a gap in the literature and can aid in informed material selection.

Nonetheless, the study has limitations, primarily related to its controlled laboratory setup, which does not capture field variability such as changes in moisture content, temperature, or soil heterogeneity. Future research should investigate the long-term behavior of geosynthetics in real-world conditions, including the impact of environmental exposure during handling and installation phases.

Additionally, geosynthetics' environmental impact and degradation should be evaluated, particularly considering the potential for leaching and long-term material degradation, to ensure sustainable and safe use in construction.

Future studies should also examine the behavior of geosynthetics in reinforcing other types of soil, such as granular soils, and investigate the performance of multi-layer reinforcement systems. Expanding the scope of research to different soil types and reinforcement configurations allows a more comprehensive understanding of geosynthetics' applicability in diverse geotechnical scenarios. This would help address the gaps related to material performance in various environmental contexts**.**

The findings from this study provide valuable insights into the performance of geosynthetics for clay soil reinforcement. By highlighting the superior performance of woven geotextile, this research contributes to more informed material selection in geotechnical engineering, helping to optimize the design and construction of stable, long-lasting infrastructure. This study's contribution lies in confirming the superior properties of woven geotextile and in providing new insights that help close gaps in the application of geosynthetics in soil reinforcement, particularly in the context of soft and clayey soils.

ACKNOWLEDGMENT

This research was supported by the Civil Engineering Doctoral Program at Andalas University, Padang, West Sumatra, Indonesia, and PT Geoforce Indonesia for providing geosynthetic materials for this research.

REFERENCES

[1] Al-Khalid, K.W.A., Fattah, M.Y., Hameedi, M.K. (2022). Compressibility and strength development of soft soil by polypropylene fiber. International Journal of Geomate, 22(93): 91-97. https://doi.org/10.21660/2022.93.3206

[2] Grizi, A., Al-Ani, W., Wanatowski, D. (2022). Numerical analysis of the settlement behavior of soft soil improved with stone columns. Applied Sciences, 12(11): 5293. https://doi.org/10.3390/app12115293

[3] Hasan, M., Samadhiya, N.K. (2016). Experimental and numerical analysis of geosynthetic-reinforced floating granular piles in soft clays. International Journal of Geosynthetics and Ground Engineering, 2: 22. https://doi.org/10.1007/s40891-016-0062-6

[4] Khalid, B., Alshawmar, F. (2024). Comprehensive review of geotechnical engineering properties of recycled polyethylene terephthalate fibers and strips for soil stabilization. Polymers, 16(13): 1764. https://doi.org/10.3390/polym16131764

[5] Medina-Martinez, C.J., Sandoval Herazo, L.C., Zamora-Castro, S.A., Vivar-Ocampo, R., Reyes-Gonzalez, D. (2023). Use of sawdust fibers for soil reinforcement: A review. Fibers, 11(7): 58. https://doi.org/10.3390/fib11070058

[6] Mirzababaei, M., Arulrajah, A., Haque, A., Nimbalkar, S., Mohajerani, A. (2018). Effect of fiber reinforcement on shear strength and void ratio of soft clay. Geosynthetics International, 25(4): 471-480. https://doi.org/10.1680/jgein.18.00023

[7] Srihandayani, S. (2020). Alternative foundation for reducing building losses due to foundation failure in soft soil. E3S Web of Conferences, 156: 02006. https://doi.org/10.1051/e3sconf/202015602006

[8] Srihandayani, S., Putri, D., Kurniasih, N., Putri, L. D. (2018). Bearing capacity of floating foundations used PVC (poly vinyl chloride) on soft soil with the scale model in the field. International Journal of Engineering & Technology, 7(2.5): 84-87. https://doi.org/10.14419/ijet.v7i2.5.13957

[9] Moayed, R.Z., Nazari, M., Allahyari, F. (2013). Effect of geosynthetic inclusion on the bearing ratio of two-layered soil. Journal of the Chinese Institute of Engineers, 36(7): 914-931. https://doi.org/10.1080/02533839.2012.743230

[10] Kamalzare, M., Ziaie-Moayed, R. (2011). Influence of geosynthetic reinforcement on the shear strength characteristics of two-layer sub-grade. Acta Geotechnica Slovenica, 8(1): 39-49.

[11] Zhao, Y., Lu, Z., Liu, J., Zhang, J., Yao, H. (2023). Influence of different infill materials on the performance of geocell-reinforced cohesive soil beds. Scientific Reports, 13(1): 12330. https://doi.org/10.1038/s41598-023-39580-x

[12] Zhan, G. (2014). Old and new embankment splicing technology in highway reconstruction project. Applied Mechanics and Materials, 587: 1190-1193. https://doi.org/10.4028/www.scientific.net/AMM.587-589.1190

[13] Yapage, N., Liyanapathirana, S. (2018). Behaviour of geosynthetic reinforced column supported embankments. Journal of Engineering, Design and Technology, 16(1): 44-62. https://doi.org/10.1108/jedt-10-2015-0062

[14] Aissi, A., Bensihamedi, S., Bouafia, A., Saihia, A., Belagra, L. (2013). Behaviour study of monitored embankment founded on compressible soil. World Journal of Engineering, 10(5): 449-456. https://doi.org/10.1260/1708-5284.10.5.449

[15] Yang, S., Liao, W., Wang, X., Zhou, M., Zhang, X., Zhuang, S. (2023). Behavior of the geotextile reinforced dykes on sand-overlying-clay deposit. Frontiers in Marine Science, 10: 1070900. https://doi.org/10.3389/FMARS.2023.1070900

[16] Akene, J.E., Okoto, I.A. (2023). Pavement design a trans-construction research analysis case study: Geotextiles. Federal University Otuoke, Nigeria.

[17] Murakami, A., Shuku, T., Fujisawa, K. (2024). An application of particle filter for parameter estimation and prediction in geotechnical engineering. IntechOpen. https://doi.org/10.5772/intechopen.1005562

[18] Koerner, G.R., Loux, T., Filshill, A., Schuller, J. (2023). Geosynthetic damage due to installation stresses in ultra-light weight foamed glass aggregate versus conventional aggregate. In Geosynthetics: Leading the Way to a Resilient Planet. CRC Press, pp. 213-218.

[19] Kukreja, K. (2021). Geosynthetics: An overview. Btra Scan, 50(2): 11-19. https://www.btraindia.com/wp-content/uploads/2022/07/BTRA-Scan-April-2021-issue.pdf.

[20] Lin, C., Zhang, X., Galinmoghadam, J., Guo, Y. (2022). Working mechanism of a new wicking geotextile in roadway applications: A numerical study. Geotextiles and Geomembranes, 50(2): 323-336. https://doi.org/10.1016/j.geotexmem.2021.11.009

[21] Beaumier, D., Fourmont, S., Koerner, G. (2024). Lifetime considerations of geotextile UV exposure before installation. E3S Web of Conferences, 569: 26003. https://doi.org/10.1051/e3sconf/202456926003

NOMENCLATURE

P_{max}	Maximum load, kg
τ	Geosynthetic strain, N/cm²
Max Displacement	Maximum displacement, cm

G.Woven	Woven geotextile (material type)
G.Non-woven	Non-woven geotextile (material type)
Geogrid	Geogrid (material type)
c	Cohesion, N/cm^2
φ	Friction angle, degrees
5 cm	Placement depth of 5 cm
10 cm	Placement depth of 10 cm
5 cm & 10 cm	Combined placement depth of 5 cm and 10 cm
G	Geosynthetics material (general term for woven geotextile, non-woven geotextile, or geogrid)
Woven Geotextile	A type of geosynthetic used for soil reinforcement
Non-Woven Geotextile	A type of geosynthetic used for filtration and reinforcement
Geogrid	A geosynthetic material used for load distribution and soil stabilization
m	Mass, kg
N	Newton, unit of force ($kg \cdot m/s^2$)
cm	Centimeter, unit of length (1 cm = 10^{-2} m)