Investigation of the Performance of Geosynthetics for Subgrade Soil Stabilization

Authors

Kaleemullah	CU-971-2020
Bakht Bedar	CU-1007-2020
Fazal Dawar	CU-989-2020
Zohaib Ullah Khan	CU-962-2020

Supervisor

Dr. Bakht Zamin

Professor CECOS University

Co-Supervisor

Engr. Haris Alam

Asst. Director PDA

DEPARTMENT OF CIVIL ENGINEERING

CECOS University of It and Emerging Sciences Hayatabad Peshawar

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A Thesis submitted in partial fulfilment of the requirements of the degree of
B.Sc. Civil Engineering

Thesis Supervisor
Dr. Bakht Zamin
Professor
Department of Civil Engineering

Thesis Supervisor Signature

Chairman CED, Signature

DEPARTMENT OF CIVIL ENGINEERING
CECOS University of It and Emerging Sciences Hayatabad Peshawar
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Abstract

In various regions across Pakistan, soils with low bearing capacity pose significant challenges to the durability and safety of flexible pavements, leading to issues like rutting and cracking. In this project, we evaluated soil samples from two distinct locations: Warsak Road, Ashaq Abad, Peshawar, and Naguman to Charsadda Road, to assess their bearing capacity and other properties. Traditional stabilization methods often fall short in terms of cost-effectiveness and longevity. This project aims to evaluate the efficiency of geosynthetic materials, specifically biaxial and triaxial geogrids, in stabilizing subgrade soil within flexible pavement structures. The geogrids, sourced from Dezhou Hongli Geomaterial Engineering Co., Ltd. in China, are proposed as a promising alternative for subgrade soil stabilization. Through laboratory testing and practical modeling, the project examines the impact of geogrids on enhancing the bearing capacity of subgrade soil. Results show a notable increase in California Bearing Ratio (CBR) values with the incorporation of geogrids, indicating improved soil stability. Additionally, practical models depicting flexible pavement cross-sections highlight the optimal placement of geogrids within the subgrade layer. These findings suggest that geosynthetic materials offer a viable solution for strengthening weak subgrade soil, thereby enhancing the resilience and longevity of flexible pavement infrastructure. By utilizing geogrids for weak subgrade soil stabilization, the project aligns with SDG 9: "Build Resilient Infrastructure, Promote Sustainable Industrialization, and Foster Innovation," and SDG 11: "Sustainable Cities and Communities." This approach contributes to the development of sustainable cities and a safer transport system.

Keywords: Geogrids (Biaxial & Triaxial), CBR, SDG’s, Weak Subgrade Soil Stabilization.

UNDERTAKING

I certify that research work titled “Investigation of the Performance of Geosynthetics for Subgrade Soil Stabilization” is my work.

The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged/referred.

Kaleemullah	CU-971-2020	___________________________
Bakht Bedar	CU-1007-2020	___________________________
Fazal Dawar	CU-989-2020	___________________________
Zohaib Ullah Khan	CU-962-2020	___________________________

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Chapter No.1

Introduction

1.1. Background

In the construction and maintenance of pavement structures, the subgrade layer holds an important role as the foundation upon which the entire pavement rests. Its strength and stiffness are crucial factors influencing the design, construction, and overall performance of flexible pavements. As traffic volume increases over time, so does the loading on pavements, causing more distress on roadway surfaces. This heightened traffic loading primarily impacts the subgrade layer, amplifying its response and potentially leading to various distresses on the pavement such as fatigue cracking, bleeding, block cracking, depression, shoving, joint reflection cracking, potholes, raveling, and rutting. [1]

Pavement engineers encounter substantial hurdles when designing structures over weak subgrades. As traffic loads continue to increase, there's a growing need to construct supporting layers capable of enduring these pressures while also reducing material expenses. In response to this challenge, integrating geosynthetic materials into pavement structures emerges as a promising solution. These materials serve to stabilize and reinforce the subgrade layer, enhancing its ability to withstand the rigors of heavy traffic. By incorporating geosynthetics, engineers can optimize pavement design, bolstering its resilience and longevity while simultaneously curbing material costs. This innovative approach represents a significant advancement in pavement engineering, offering sustainable solutions to address the complex demands of modern infrastructure development.

Over the years, numerous studies have been conducted to explore the behavior of geosynthetic-reinforced paved roads, undertaken by researchers [2], [3], [4], [5], [6], and [7]. These studies have underscored the significant benefits of utilizing geosynthetic materials, particularly in scenarios where subgrade soils exhibit weakness. By providing reinforcement and stabilization, geosynthetics offer an efficient alternative to traditional methods, thereby enhancing the durability and longevity of flexible pavements.

In Pakistan, the absence of locally sourced geosynthetic materials poses a challenge for infrastructure projects necessitating soil stabilization solutions. Consequently, these materials are imported from various countries to fulfill the demands of construction projects across the nation. This reliance on imports underscores the critical need for developing local manufacturing capabilities to produce geosynthetics domestically. By establishing indigenous production facilities, Pakistan can reduce its dependence on foreign imports, ensuring a stable supply chain for infrastructure development initiatives. Moreover, local manufacturing would not only enhance accessibility to geosynthetic materials but also stimulate economic growth by creating employment opportunities and fostering technological innovation within the country's construction sector.

Therefore, the primary objective of this investigation is to assess the feasibility and effectiveness of utilizing geosynthetic materials for stabilizing subgrade soils that exhibit inherent weaknesses. By conducting comprehensive analyses and practical experiments, this study aims to determine the practicality and potential benefits of integrating geosynthetics into soil stabilization practices. Through thorough examination and evaluation, we seek to provide valuable insights into the applicability and performance of geosynthetic solutions in addressing subgrade soil challenges.

1.2. Problem Statement

Ensuring the stability and strength of subgrade soil is crucial for the effective performance of roads, particularly in Pakistan where diverse soil conditions prevail, ranging from expansive clays to lose sands. These varying soil characteristics frequently contribute to subgrade instability, presenting significant challenges to the durability and safety of infrastructure. The consequences of such instability manifest in various forms, including uneven settlement and rutting, which not only compromise road quality but also pose risks to vehicle safety and operational efficiency.

Conventional approaches such as soil removal, soil-cement mixing, and increasing base course thickness have long been employed to tackle subgrade issues. While these methods have been effective to some extent, they come with some limitations, particularly regarding their efficiency. As infrastructure demands continue to rise, there is a pressing need for more robust and dependable soil stabilization techniques. These techniques should offer enhanced performance while also being adaptable to diverse soil conditions encountered in different regions. By exploring innovative approaches to soil stabilization, the construction industry can address the shortcomings of traditional methods and ensure the sustainable development of infrastructure projects across various terrains.

Geosynthetics, such as geogrids, offer a promising solution to improve soil performance and tackle subgrade instability. By reinforcing roadway sections, geogrids help distribute loads more efficiently and enhance the subgrade's bearing capacity. This approach provides a more efficient alternative to conventional stabilization methods.

When facing weak subgrades that necessitate stabilization, geosynthetic materials emerge as a practical alternative to traditional lime or cement stabilization methods. Through the integration of geogrids into the construction process, engineers can establish a better working platform capable of withstanding the pressures exerted by surface vehicular loads. This approach not only enhances the stability of the subgrade but also contributes to the overall safety and durability of infrastructure in road construction projects. By utilizing the benefits of geosynthetics, construction teams can effectively address the challenges raised by weak subgrades, ensuring the longevity and resilience of transportation networks.

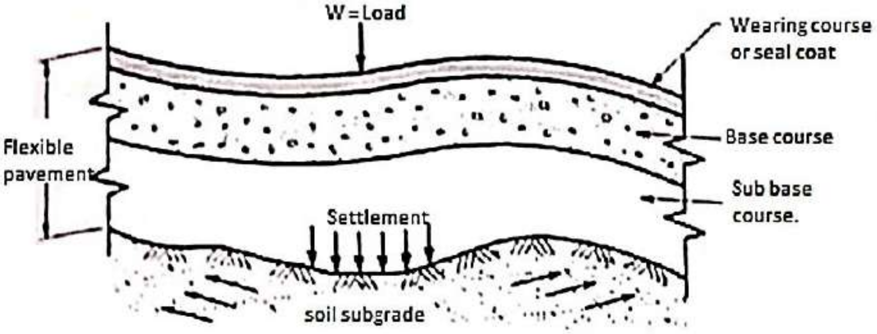


Figure 1.1: Subgrade Failure of Flexible Pavement [26]

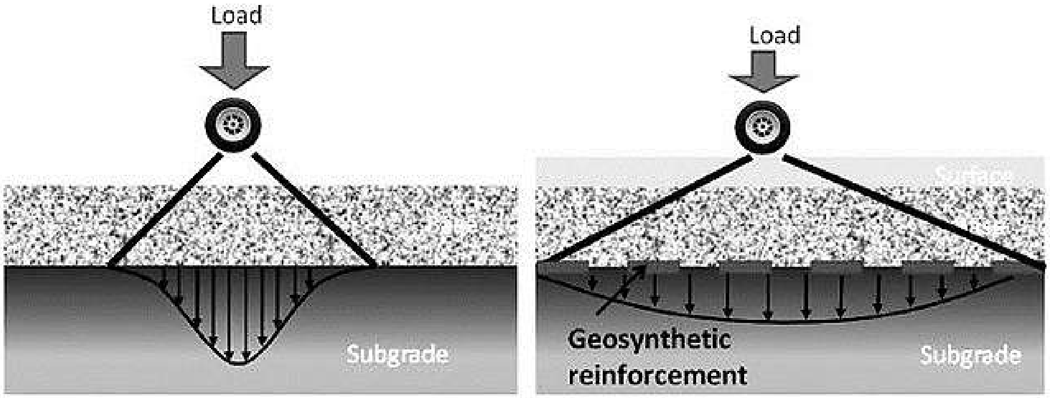


Figure 1.2: Shows wheel load distribution mechanism [33]

1.3. Aims and Objectives

The following points outline the aims and objectives of the project "Investigation of the performance of geosynthetics for subgrade soil stabilization":

1) Assess the performance of geosynthetic materials (e.g., Biaxial and Triaxial geogrids) in stabilizing subgrade soils.
2) Determine the ideal proportion of geomaterials to optimize their beneficial use in subgrade soils.
3) Evaluate the performance of geogrid placement at a specific depth within the subgrade layer of flexible pavement structures to determine the optimal placement for maximum stabilization effectiveness.
4) To study and compare the performance of the conventional soil and reinforced soil.
5) Investigate the difference in performance of different geosynthetic materials.
6) Investigate the potential implementation of geosynthetics in Pakistan, where they are still emerging.
7) Explore the transformative impact of geosynthetics on construction methodologies across Pakistan.

1.4. Significance of Research

The investigation of geosynthetics for subgrade soil stabilization holds significant implications for addressing various environmental, pollution, and public safety challenges. Through the integration of geosynthetic materials in stabilizing subgrade soils, we can effectively mitigate road accidents, enhance transportation efficiency, and minimize the economic losses associated with pavement failures. Furthermore, the utilization of geosynthetics contributes to a reduction in the frequency of road repairs, thereby lowering environmental impact and decreasing vehicular emissions. This strategic approach is aligned with the overarching objective of fostering sustainable cities by bolstering infrastructure resilience and fostering innovation in pavement construction practices. In essence, harnessing the potential of geosynthetics presents a multifaceted solution that not only improves road safety but also drives economic productivity and advances forward infrastructure development initiatives.

1.5. Thesis Organization

This thesis is structured into five chapters, each focusing on distinct aspects of the research topic. Below is a concise overview of the contents covered in each chapter.

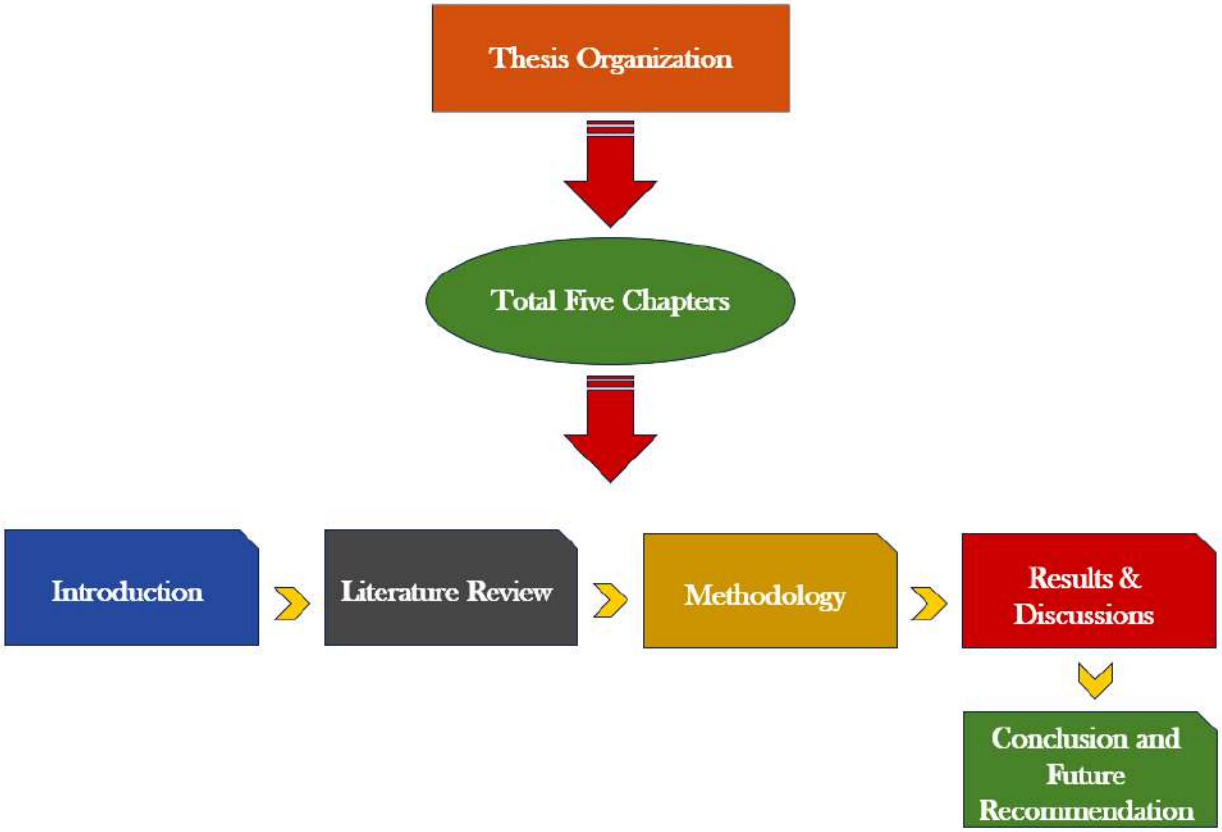


Figure 1.3: Flow chart of Thesis Organization

1.5.1 Chapter 1 (Introduction)

The introduction section serves as a comprehensive overview of the project, establishing the background and context for the study. It emphasizes the significance of employing geosynthetics, specifically geogrids, as a viable solution for stabilizing weak subgrade soil. By outlining the potential benefits of geosynthetics in subgrade soil stabilization, the introduction underscores the necessity of the research. Furthermore, it outlines the structure of the thesis, providing readers with a clear roadmap of the subsequent chapters. Lastly, the introduction poses the research question or hypothesis, setting the stage for the in-depth exploration that follows.

1.5.2 Chapter 2 (Literature Review)

In the literature review section, a detail examination of the existing body of knowledge and research concerning geosynthetics and their application in subgrade soil stabilization is conducted. This segment offers a thorough overview of relevant theories, studies, and findings gathered from previous researches. By synthesizing information from various scholarly sources, the literature review aims to provide a comprehensive understanding of the subject matter, clarifying the effectiveness and limitations of geosynthetics in addressing subgrade soil instability.

1.5.3 Chapter 3 (Methodology)

The methodology section offers a comprehensive explanation of the research methods employed to gather and analyze data. It serves to ensure the reproducibility of the study by outlining the steps taken to reach our conclusions. By delineating the specific procedures and techniques utilized in data collection and analysis, the methodology section provides transparency and clarity to the research process.

1.5.4 Chapter 4 (Results and Discussions)

This section presents the research findings, offering a detailed analysis and interpretation of the results. It encompasses the use of tables, graphs, and figures to bolster the findings and enhance comprehension. The results are thoroughly discussed in light of the research objectives and existing literature, facilitating a comprehensive understanding of their implications.

1.5.5 Chapter 5 (Conclusion and Future Recommendations)

In the conclusion section, we summarize the main findings of the study and underscore their importance and implications. We highlight how these findings contribute to our understanding of the subject and discuss their potential impact on practical applications. Additionally, we offer recommendations for future research, suggesting areas that warrant further exploration. This includes potential improvements in methodology to enhance the strength of future studies. Moreover, we provide practical recommendations for the implementation of geosynthetics, specifically geogrids, in stabilizing weak subgrade soil, emphasizing the potential benefits and advantages of this approach.

1.6. Thesis Limitations

1.6.1 Availability of Data

One potential limitation of the thesis could be the scarcity of data pertaining to geosynthetic materials in Pakistan. Given the lack of prior studies or research on this topic and the unavailability of geosynthetic materials within the country, there are constraints on the accessibility, quantity, and quality of such materials in Pakistan. This limitation may pose challenges in obtaining comprehensive data and conducting thorough analysis regarding the utilization of geosynthetics for subgrade soil stabilization in the local context.

1.6.2 Technical Challenges

As the utilization of geosynthetic materials in subgrade soil stabilization primarily involves fieldwork, advanced technology is essential for conducting real-life scenario tests in the field. These tests are crucial for gaining insights into the practical properties and effects of employing geosynthetics in soil stabilization. However, due to the absence of prior studies and the limited availability of technological resources or research standards in Pakistan, significant limitations arise.

1.6.3 Economic Viability

The economic limitations of geosynthetic materials for soil stabilization stem from their high initial procurement and installation costs, which may discourage adoption by project planners. Despite long-term benefits, the upfront investment may conflict with short-term budget constraints, posing financial challenges. Additionally, the unavailability of geosynthetics in Pakistan may necessitate costly imports, further dissuading some project planners from considering their use.

Chapter No.2

Literature Review

This chapter explores existing literature on the main subject of this thesis, focusing on the performance of geosynthetic materials, like Geogrid, in stabilizing subgrade soil. It highlights research findings and studies related to the behavior and effectiveness of Geogrid in soil stabilization. The literature review examines various applications and case studies showcasing the use of Geogrid in different soil conditions. It provides valuable insights into the role and impact of Geogrid in enhancing the stability and strength of subgrade soils.

2.1 General

Geosynthetics are special materials used in construction and civil engineering that have at least one part made from synthetic or natural polymers. They come in different forms like sheets or three-dimensional structures and are used in contact with the ground or other materials. These materials have a wide range of uses in construction projects worldwide. They play vital roles in areas like building roads, constructing hydraulic systems, preventing erosion, and addressing environmental concerns.

When it comes to making geosynthetics, manufacturers typically use methods like extrusion and textile technology. Sometimes, they combine both methods to create these materials. Geosynthetics are crafted from artificial fibers, which are essentially made from polymers. These polymers include polypropylene, polyester, polyamide, and polyethylene. Among these, polypropylene and polyester are the most commonly used now a days.

2.2 Classification of Geosynthetics

Geosynthetics come in different types, each made in specific ways. Here's a simple breakdown of these types and what they do:

2.2.1 Geotextiles:

These are like flexible sheets made of woven, nonwoven, knitted, or stitch-bonded fibers or yarns. They look like fabric and are used for various purposes like separating different materials, filtering, draining water, reinforcing soil, and controlling erosion.

2.2.2 Geogrids:

These materials have a grid-like appearance, kind of like a net. They're mainly used to strengthen soil by providing reinforcement.

2.2.3 Geonets:

Geonets are also grid-like, but they're made differently. They're formed by two sets of coarse, parallel polymeric strands that cross at an angle. They create a sheet with holes that can carry large flows of fluid or gas.

2.2.4 Geomembranes:

These are flexible sheets made from synthetic materials. They're really good at keeping liquids or gases from leaking through, so they're often used as liners for things like ponds or landfills, or as vapor barriers.

2.2.5 Geo-composites:

These are made by combining two or more types of geosynthetics. For example, you might have a combination of geotextile and geonet, or geotextile and geomembrane. They're used for specific purposes like drainage or preventing leaks.

2.2.6 Geocells:

These are like thick, three-dimensional nets made from strips of polymeric sheet. They're joined together to make cells, which can then be filled with soil or sometimes concrete. They're great for stabilizing soil or creating strong foundations.

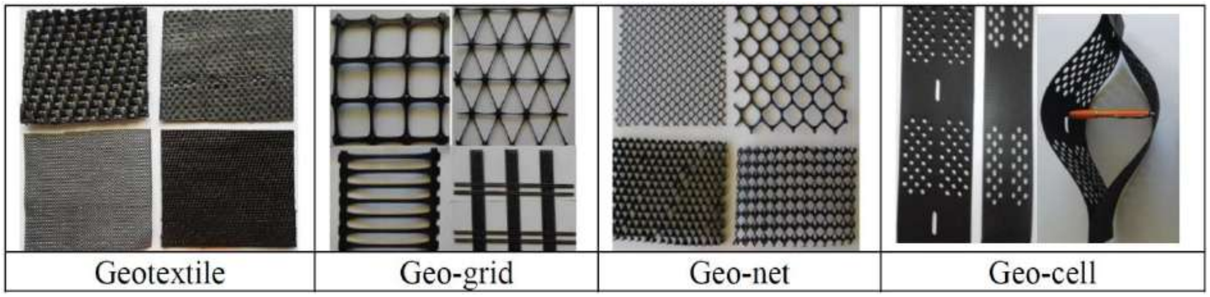


Figure 2.1: Some typical Geosynthetics [34]

2.3 Geogrid Reinforced Geomaterial

The utilization of inclusions like geosynthetics to enhance the mechanical properties of geomaterials has roots dating back to ancient civilizations. Research indicates that geosynthetics have the potential to prolong the lifespan of pavements, as evidenced by studies [3], [8]. Moreover, they have been shown to enable the reduction of layer thickness required for a specified service life, as demonstrated in studies [9].

The primary type of geosynthetics commonly employed for reinforcing subgrade layers in flexible pavements is geogrids. Geogrids are characterized by their large openings, which are formed through various manufacturing methods. These methods include coating woven or knit products to create a grid structure, welding oriented strands together, or punching holes in flat sheets and then aligning the polymer molecules. Polyester geogrids are known for their flexibility, whereas polypropylene and polyethylene geogrids are rigid in nature. The openings in geogrids allow for partial penetration of soil particles, facilitating a strong interlocking action. This interaction is crucial for enhancing the stability and performance of the pavement structure, as demonstrated [10]. The openings in geogrids can take various shapes, such as elongated ellipses, squares with rounded corners, rectangles, or triangles..

Geosynthetics are now recognized as a highly favorable solution for reinforcing subgrade layers, offering significant potential to address issues in pavements built over weak subgrades. This approach promises substantial cost savings while effectively improving pavement performance and durability

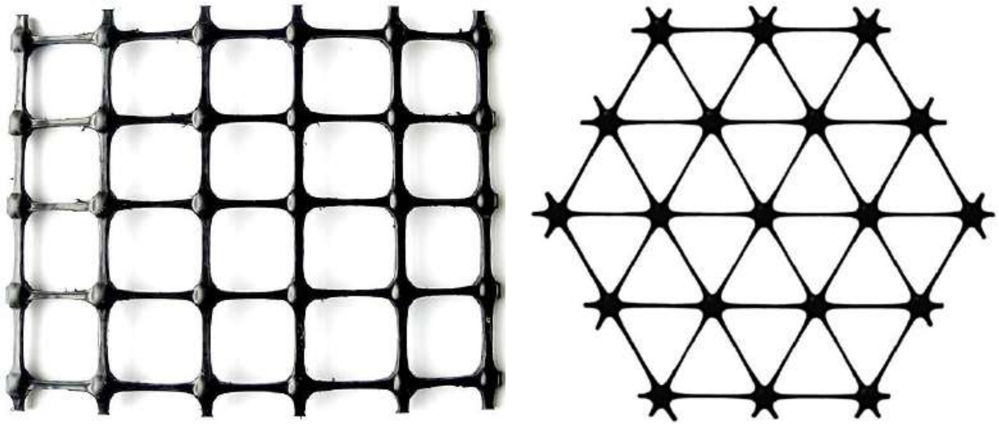


Figure 2.2: Biaxial and Triaxial Geogrids [27]

2.4 Influence of geosynthetic Material

The interaction between the subgrade soil and geogrid reinforcement is primarily occurs through their complex interlocking within the apertures. This interdependent relationship is further reinforced by the ribs of the geogrid, which play a pivotal role in confining the soil particles, thereby strengthening the resistance against lateral movement when subjected to surface loads. Geosynthetics, functioning as soil reinforcement agents, operate through a spectrum of mechanisms outlined in [11], each contributing to the overall stabilization and enhancement of the pavement structure. These mechanisms encompass:

1. Geosynthetics improve shear strength by effectively opposing the interaction between soil and material, thereby lessening the likelihood of soil displacement and instability.
2. Anchorage occurs when geosynthetics resist being dislodged or extracted from the soil, maintaining their position and integrity within the pavement structure.
3. Geosynthetics contribute to structural stability by offering resistance against normal loads, thereby minimizing the adverse effects of tensile membrane and lateral deformation.

These mechanisms collectively lead to a reduction in shear stress within the underlying soil, decreased permanent deformation, and improved bearing capacity, as emphasized in [11].

2.5 Placement (Location of Geogrid)

In subgrade soil stabilization for flexible pavement construction, geogrid serves as a reinforcement in weak subgrade soil to enhance stability. Previous research by scholars [12], [13], [14], has explored the optimal placement of geogrid within the subgrade soil. Their findings suggest that positioning the geogrid approximately 0.2H from the top of the specimen yields favorable engineering properties. This strategic placement is deemed optimal, as it facilitates favorable reinforcement effects within the compromised subgrade soil, thereby culminating in a comprehensive enhancement of various performance parameters observed in the flexible pavement structure. Through meticulous analysis and experimentation, these findings illuminate the significance of precise geogrid placement in achieving optimal subgrade stabilization and, consequently, the overall durability of pavement infrastructure.

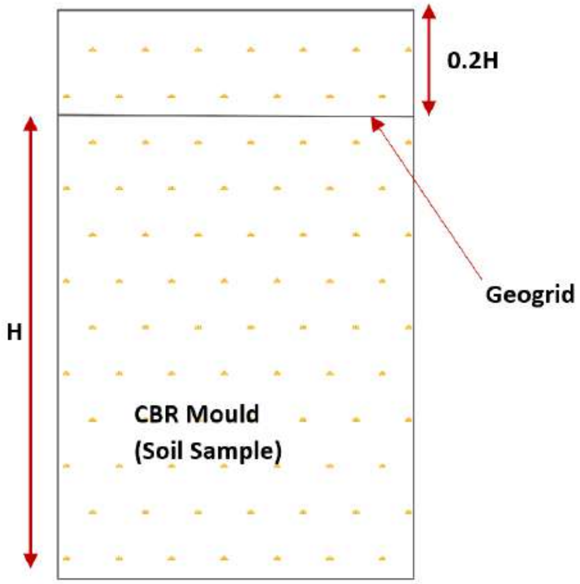


Figure 2.3: Placement of Geogrid in CBR Mould

2.6 Effect of Subgrade Strength

Numerous researchers have extensively studied the impact of geosynthetics on subgrade soil, consistently concluding that it is highly effective in stabilizing weak subgrade conditions. According to researchers, geosynthetics demonstrate superior performance, particularly when the California Bearing Ratio (CBR) of the subgrade is less than three [15]. In such weaker subgrade conditions, geosynthetics exhibit enhanced mobilization. [16] further corroborated these findings, noting that geogrid significantly reduces rutting when the CBR is below 3%. However, for stronger subgrade materials like stiff clay, geosynthetics may not effectively mobilize. Different studies indicate optimal performance of geosynthetics when the CBR of the subgrade is less than 1.5 [17]. These findings underscore the effectiveness of geosynthetics in addressing weaker subgrade conditions, with implications for improved pavement performance and durability. [25]

2.7 Cost Effectiveness of using Geosynthetic materials

The integration of geosynthetics into construction projects is anticipated to incur costs ranging from less than 1% to 5% of the initial construction expenses. Beyond their primary function of stabilizing the subgrade, geosynthetics play a multifaceted role in preventing premature subgrade failure, facilitating separation from the base layer, and enhancing base support. These contributions extend to cost-saving measures associated with surface rehabilitation and pavement design life.

The financial benefits of utilizing geosynthetics may be realized immediately or over the long term, or both. Immediate savings can be achieved through simplified installation processes, reduced soil material requirements, or expedited construction timelines. By leveraging the advantages offered by geosynthetics, construction projects can optimize efficiency and cost-effectiveness while ensuring the longevity and durability of infrastructure assets. [34]

2.8 Flexible Pavement Layers Thickness

The utilization of geogrid for subgrade soil stabilization in weak soil has notable effects on the thickness of various layers within the flexible pavement structure. Extensive research conducted indicates a significant reduction in the thickness of the base layer of the road when geogrid is employed in the subgrade layer. [15], [20]. Also suggests a decrease in the base layer thickness, some researchers observed a minimum reduction of 15% in the base course layer thickness with the use of geogrid [15]. Additional, findings highlight a substantial reduction of up to 50% in the additional material thickness at the interface of the sub-base layer, base layer, and soil subgrade [8]. These studies underscore the potential for optimizing pavement design and material usage through the incorporation of geogrid for subgrade soil stabilization. [24]

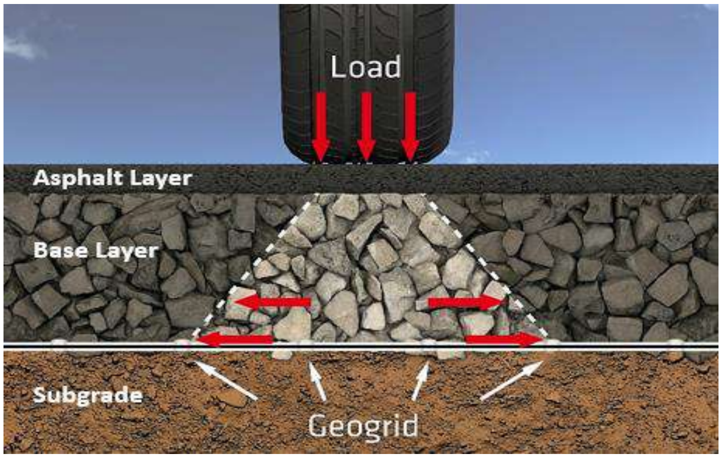


Figure 2.4: Different Layers of Flexible Pavement [28]

2.9 CBR (California Bearing Ratio) Lab Test

Various laboratory and field tests are employed to determine the bearing ratio of subgrade soil. Among these tests, the California Bearing Ratio (CBR) test is commonly utilized by researchers to assess the bearing capacity of subgrade soil. Past studies conducted by researchers have utilized the CBR test method for this purpose [12][13][22] [15-18]. Through the CBR test, researchers are able to calculate and evaluate the load-bearing capacity of subgrade soil, providing valuable insights into its strength and suitability for supporting pavement structures. In this project, soaked California Bearing Ratio (CBR) tests have been employed. This methodological approach facilitates informed decision-making in pavement design and construction, contributing to the overall performance and durability of transportation infrastructure. [25]

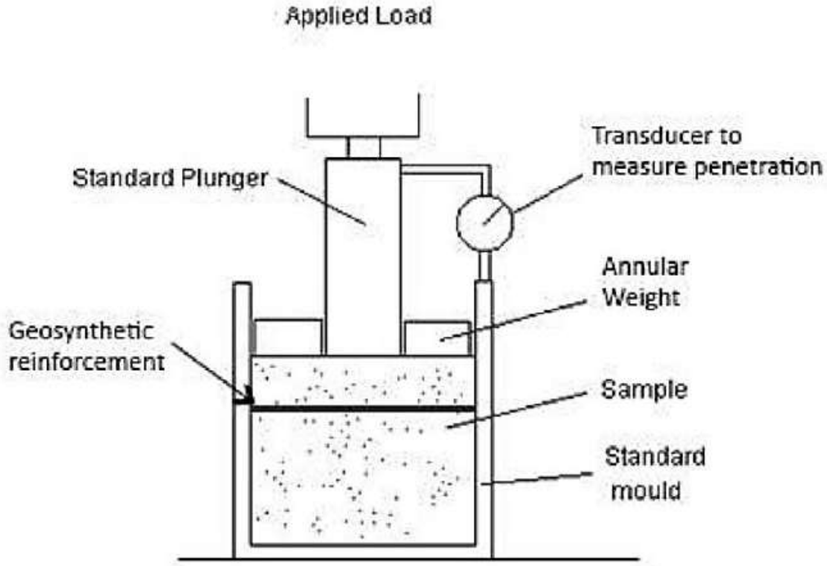


Figure 2.5: CBR Mould With Geosynthetic Reinforcement (Geogrid) [29]

2.10 Effectiveness of Geosynthetics on Roads Life

The incorporation of geosynthetics into road construction projects offers significant benefits, particularly when dealing with weak subgrade conditions. By overlaying such subgrades with geosynthetics, roads can experience a notable improvement in performance, characterized by reduced permanent vertical deformations and enhanced lateral restraint capability. This enhancement ultimately extends the service life of the pavement, representing the duration from construction commencement to the need for major reconstruction or rehabilitation. Geosynthetics have been shown to prolong pavement life by over 5% in various road applications. Research conducted by (IGCSE. I) explained the impact of geotextile strengthening on road service life, considering different combinations of layers and their effects on costs and rutting reduction. [34]

- Employing a single strengthening layer of geosynthetics results in a modest 14% increase in road cost but offers a substantial 85% reduction in rutting.
- Similarly, incorporating two strengthening layers leads to a slightly higher cost increase of 28% but achieves an impressive 93% reduction in rutting.
- Finally, utilizing three strengthening layers sees a cost increase of 42%, yet delivers an outstanding 96% reduction in rutting.

These findings underscore the cost-effectiveness and efficacy of geosynthetics in prolonging pavement life and improving road performance, making them a valuable asset in road construction and maintenance endeavors. [34]

2.11 Effect of multiple layer reinforcements

The results of the CBR tests conducted on soil reinforced with three different types of geosynthetics reveal significant improvements in the CBR value at various depths. The reinforcement ratio for these geosynthetic reinforcements placed at depths H/2, H/3, and H/4, as well as double layers, consistently exceeds unity ($\eta > 1$) throughout the tests. This observation underscores the beneficial impact of reinforcement on enhancing the subgrade strength of geosynthetic-reinforced unpaved roads.

The positioning of geosynthetic reinforcement within the subgrade emerges as a crucial factor influencing the performance of unpaved roads. The reinforcement ratio ranges from 1.05 to 1.58 for single layers of geosynthetic reinforcement and 2.12 to 4.25 for double layers. Among the three types of geosynthetic reinforcements studied, geogrids demonstrate superior performance compared to geonet when a single layer of reinforcement is used. However, there is an exception where geonet reinforcement achieves maximum strength when placed at ξ=H/2 from the top, outperforming the other two geogrids.[35]

Furthermore, when soil is reinforced with double layers of reinforcement, geonet emerges as the most effective among the three types of geosynthetics. The increase in the number of reinforcement layers leads to a further enhancement in the strength and load-carrying capacity of the soil. With the reinforcement ratio ranging between 2 and 5, the introduction of geosynthetics as double layers of reinforcement offers robust resistance against penetration, indicating its potential for effectively stabilizing unpaved roads. These findings underscore the importance of careful consideration of geosynthetic type and placement depth for optimal performance in soil reinforcement applications.[35]

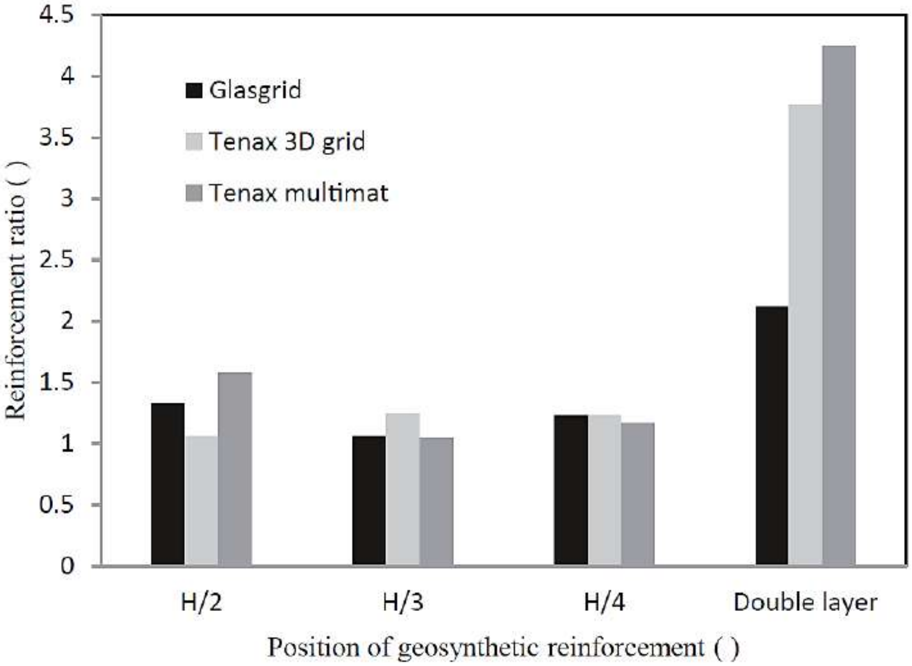


Figure 2.6: Reinforcement ratio for the various positions of geosynthetic reinforcement. [35]

2.12 Previous Studies

One of the most conspicuous issues encountered on roads is rutting failure, particularly prevalent in areas with mandatory traffic stops or slow-moving transportation. The escalation in traffic intensity over pavement surfaces gradually induces rutting, exacerbating other road weaknesses such as cracking and potholing. Moreover, the influx of trucks and heavy vehicles further hastens pavement deterioration. Rutting stands as a primary concern in road pavement damages, typically manifesting as longitudinal depressions along wheel paths. These depressions result from either the consolidation or horizontal movement of the subgrade layer under repetitive loads. [34-36]

In asphalt pavements, rutting distortion mainly arises from two causes: accumulative permanent deformation in the asphalt surface layer and permanent deformation of the subgrade or underlying stratum. When rutting occurs within the asphalt mix itself, the performance of underlying layers remains relatively unaffected, with their boundary lines remaining intact despite distress in the weak asphalt layer. This distinction underscores the complex interplay between surface and subsurface layers in the manifestation and propagation of rutting failure along road pavements. Addressing this issue requires a comprehensive understanding of underlying mechanisms and careful consideration of preventive measures to mitigate its detrimental effects on road infrastructure and vehicular safety. [34-37]

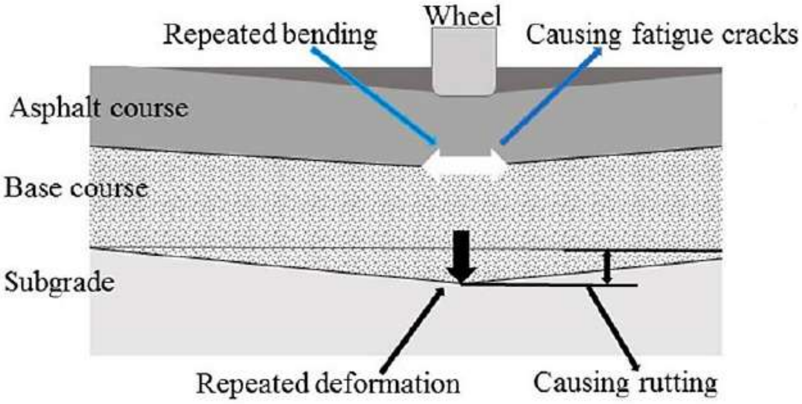


Figure 2.7: Shows mechanism of rutting occurs in flexible pavement [38]

Numerous researchers have conducted extensive studies on reinforcing locally available weak soils using geosynthetics, presenting a cost-effective and beneficial solution for mechanically stabilized earth structures. In road design, addressing weak subgrade conditions, which inherently possess low bearing capacity, often necessitates increasing pavement thickness. Presently, reinforcing weak subgrades with woven or nonwoven geotextiles is a widely adopted method. However, geogrids offer enhanced pullout resistance for all soil types considered, attributed to the passive resistance developed along their ribs. The effectiveness of geosynthetics in soil reinforcement varies depending on soil properties, with different types of geosynthetics showing varying degrees of enhancement in both resilient and permanent strains.[34]

For instance, sandy soils with particle sizes up to 2 mm may benefit from certain types of geogrids, while cohesive soils can be successfully reinforced by various geogrid types, albeit achieving better reinforcement effects with the same geosynthetics for sandy soils. Expansive soils, characterized by high plasticity indexes and susceptible to swelling and contractive deformations, can benefit from geogrids placed at the subgrade-pavement interface, aiding in absorbing or smoothing swell pressure and reducing truck geometry damages. Biaxial geogrid inclusion in such soils significantly increases subgrade strength, with optimal placement typically at 3/4 of the soil depth for a single layer.[34]

However, an increase in moisture content can diminish reinforcement efficiency due to reduced suction in saturated expansive clays and the potential development of excess pore water pressure, leading to decreased effective stresses and shear resistance. Studies indicate that soil particle size significantly influences soil-geosynthetics interface resistance, with higher average soil particle sizes correlating with increased resistance. Furthermore, the efficiency of geogrid-soil interlock is governed by geogrid properties such as aperture size and in-plane stiffness, relative to soil grain size.

For optimal performance, the aperture size of geogrids should be related to soil grain size, typically ranging between 2-3 times larger than the average particle size (D50) of the soil. The incorporation of geogrids substantially improves the low strength of poor soils, resulting in higher California Bearing Ratio (CBR) values, reflecting enhanced soil stability and load-bearing capacity.[34]

A subgrade soil beneath a paved or unpaved surface is susceptible to failure under load in two primary ways: localized shear failure and bearing capacity failure. Localized shear failure often manifests as severe deformation or rutting in soft subgrades when the applied load exceeds the subgrade's strength. Geogrid reinforcement of granular fills over soft soil has shown promise in preventing localized shear failure of the subgrade, thereby significantly increasing its effective bearing capacity.[39]

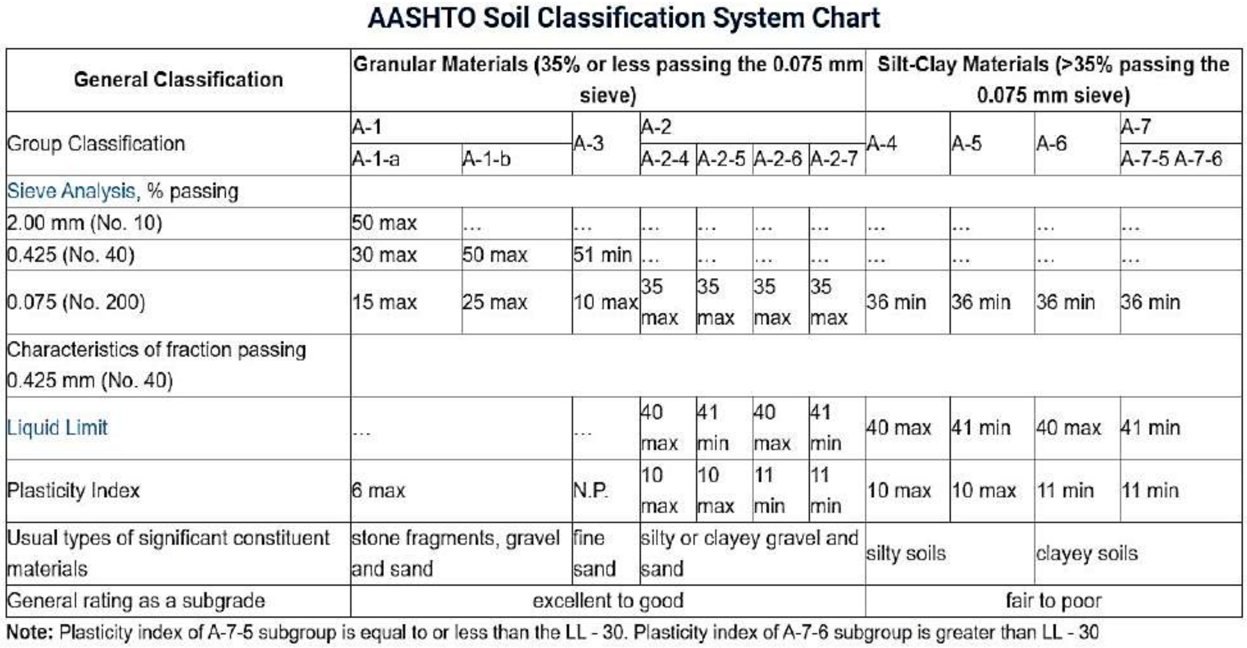
The primary mechanism through which geogrids stabilize the subgrade is by providing lateral restraint to the aggregate materials through interlocking between the aggregate and the apertures of the geogrid. The level of lateral restraint achieved depends on factors such as the type of geogrid used and the quality and gradation of the aggregate material placed on the geogrid. To optimize the performance of the geogrid, it is essential to select a well-graded granular material that is appropriately sized for the aperture size of the geogrid.[39]

When aggregate is placed over the geogrid, it becomes quickly confined within the apertures, preventing it from punching into the soft subgrade and shoving laterally. This confinement results in the formation of a "stiffened" aggregate platform over the geogrid, enhancing the overall stability of the pavement system.

A study investigated the reinforcement mechanisms of geogrids used in paved roads, revealing that geogrid reinforcement can effectively reduce permanent deformations in flexible pavement systems. Additionally, the study indicated that geogrid reinforcement allows for a significant reduction of up to 50% in the required thickness of a granular base, based on equal load-deformation performance. [39-40]

2.13 AASHTO Soil Classification

The AASHTO Soil Classification System, created by the American Association of State Highway and Transportation Officials, guides the classification of soils and soil-aggregate mixtures for highway construction. Initially developed by Hogentogler and Terzaghi in 1929, the system has undergone multiple revisions over the years. This chart is used to classify the soil sample collected for this project.



AASHTO Soil Classification System Chart

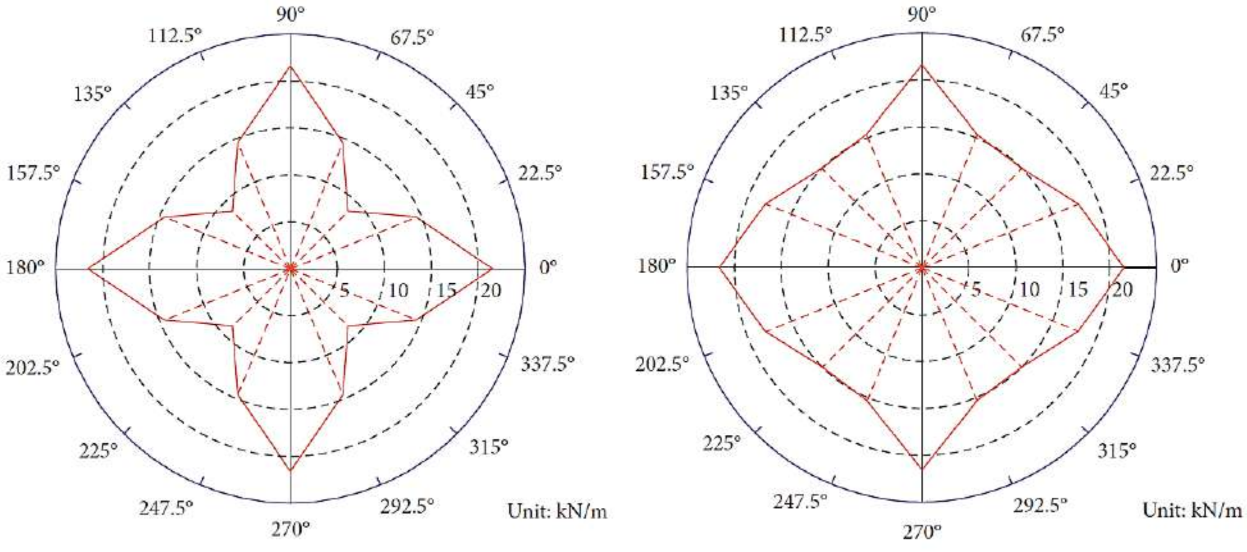
General Classification	**Granular Materials (35% or less passing the 0.075 mm sieve)**							**Silt-Clay Materials (>35% passing the 0.075 mm sieve)**			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % passing											
2.00 mm (No. 10)	50 max	...	...	...	...	...	...	...	...	...	...
0.425 (No. 40)	30 max	50 max	51 min	...	...	...	...	...	...	...	...
0.075 (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid Limit	...		...	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	stone fragments, gravel and sand		fine sand	silty or clayey gravel and sand				silty soils		clayey soils	
General rating as a subgrade	excellent to good							fair to poor			

Note: Plasticity index of A-7-5 subgroup is equal to or less than the LL - 30. Plasticity index of A-7-6 subgroup is greater than LL - 30

Figure 2.8: AASHTO Soil Classification Chart [18]

2.14 Biaxial and Triaxial Geogrids

A new geogrid product with triangular apertures has been developed and introduced to address the limitations of biaxial geogrids with rectangular or square apertures. This triangular-aperture geogrid offers a more stable grid structure, ensuring uniform resistance in all directions compared to traditional biaxial geogrids. Both experimental and numerical studies have confirmed the superior performance of triaxial geogrids over biaxial ones in certain aspects due to their stable grid structure, which provides nearly uniform properties in all directions. When utilized to improve soft subgrade and reinforce weak subgrade, triaxial geogrids have demonstrated a significant reduction in maximum vertical stress on the subgrade and have led to a more uniform stress distribution. [30-32]



(a)

(b)

Figure 2.9: Comparison of ultimate tensile strength in different loading directions. (a) Biaxial geogrid. (b) Triaxial geogrid. [31]

Chapter No.3

Methodology

In this section, we outline the methodology employed to assess the soil's suitability for the project, particularly its strength characteristics to determine if it meets the criteria for weak subgrade soil. Additionally, we detail the process of selecting the appropriate geosynthetic material, specifically geogrids, for stabilizing the destabilized subgrade soil. To facilitate this evaluation, soil samples were collected from two distinct locations: "Warsak Road, Ashaq Abad, Peshawar" and "Naguman to Charsadda Road." The geogrid used in the study was sourced from Dezhou Hongli Geomaterial Engineering Co., Ltd. in China.

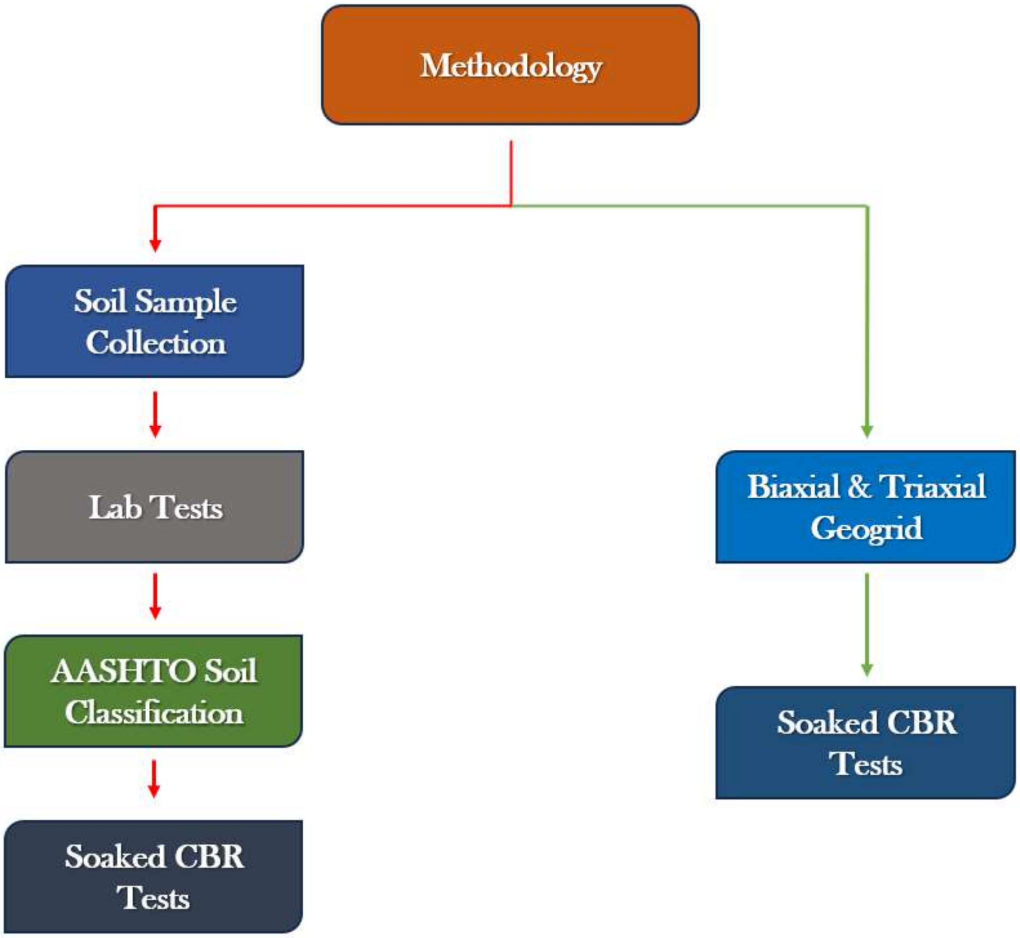


Figure 3.1: Steps Involve in Methodology of this Project

Subsequently, a series of laboratory tests were conducted following relevant ASTM (American Society for Testing and Materials) standards to assess various properties of the soil samples:

3.1 Soil Sample Collection

Two soil samples were obtained, one from "Warsak Road, Ashaq Abad, Peshawar" and the other from "Naguman to Charsadda Road, Peshawar." To ensure proper identification, both samples were meticulously labeled. Prior to collection, the top layer of soil, measuring 2 feet, was carefully removed from each site to eliminate any small plants, plant roots, or impurities. Subsequently, soil samples were collected from the prepared ground surface for analysis.

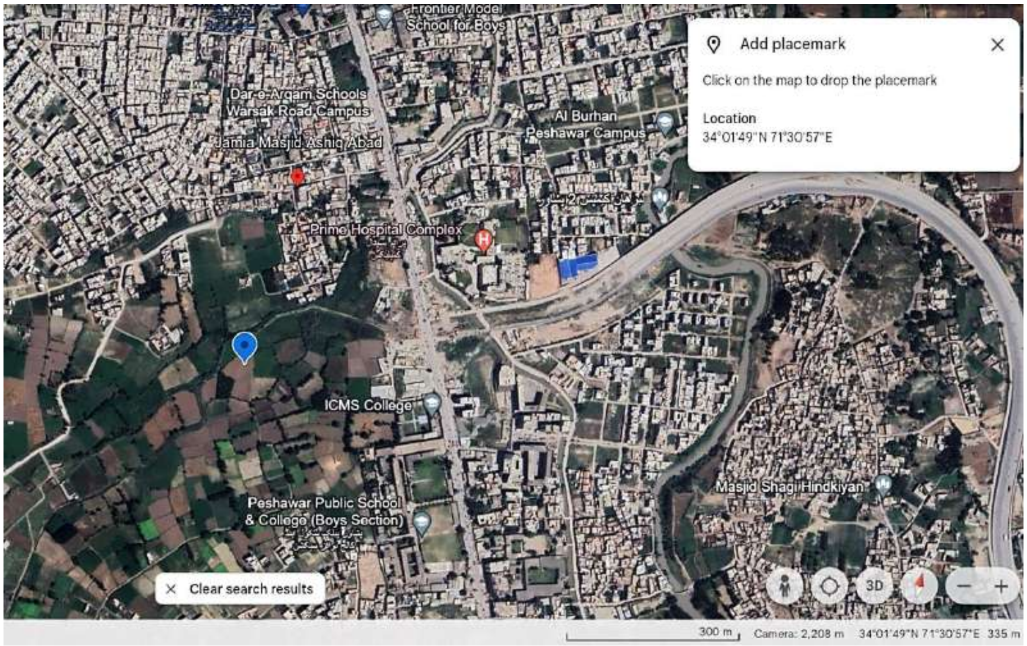


Figure 3.2: Shows Site Map of Warsak Road, Ashaq Abad, Peshawar

Figure 3.3: Site-1 Soil Sample Collection in Process

Figure 3.4: Shows Site Map of Naguman to Charsadda Road, Peshawar

Figure 3.5: Site-2 Soil Sample Collection in Process

3.2 Geosynthetic Materials (Geogrid)

We have initiated an online purchase for a sample of geosynthetic material, a Plastic Biaxial and Triaxial geogrid, due to its unavailability in Pakistan. This specific geogrid is sourced from Dezhou Hongli Geomaterial Engineering Co., Ltd. situated in China. It is crafted utilizing a mixture of polypropylene, polyvinyl chloride, and other polymers, which undergo processing via thermoplastic methods or molding techniques.

Figure 3.6: Geosynthetic Material (Biaxial Geogrid) used in this project

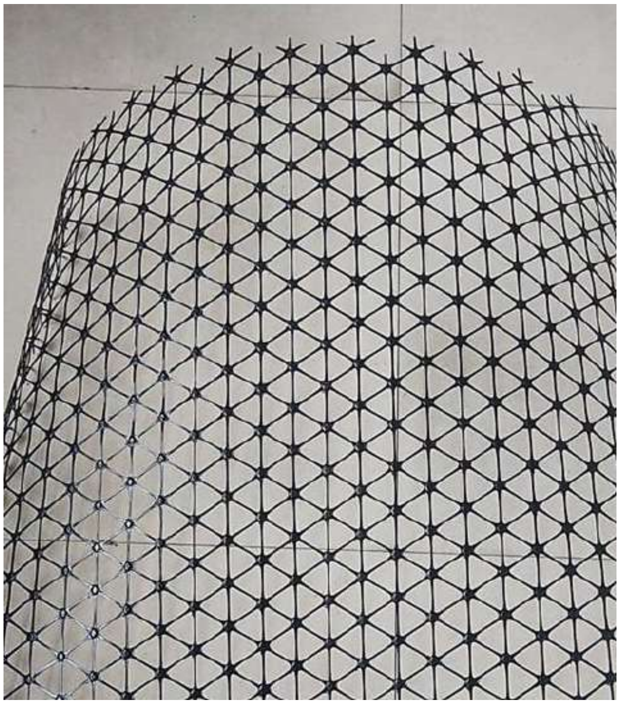


Figure 3.7: Geosynthetic Material (Triaxial Geogrid) used in this Project

3.3 Properties & Specification of Biaxial Geogrid Material Used

In our project we have employed Biaxial Geogrid material for subgrade soil stabilization, comprising polypropylene as its primary constituent. This material features a two-way design and is characterized by its black color. The main parameters/specifications of the Biaxial geogrid used in this project are as follows:

S. No	**Description**	**Specifications**
1.	Longitudinal and transverse nominal tensile strength (KNm)	≥ 50
2.	Tensile strength at 2% elongation in longitudinal and transverse direction (KN/m)	≥ 17.5
3.	Tensile strength at 5% elongation in longitudinal and transverse direction (KN/m)	≥ 35
4.	Longitudinal nominal elongation (%)	≤ 15
5.	Nominal elongation in transverse direction (%)	≤ 13
6.	Carbon black content and distribution	Carbon black content ≥ 2.0%, ash content ≤ 1.0%, the distribution of carbon black should be uniform, and the apparent dispersion grade should not be lower than grade B.
7.	UV resistance strength retention rate (%)	≥ 90

Table 3.1: Shows Properties & Specification of Biaxial Geogrid Material Used

3.4 Properties & Specification of Triaxial Geogrid Material Used

In our project, the Triaxial Geogrid material has been strategically utilized for subgrade soil stabilization, with polypropylene serving as its predominant constituent. This geogrid material stands out due to its three-way design configuration and distinctive black coloration. The primary parameters and specifications of the Biaxial geogrid employed in this project are meticulously outlined to ensure optimal performance and compatibility with the soil stabilization requirements. Following are the specification of triaxial geogrid material used in this project:

S. No	Description	Specifications
1.	Name	TX160
2.	Average quality control tensile modulus under 2% strain (KN/m^2)	≥ 225
3.	Radial tensile modulus ratio at 2% strain	≥ 0.65
4.	Mechanical properties	Longitudinal (0°) Oblique (30°) Oblique (60°) Transverse (90°)

Table 3.2: Shows Properties & Specification of Triaxial Geogrid Material Used

We procured both biaxial and triaxial geogrid samples from a supplier in China. Each sample measures 1 meter by 1 meter in size. The biaxial geogrid boasts a tensile strength of 50 kilonewton per meter (KN/m), while the triaxial geogrid, labeled TX-160, exhibits a tensile modulus of 225 kilonewton per square meter (KN/m^2). The cost of the biaxial geogrid is approximately Rs. 83 PKR per square meter of sample, whereas the triaxial geogrid costs about Rs. 97 PKR per square meter of sample.

3.5 Laboratory Tests

Following are the various laboratory tests conducted on soil samples to evaluate its different properties thoroughly:

3.5.1 Grain Size Analysis Test (Sieve analysis ASTMD 422-63)

In the laboratory, we carried out the Grain Size Analysis Test, following the ASTM D422-63 standard protocol. This test was employed to assess the particle size distribution within the soil sample. Utilizing a sequence of sieves with incrementally diminishing apertures, we meticulously sifted the soil sample, enabling the segregation and quantification of particles across different size ranges. This systematic approach provided invaluable insights into the granular composition of the soil, facilitating a comprehensive understanding of its physical characteristics and behavior.

Figure 3.8: Grain Size Analysis Test

3.5.2 Atterberg Limit Test (ASTM D4318)

In our laboratory experimentation, we diligently executed the Atterberg Limit Test in strict adherence to the ASTM D4318 standard protocol. This pivotal test was conducted to gain comprehensive insights into the plasticity and overall behavior exhibited by the soil samples under scrutiny. By meticulously following the prescribed test method, we meticulously determined crucial parameters such as the liquid limit, plastic limit, and plasticity index for each sample.

Figure 3.9: Atterberg Limit Test

3.5.3 Proctor Compaction Test (ASTM D698)

We have conducted the Proctor Compaction Test following the guidelines outlined in the ASTM D698 standard. This test aimed to evaluate the compaction properties of the soil samples used in our study. Each soil sample underwent compaction at various moisture contents, simulating different field conditions. After compaction, we measured the resulting dry density of each sample. This data enabled us to determine two critical parameters: the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). The OMC represents the moisture content at which the soil achieves maximum compaction, while the MDD indicates the highest dry density achievable under compaction efforts. These parameters are essential for optimizing soil compaction efforts in engineering and construction projects.

Figure 3.10: Proctor Compaction Test

3.5.4 Direct Shear Test (ASTM D3080)

We have performed the Direct Shear Test in accordance with the ASTM D3080 standard. The primary objective of this test was to assess the shearing strength characteristics of the soil samples under investigation. To accomplish this, we utilized a direct shear apparatus, which allowed us to subject the soil samples to controlled shearing forces. By applying incremental shear stress to the samples until failure occurred, we were able to determine two crucial parameters: the Cohesion (C) and the internal angle of friction (Φ). The cohesion represents the shear strength of the soil in the absence of normal stress, while the angle of friction indicates the resistance to shearing along the plane of failure. These parameters are fundamental in understanding the mechanical behavior of soils and are essential for various geotechnical and civil engineering applications.

Figure 3.11: Shows Direct Shear Test

3.5.5 AASHTO Soil Classification

After completing the aforementioned laboratory tests, the next step involves classifying our soil according to the AASHTO soil classification chart. This classification system helps determine the suitability of the soil material for use in subgrade soil in road construction projects.

3.5.6 CBR Test (California bearing ratio ASTM D1883)

The Soaked CBR Test, conducted in accordance with ASTM D1883 standard, serves to measure the strength of subgrade soil samples. This test evaluates the California bearing ratio (CBR) of the soil, which is a crucial indicator of its load-bearing capacity. By subjecting the soil sample to standardized testing conditions, the CBR Test provides valuable insights into the soil's ability to support pavement and other structural loads. In this project, soaked California Bearing Ratio (CBR) test have been employed on both the soil samples. Also, it is conducted on soil samples when Biaxial and Triaxial geogrids have been incorporated, in order to check the effect of geogrids on the bearing capacity of that subgrade soil.

Figure 3.12: CBR (California Bearing Ratio) Test

Figure 3.13: Placing CBR Mould in Water

3.5.7 CBR Test on Biaxial Geogrid

We positioned a Biaxial geogrid at a depth of 0.2H from the top within the CBR mold. Following its placement, we conducted a soaked CBR test on the soil sample with the Biaxial geogrid. This procedure was carried out for both soil samples obtained from the respective sites.

Figure 3.14: Placing Biaxial Geogrid in CBR mold

3.5.8 CBR Test on Triaxial Geogrid

We placed a Triaxial geogrid at a depth of 0.2H from the top within the CBR mold. Subsequently, we conducted a soaked CBR test on the soil sample with the Triaxial geogrid. This process was performed for both soil samples obtained from their respective sites.

Figure 3.15: Placing Triaxial Geogrid in CBR mold

3.6 Model Design (AutoCAD)

We have created the cross-sectional design of the flexible pavement road using AutoCAD software. This design encompasses both the top view and the longitudinal section of the pavement model, complete with hatching to represent different materials.

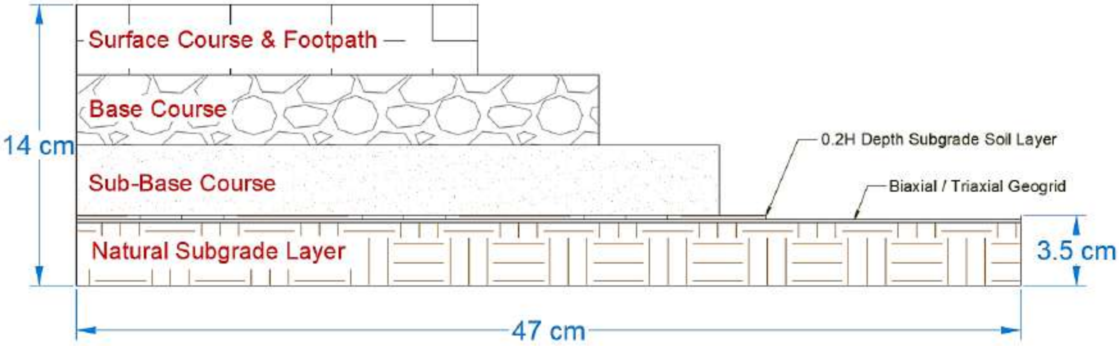


Figure 3.16: Shows Long Section of Project Practical Model Designed in AutoCAD

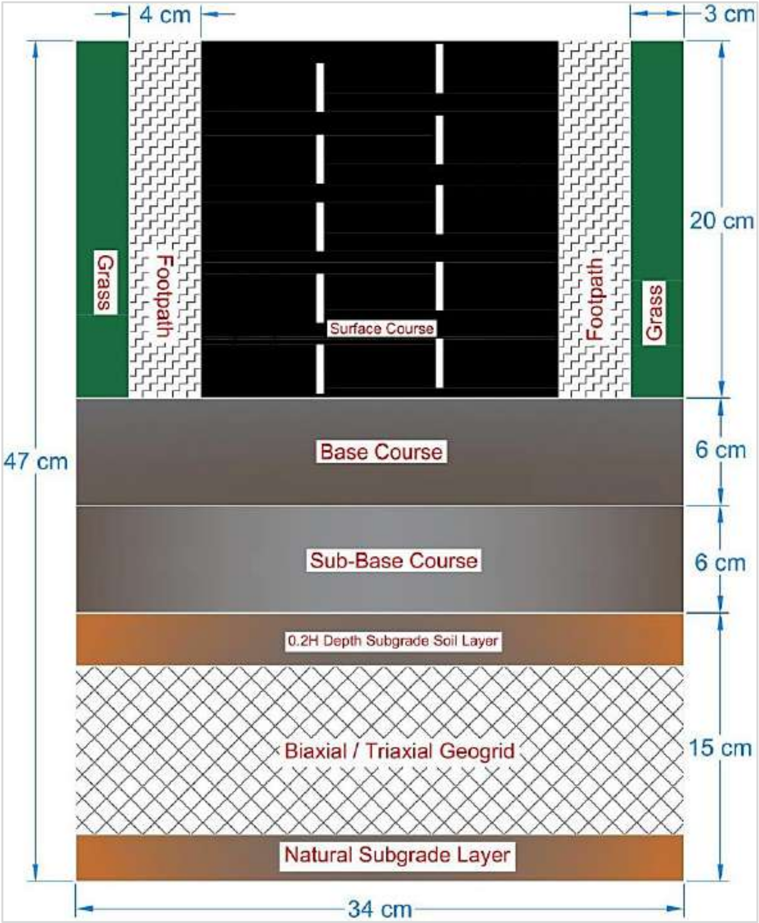


Figure 3.17: Shows Top View of Project Practical Model Designed in AutoCAD

3.7 Targeted SDG's

SDG 09: "Build Resilient Infrastructure, Promote Sustainable Industrialization and Foster Innovation"

Utilizing geosynthetic materials for subgrade soil stabilization promotes resilient infrastructure, sustainable industrialization, and innovation. These materials enhance the durability of projects, bolstering resilience against environmental challenges. Moreover, their adoption fosters sustainable construction practices, reducing environmental impact and stimulating innovation in infrastructure development.

SDG 11: "Sustainable Cities and Communities"

By employing geosynthetic materials for subgrade soil stabilization, we contribute to the advancement of sustainable cities and communities. These materials enhance the resilience of urban infrastructure, mitigating the impact of natural hazards and promoting long-term sustainability. Additionally, their use fosters environmentally-friendly construction practices, ensuring the development of resilient and eco-conscious communities.

Chapter 4

Results and Discussions

4.1 Soil Sample Collection

Two soil samples were collected: sample-1 from "Warsak Road, Ashaq Abad, Peshawar," and sample-2 from "Naguman to Charsadda Road, Peshawar." Various tests were conducted at room temperature, yielding the following results:

Figure 4.1: Soil sample-1 collection

Figure 4.2: Soil sample-2 collection

4.1.1 Grain Size Analysis Test (Sieve analysis ASTMD 422-63)

The Grain Size Analysis Test, conducted according to ASTM D422-63 standards, is utilized to determine the particle size distribution of soil samples. This test involves sieving soil through a series of mesh screens and analyzing the amount of soil retained on each screen to characterize the soil's gradation. Following are the results of Sieve analysis test:

S/NO	DESCRIPTION	SIEVE ANALYSIS		
		10	40	200
1.	Excavated Material	**100%**	**96.6%**	**75.6%**

Table 4.1: Shows Result of Sieve Analysis Test of (Sample-1)

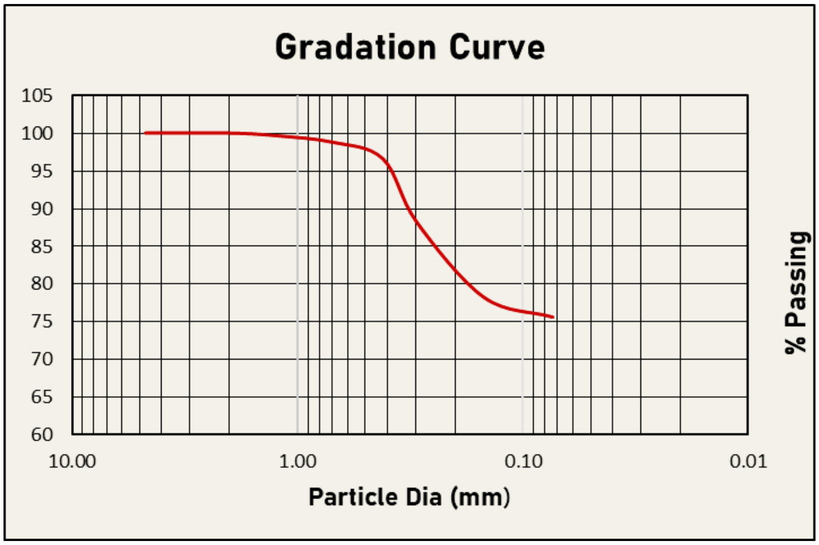


Figure 4.3: Shows Gradation Curve of Soil Sample-1

S/NO	DESCRIPTION	SIEVE NUMBER (% PASSING)		
		10	40	200
1.	Excavated Material	**99.5%**	**95.8%**	**72.4%**

Table 4.2: Shows Result of Sieve Analysis Test of (Sample-2)

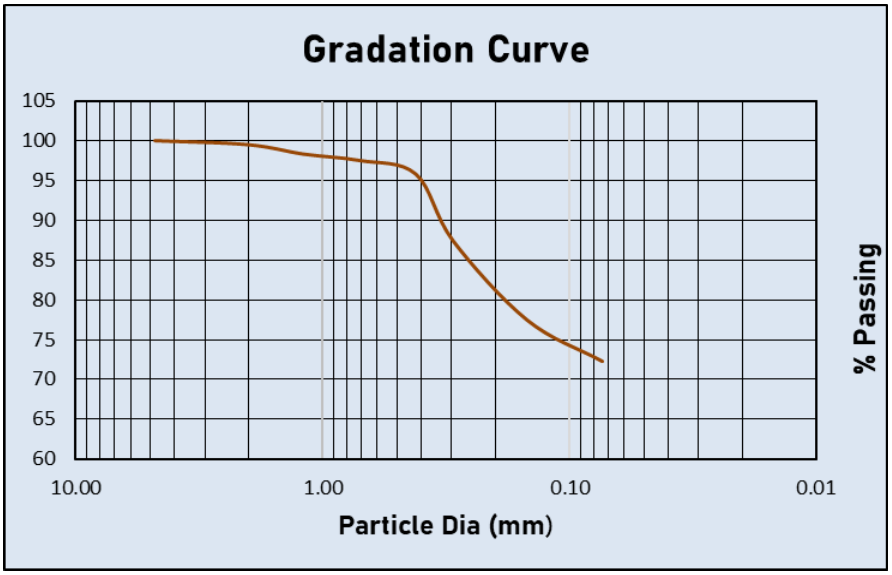


Figure 4.4: Shows Gradation Curve of Soil Sample-2

Remarks

Upon completing the Grain Size Analysis Test, the outcomes revealed that both samples exhibited a particle size distribution indicating more than 35% of particles passing through sieve no. 200 (0.075mm). According to the AASHTO soil classification system, materials with such characteristics are categorized as Silt-Clay. This classification signifies the predominance of fine-grained particles, typically comprising silt and clay constituents, within the soil samples. The designation of Silt-Clay material implies specific engineering properties and behavior, including high plasticity, as well as challenges related to compaction and permeability.

4.1.2 Atterberg Limit Test (ASTM D4318)

The Atterberg Limit Test, conducted in accordance with ASTM D4318 Standards, serves as a crucial method for assessing the plasticity characteristics of soil samples. By determining key parameters such as the liquid limit, plastic limit, and plasticity index, this test offers valuable insights into the soil's behavior under different moisture conditions. These insights are instrumental in various engineering applications, including soil classification, foundation design, and construction planning. Through the Atterberg Limit Test, engineers and geotechnical professionals gain a deeper understanding of how soil properties change with variations in moisture content, enabling them to make informed decisions regarding soil management and engineering practices.

S/NO	DESCRIPTION	ATTERBERG'S LIMITS		
		LL	PL	PI
1.	Excavated Material	**46.15%**	**33.33%**	**12.82%**

Table 4.3: Shows Result of Atterberg Limit Test of (Sample-1)

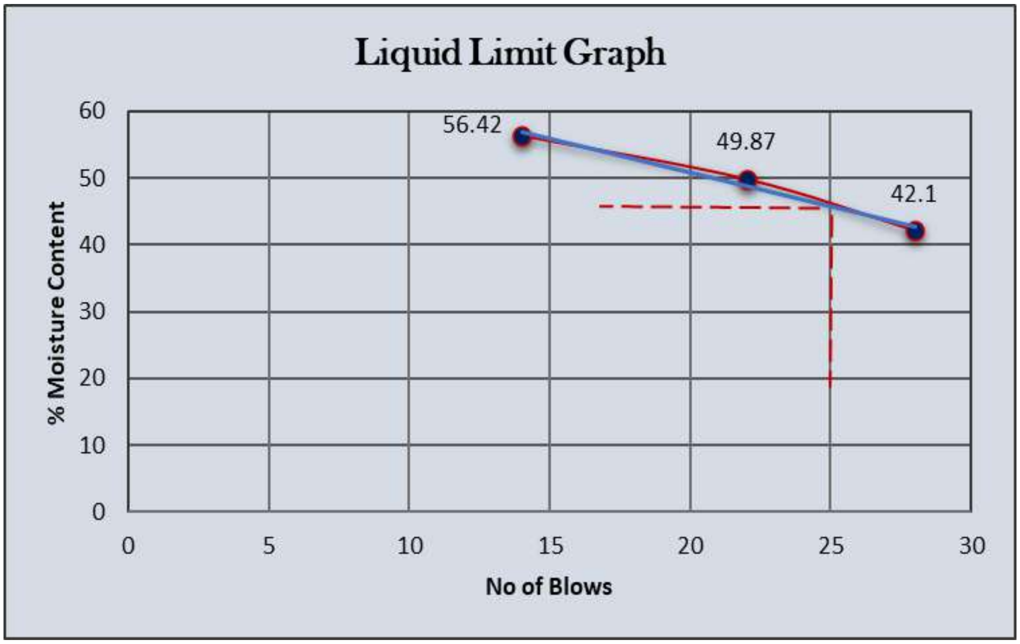


Figure 4.5: Shows Liquid Limit Graph of Soil Sample-1

S/NO	DESCRIPTION	ATTERBERG'S LIMITS		
		LL	PL	PI
1.	EXCAVATED MATERIAL	**41.5%**	**29.7%**	**11.80%**

Table 4.4: Shows Result of Atterberg Limit Test of (Sample-2)

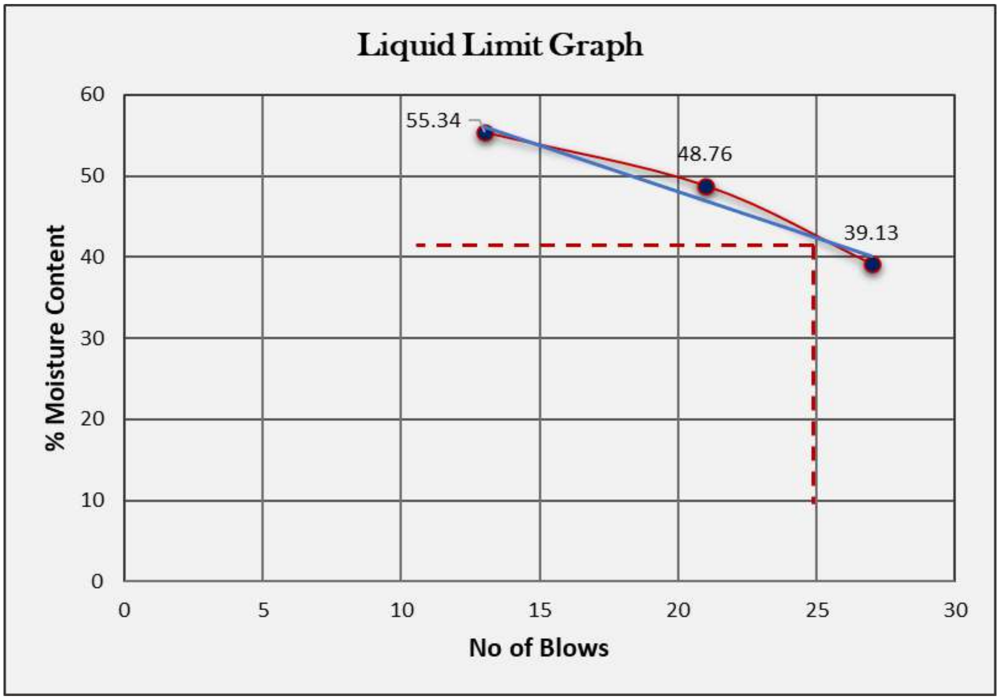


Figure 4.6: Shows Liquid Limit Graph of Soil Sample-2

Remarks

Following the Atterberg Limit Test conducted in accordance with ASTM D4318 Standards, the obtained results provide valuable insights into the plasticity characteristics of the soil samples collected from two distinct sites. For the soil sample obtained from site-1, the plasticity index is determined to be 12.82%, with a corresponding liquid limit of 46.15%. Similarly, the soil sample from site-2 exhibits a plasticity index of 11.80%, accompanied by a liquid limit of 41.5%.

These findings indicate that both soil samples fall within the A-7 classification category according to the AASHTO soil classification chart. The A-7 classification typically refers to soils with moderate to high plasticity, which can undergo significant changes in volume and consistency with variations in moisture content.

4.1.3 Proctor Compaction Test (ASTM D698)

The Proctor Compaction Test, as per ASTM D698, assesses the compaction characteristics of soil by compacting it at various moisture levels and measuring the resulting dry density. This test aids in determining the optimum moisture content and maximum dry density for soil compaction, crucial for designing resilient and stable pavement structures. Following are the results of Proctor Compaction Test:

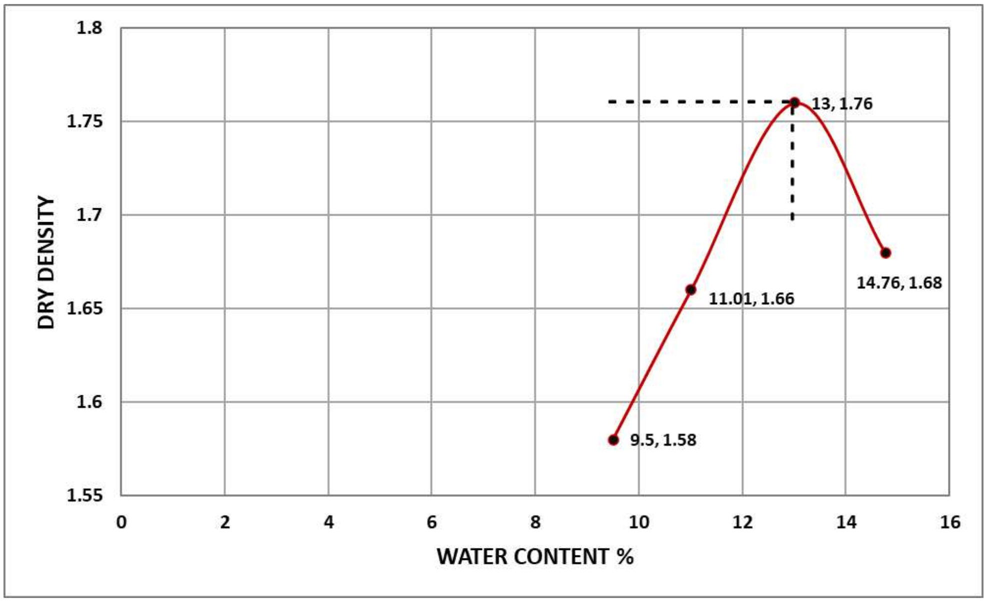


Figure 4.7: Shows Proctor Compaction Test Graph of Soil Sample-1

From this test, we obtained an optimum moisture content of 13% and a maximum dry density of 1.76 g/cm³ of Soil Sample-1.

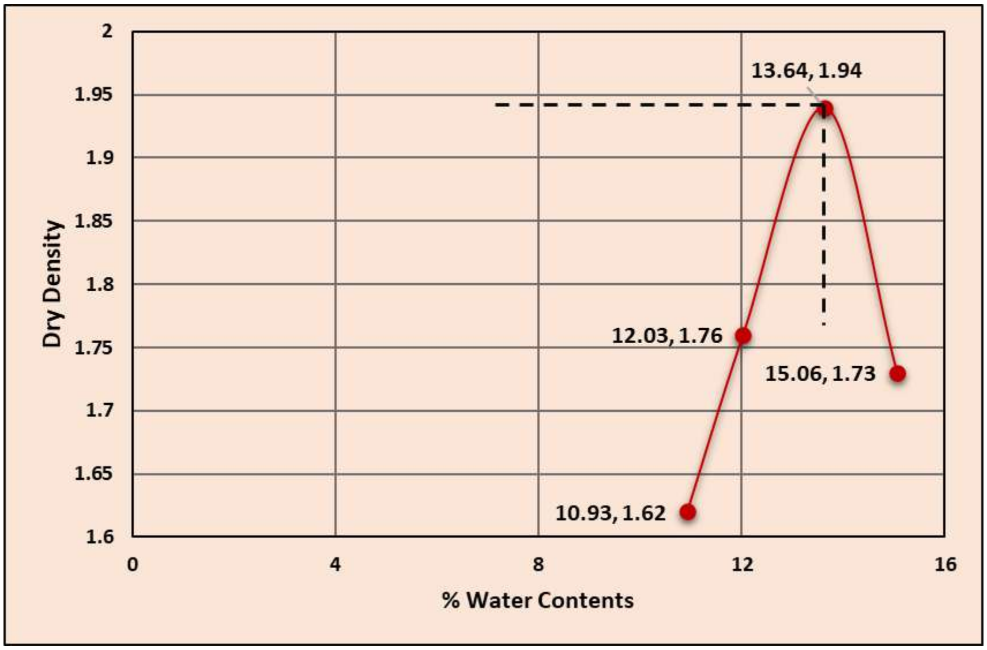


Figure 4.8: Shows Proctor Compaction Test Graph of Soil Sample-2

From this test, we obtained an optimum moisture content of 13.64% and a maximum dry density of 1.94 g/cm³ of Soil Sample-2.

4.1.4 Direct Shear Test (ASTM D3080)

The Direct Shear Test, conducted according to ASTM D3080, assesses the shear strength parameters of soil samples. This test involves applying a shear force to determine cohesion and internal friction angle, crucial for understanding soil behavior under various loading conditions. Following are the results of Direct Shear Test:

S. No	Test Description	Test Results
1	Angle of Internal Friction (degree), Direct Shear Test	8.4
2	Cohesion (PSF), Direct Shear Test	497.0
3	Bulk Unit weight (PCF)	112.6

Table 4.5: Shows Results of Direct Shear Test of (Sample-1)

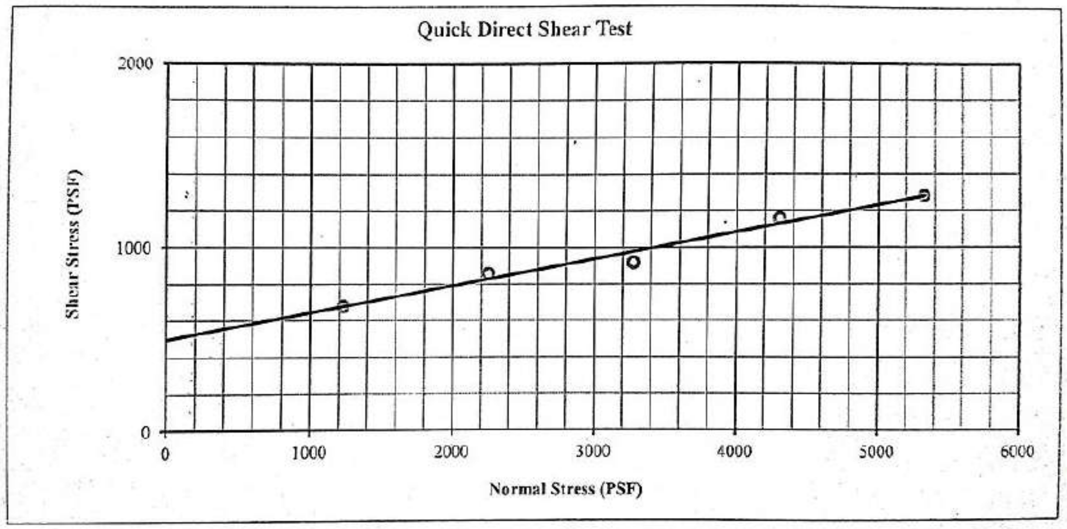


Figure 4.9: Shows Direct Shear Test Graph of Soil Sample-1

S. No	Description	Test Results
1	Angle of Internal Friction (degree), Direct Shear Test	8.1
2	Cohesion (PSF), Direct Shear Test	499.0
3	Bulk Unit weight (PCF)	113.8

Table 4.6: Shows Results of Direct Shear Test of (Sample-2)

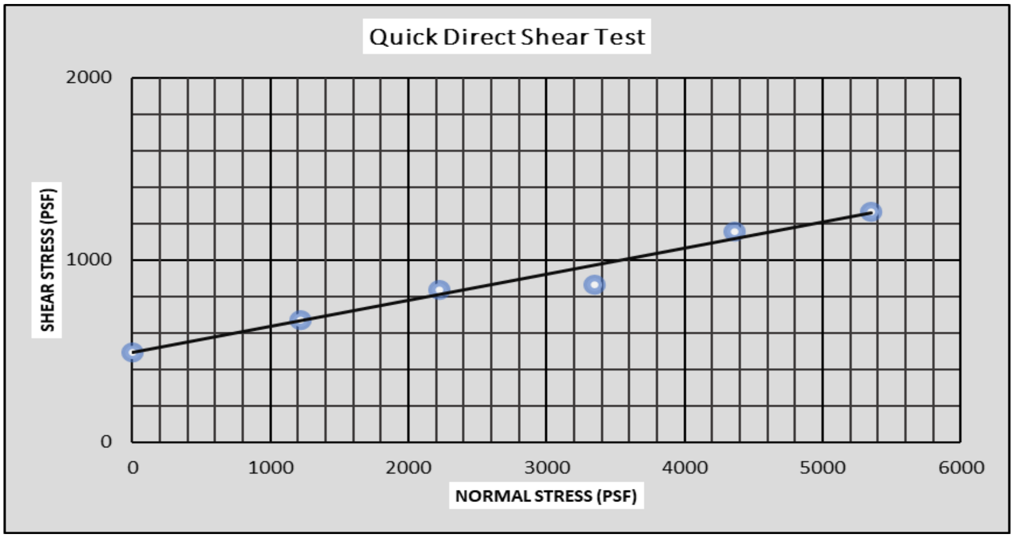


Figure 4.10: Shows Direct Shear Test Graph of Soil Sample-2

4.1.5 AASHTO Soil Classification

Following the completion of the specified tests, a thorough analysis of the results was conducted utilizing the AASHTO soil classification chart. This analytical approach aimed to ascertain the soil types present in the collected samples. Upon meticulous examination, it was determined that Soil Sample-1, collected from Warsak Road, Ashaq Abad, Peshawar, corresponds to A-7-5 soil classification, signifying a clayey soil composition. Similarly, Soil Sample-2, obtained from Naguman to Charsadda Road, Peshawar, was categorized as A-7-6 soil, also falling under the clayey soil classification. As per AASHTO standards, both soil samples are categorized within the Fair to Poor rating category for subgrade applications.

4.1.6 CBR Test (California bearing ratio ASTM D1883)

The Soaked CBR Test, conducted in accordance with ASTM D1883, is utilized to determine the California Bearing Ratio (CBR) of soil under saturated conditions. This test provides crucial information on the strength and load-bearing capacity of soil, particularly in conditions where the subgrade may experience significant moisture saturation. Following are the results of Soil sample-1 Soaked CBR test:

S. No	Description	Values
1.	Load at (2.5 mm)	0.682 KN
2.	Load at (5.0 mm)	0.935 KN
3.	CBR Index (1)	2.301 %
4.	CBR Index (2)	2.001 %

Table 4.7: Shows CBR Test Results of Soil Sample-1

By conducting test, we obtained Soaked CBR value of 2.30% which falls below the threshold of 3%. According to previous research findings, a CBR value below 3% indicates the weakness of the subgrade soil. It is concluded that the soil sample-1 (Warsak Road, Ashaq Abad, Peshawar) is weak subgrade soil.

S. No	Description	Values
1.	Load at (2.5 mm)	0.835 KN
2.	Load at (5.0 mm)	1.005 KN
3.	CBR Index (1)	2.890 %
4.	CBR Index (2)	2.023 %

Table 4.8: Shows CBR Test Results of Soil Sample-2

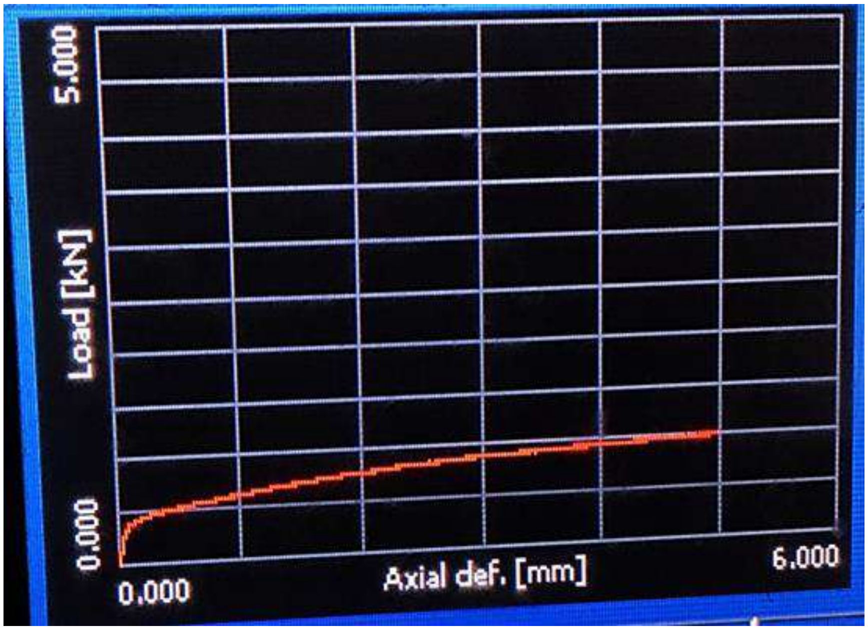


Figure 4.11: Shows CBR Test Graph of Soil Sample-2

We obtained Soaked CBR value of 2.89%, which falls below the threshold of 3%. According to previous research findings, a CBR value below 3% indicates the weakness of the subgrade soil. It is concluded that the soil Sample-2 (Naguman to Charsadda Road, Peshawar) is also weak subgrade soil.

4.2 CBR Tests (After Placing Geosynthetic Materials in Subgrade Soil)

Following the identification of weak subgrade soil at both sites through the CBR tests, the subsequent step involved the placement of both Biaxial and Triaxial Geogrids at a depth of 0.2H from the top within the CBR mold for each soil sample. This strategic positioning aimed to assess the effectiveness of geogrid reinforcement in enhancing the subgrade soil's bearing capacity. Subsequently, soaked CBR tests were conducted on each mold, in accordance with the standards outlined in ASTM D1883, to simulate the soil's behavior under saturated conditions. The results of these soaked CBR tests are presented below, providing valuable insights into the performance of the geogrid-reinforced subgrade soil under realistic moisture conditions.

4.2.1 CBR Test with Biaxial Geogrid on (Soil Sample-1)

After carefully positioning the biaxial geogrid at a depth of 0.2H from the top of the CBR mold, which corresponds to approximately 1.4 inches below the top surface of the CBR test mold, we proceeded to conduct a soaked CBR test on the soil sample. This meticulous placement of the geogrid aimed to simulate real-world conditions and assess its effectiveness in reinforcing the subgrade soil. The following are the results obtained for Soil Sample-1 with the biaxial geogrid material, providing valuable data on the soil's behavior and the geogrid's impact on its strength and stability under saturated conditions.

Figure 4.12: Shows Placing of Biaxial Geogrid in CBR mold

S. No	Description	Values
1.	Load at (2.5 mm)	1.888 KN
2.	Load at (5.0 mm)	1.968 KN
3.	CBR Index (1)	11.121 %
4.	CBR Index (2)	9.839 %

Table 4.9: Shows CBR Test Result of Soil Sample-1 with (Biaxial Geogrid)

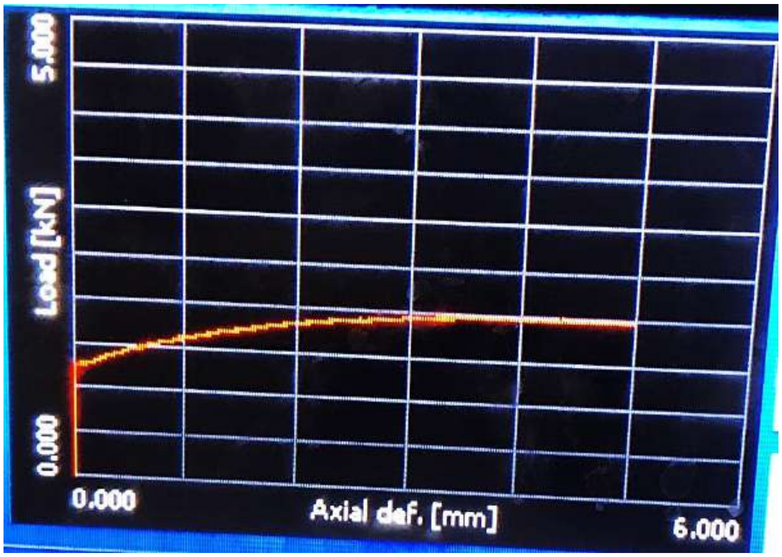


Figure 4.13: Shows CBR Test Graph of Soil Sample-1 with (Biaxial Geogrid)

Remarks

Through the integration of Biaxial Geogrid into the soil sample at a depth of 0.2H from the top surface, a notable enhancement in the California Bearing Ratio (CBR) value was observed. Specifically, the initial CBR value of 2.30% recorded for Site-1 soil sample significantly increased to 11.121% following the incorporation of the biaxial geogrid. This substantial improvement highlights the positive impact of the geogrid on the soil's engineering properties, demonstrating its efficacy in strengthening the subgrade. The remarkable increase in the CBR value by approximately five times underscores the effectiveness of the biaxial geogrid in enhancing the load-bearing capacity and stability of the soil sample at Site-1.

4.2.2 CBR Test with Triaxial Geogrid on (Soil Sample-1)

After carefully positioning the Triaxial geogrid at a depth of 0.2H from the top surface of the CBR mold, equivalent to approximately 1.4 inches below the upper surface of the CBR test mold, we proceeded to conduct a soaked CBR test on the soil sample. The purpose of this test was to evaluate the impact of the Triaxial geogrid on the engineering properties of the soil. The results obtained for Soil Sample-1 with the Triaxial geogrid material are as follows:

Figure 4.14: Shows Placing of Triaxial Geogrid in CBR mold

S. No	Description	Values
1.	Load at (2.5 mm)	2.338 KN
2.	Load at (5.0 mm)	2.629 KN
3.	CBR Index (1)	12.828 %
4.	CBR Index (2)	11.221 %

Table 4.10: Shows CBR Test Result of Soil Sample-1 with (Triaxial Geogrid)

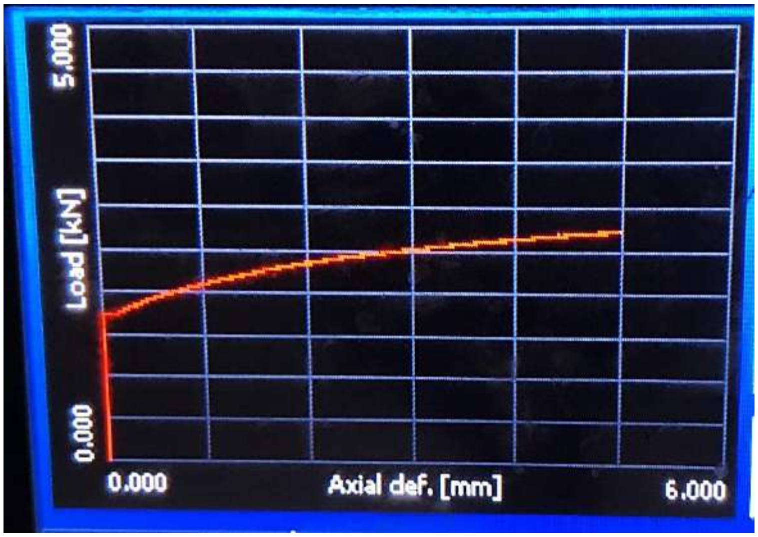


Figure 4.15: Shows CBR Test Graph of Soil Sample-1 with (Triaxial Geogrid)

Remarks

Upon integrating the Triaxial Geogrid into the soil sample at a depth of 0.2H from the top surface of the soil, we observed a notable enhancement in the California Bearing Ratio (CBR) value. Specifically, the CBR value increased from 2.30% to 12.828%. This significant increase in CBR value indicates that the Triaxial Geogrid had a positive impact on the engineering properties of the soil sample obtained from Site-1. The improvement in the CBR value suggests enhanced soil stability and load-bearing capacity, critical factors for subgrade performance in road construction projects.

The substantial increase in the CBR value, approximately five to six times higher than the initial value, underscores the effectiveness of the Triaxial Geogrid in soil stabilization applications. This result highlights the Triaxial Geogrid's ability to reinforce and strengthen weak subgrade soils, thereby improving their suitability for road construction projects. Moreover, the comparison between the performance of Triaxial Geogrid and Biaxial Geogrids reveals that the Triaxial geogrids best performs in terms of soil stabilization effectiveness.

4.2.3 CBR Test with Biaxial Geogrid on (Soil Sample-2)

We positioned the biaxial geogrid at a depth of 0.2H from the top of the CBR mold. Subsequently, we conducted a soaked CBR test on the soil sample. The following are the results obtained for Soil Sample-2 with the biaxial geogrid material:

S. No	Description	Values
1.	Load at (2.5 mm)	2.510 KN
2.	Load at (5.0 mm)	2.989 KN
3.	CBR Index (1)	12.982 %
4.	CBR Index (2)	11.612 %

Table 4.11: Shows CBR Test Result of Soil Sample-2 with (Biaxial Geogrid)

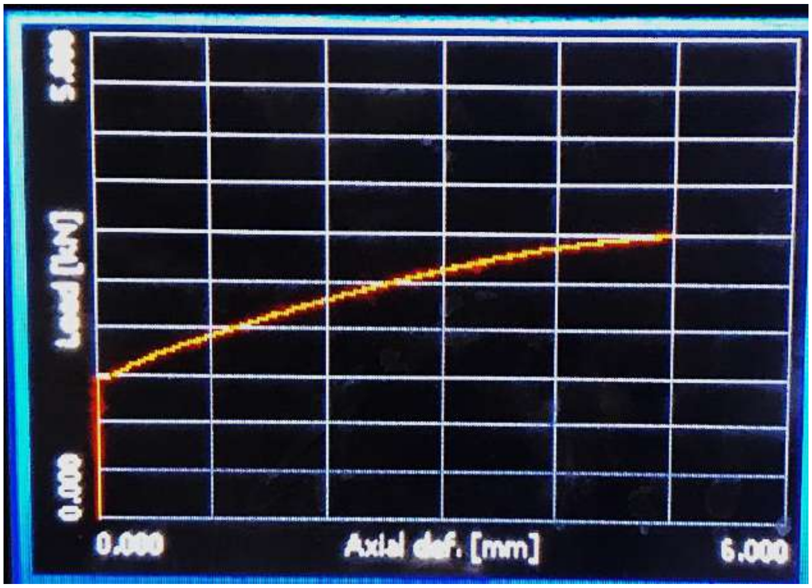


Figure 4.16: Shows CBR Test Graph of Soil Sample-2 with (Biaxial Geogrid)

Through the integration of Biaxial Geogrid into the soil sample at a depth of 0.2H from the top surface, a notable enhancement in the California Bearing Ratio (CBR) value was observed. The initial CBR value of 2.89% recorded for Site-2 soil sample significantly increased to 12.982% following the incorporation of the biaxial geogrid. This substantial improvement highlights the positive impact of the geogrid on the soil's engineering properties, demonstrating its efficacy in strengthening the subgrade. The remarkable increase in the CBR value by approximately six times underscores the effectiveness of the biaxial geogrid in enhancing the load-bearing capacity and stability of the soil sample at Site-2.

4.2.4 CBR Test with Triaxial Geogrid on (Soil Sample-2)

We positioned the Triaxial geogrid at a depth of 0.2H from the top of the CBR mold. Subsequently, we conducted a soaked CBR test on the soil sample. The following are the results obtained for Soil Sample-2 with the biaxial geogrid material:

S. No	Description	Values
1.	Load at (2.5 mm)	2.653 KN
2.	Load at (5.0 mm)	3.568 KN

3.	CBR Index (1)	13.831 %
4.	CBR Index (2)	12.213 %

Table 4.12: Shows CBR Test Result of Soil Sample-2 with (Triaxial Geogrid)

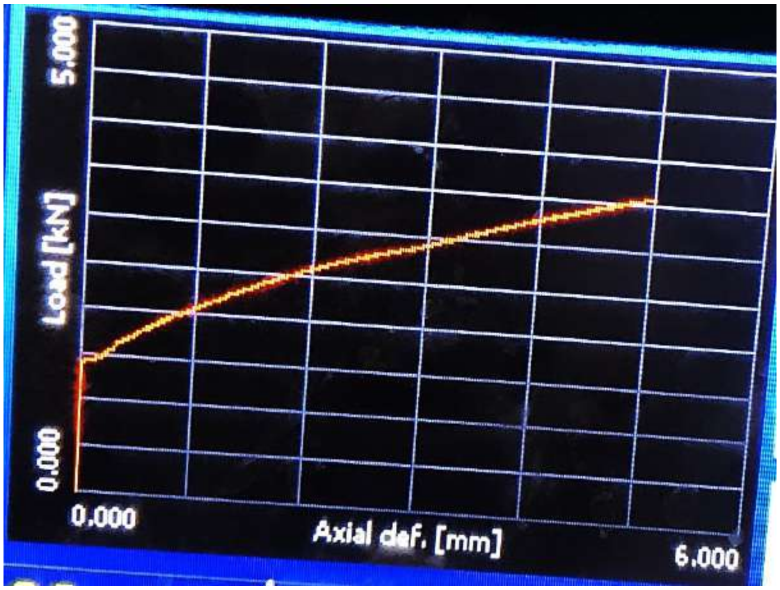


Figure 4.17: Shows CBR Test Graph of Soil Sample-2 with (Triaxial Geogrid)

Upon integrating the Triaxial Geogrid into the soil sample at a depth of 0.2H from the top surface of the soil, we observed a notable enhancement in the California Bearing Ratio (CBR) value. Specifically, the CBR value increased from 2.89% to 13.831%. This significant increase in CBR value indicates that the Triaxial Geogrid had a positive impact on the engineering properties of the soil sample obtained from Site-2. The improvement in the CBR value suggests enhanced soil stability and load-bearing capacity, critical factors for subgrade performance in road construction projects.

4.3 Results Summary (CBR Tests)

S. No	Soil Sample Location	CBR Test Without Geogrids	CBR Test with Biaxial Geogrid	CBR Test with Triaxial Geogrid
1.	Warsak Road, Ashaq Abad, Peshawar	2.301%	11.121%	12.828%

2.	Naguman to Charsadda Road, Peshawar	2.890%	12.982%	13.831%

Table 4.13: Shows CBR Test Results Summary

Results Summary Remarks

In summarizing the results obtained from the conducted tests, it becomes evident that the California Bearing Ratio (CBR) values of the weak soils at both sites experienced a significant increase upon the incorporation of geogrids at a depth of 0.2H from the top surface of the CBR mold, approximately 1.4 inches below the mold's top surface. This positioning of the geogrids aimed to reinforce the subgrade soil and enhance its load-bearing capacity.

Furthermore, the results indicate a clear distinction in performance between the two types of geogrids employed. Specifically, the Triaxial Geogrids demonstrated superior performance compared to the Biaxial Geogrids. The increase in the CBR value observed with the Triaxial Geogrids exceeded that achieved with the Biaxial Geogrids. This suggests that Triaxial Geogrids are more effective in enhancing the CBR value and, by extension, the load-bearing capacity of the subgrade soil.

Overall, these findings underscore the efficacy of geogrid reinforcement, particularly when positioned at the specified depth within the CBR mold. The superiority of Triaxial Geogrids in enhancing soil stability and load-bearing capacity highlights their potential as a preferred solution for soil stabilization in road construction projects.

4.4 Geogrid (Damage Analysis)

Following the compaction process of the soil with geogrid materials in the CBR mold and subsequent CBR tests, we conducted a detailed damage analysis of the geosynthetic materials. This analysis involved visual inspection with the naked eye to assess any signs of damage or degradation. After thorough examination, it was concluded that there was no visible damage observed in the geogrid materials following the compaction process. This observation suggests that the geogrids maintained their structural integrity and performance despite being subjected to the compaction process within the CBR mold. This finding indicates the durability and resilience of the geogrid materials, further reinforcing their effectiveness in soil stabilization applications.

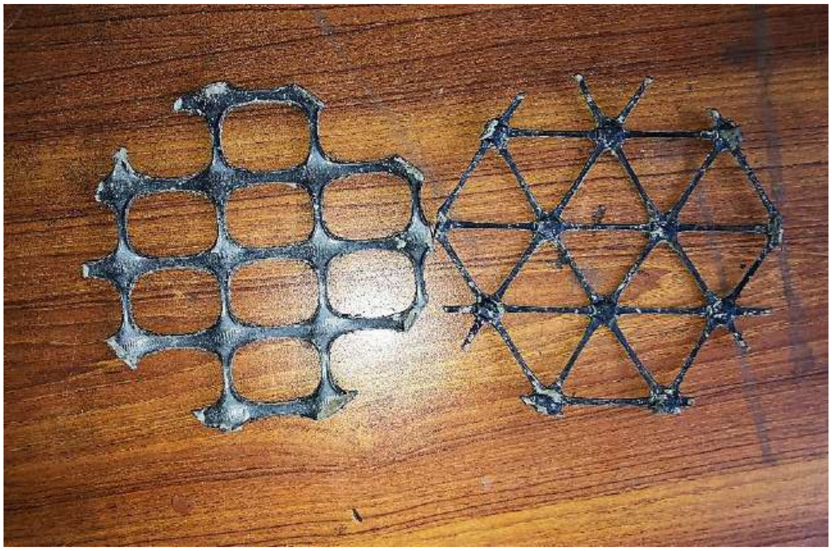


Figure 4.18: Shows Geogrid Samples Placed for (Damage Analysis)

4.5 Practical Model

In our project, we endeavored to create practical models that provide a visual representation of a cross-section of a flexible pavement. These models serve as illustrative tools, offering insights into the composition and structure of flexible pavements commonly used in road construction. Each model meticulously depicts the various layers essential to the pavement structure, including the wearing course, base layer, sub-base layer, and subgrade layer.

A key aspect of our models is the integration of geogrid placement within the subgrade layer. Recognizing the importance of soil stabilization in enhancing pavement performance, we strategically positioned the geogrids at a depth of 0.2H within the subgrade layer. This placement was chosen based on established engineering principles and recommendations, aiming to optimize the effectiveness of the geogrid reinforcement.

It is important to note that our models aimed for simplicity and clarity, and therefore, we assumed uniform thickness for each layer. While detailed pavement design specifications were not within the scope of this project, our models provide a comprehensive overview of the typical configuration of flexible pavements and emphasize the significance of geogrid placement in soil stabilization.

Following are the layers of flexible pavement practical model;

1. Surface Course
2. Base Course
3. Sub-Base Course
4. Geogrid Material
5. Subgrade Soil

In our project practical model, we utilized wood materials to construct the surface course, base layer, and sub-base layer, while the subgrade layer featured natural soil samples collected from both testing sites. The surface course, base, and sub-base layers made of wood provided a sturdy foundation for the model, allowing for the placement and integration of the natural soil samples within the subgrade layer. To provide a comprehensive representation of the model, we captured several pictures showcasing different angles and details.

Chapter 5

Conclusion and Future Recommendations

5.1 Conclusion

In many instances, the construction of flexible pavements over weak subgrade soil presents significant challenges for pavement engineers due to the potential for large deformations and rutting, which can lead to pavement deterioration. To address this issue, we have employed geosynthetic materials, specifically Biaxial and Triaxial Geogrid material, to stabilize the weak subgrade soil. Our approach centers around evaluating the California Bearing Ratio (CBR) value of the subgrade soil. Soil samples were collected from two different sites, and CBR tests were conducted to assess the subgrade's strength. The results indicated a very weak CBR value for both sites, prompting the utilization of geosynthetics for stabilization. Following the initial CBR tests, Biaxial and Triaxial Geogrids were placed in the soil samples, and subsequent CBR tests were conducted. The findings from this project will provide valuable insights into the effectiveness of geosynthetic materials in stabilizing weak subgrade soils, ultimately contributing to improved pavement performance and longevity. The conclusions drawn from the experimental testing program can be summarized as follows:

1. The results demonstrate a positive impact of geosynthetic materials specifically geogrids on the bearing capacity of subgrade soil in stabilization.
2. The CBR value of the soil increased by 2 to 5 times with the use of geogrid as a soil stabilization material.
3. The geogrid performs best when placed at a depth of 0.2H from the top of the soil surface.
4. The CBR value of the soil sample from Warsak Road, Ashaq Abad, Peshawar site increased from 2.301% to approximately 11.121% when utilizing the biaxial geogrid and further rose to 12.828% with the application of the triaxial geogrid for stabilization.
5. The CBR value of the soil sample from Naguman to Charsadda Road, Peshawar site increased from 2.890% to approximately 12.982% when utilizing the biaxial geogrid. Subsequently, it further rose to 13.831% with the application of the triaxial geogrid for stabilization.

6. A triaxial geogrid demonstrates superior performance compared to a biaxial geogrid. This difference may be attributed to the junction efficiency, as triaxial geogrids boast a 100% junction efficiency, whereas biaxial geogrids exhibit a 93% efficiency. Furthermore, the optimal distribution of applied load over a larger area, facilitated by the structural design of the triaxial geogrid, contributes to its enhanced performance. Conversely, the load distribution is not as uniform with biaxial geogrids.
7. No visible damage is observed on the geogrid material due to soil compaction through hammering process in CBR mold.

5.2 Recommendations

This research provides a comprehensive examination of geosynthetic reinforcement in flexible pavement structures. However, constraints like time, financial limitations, and available resources hindered the thorough investigation of all factors associated with geosynthetic reinforcement. As a result, the following research studies are recommended for further exploration:

1) Further research effort is advised to assess the effectiveness of various kinds of geosynthetic materials on a larger scale.
2) Long-term field studies are essential to evaluate the real-world performance of geosynthetic materials. By observing their behavior over extended periods in actual environmental conditions, researchers can gather valuable data on durability, effectiveness, and potential challenges.
3) Performing cost-benefit analyses is vital to assess the economic viability of widespread geosynthetic implementation. By weighing the upfront costs against long-term benefits, decision-makers can make informed choices regarding the adoption of geosynthetics in infrastructure projects.
4) Further research is necessary to leverage advanced testing technologies for a comprehensive understanding of geosynthetic material behavior, particularly its resistance to vertical and horizontal strains induced by applied loads. Implementing advanced testing methods will enable a deeper analysis of the performance characteristics of geosynthetics under varying conditions, thereby enhancing the reliability and effectiveness of these materials in soil stabilization applications.

5) Further research is needed to study the effects of geosynthetic materials on the environment.
6) Further research is required to investigate the impact of geosynthetic materials on the various layers of flexible pavement, particularly whether the incorporation of geogrid in the subgrade layer affects the thickness of the sub-base and base layers. This study aims to determine whether the presence of geogrid influences the dimensions of adjacent pavement layers, necessitating a thorough examination of the structural changes induced by geosynthetic reinforcement.

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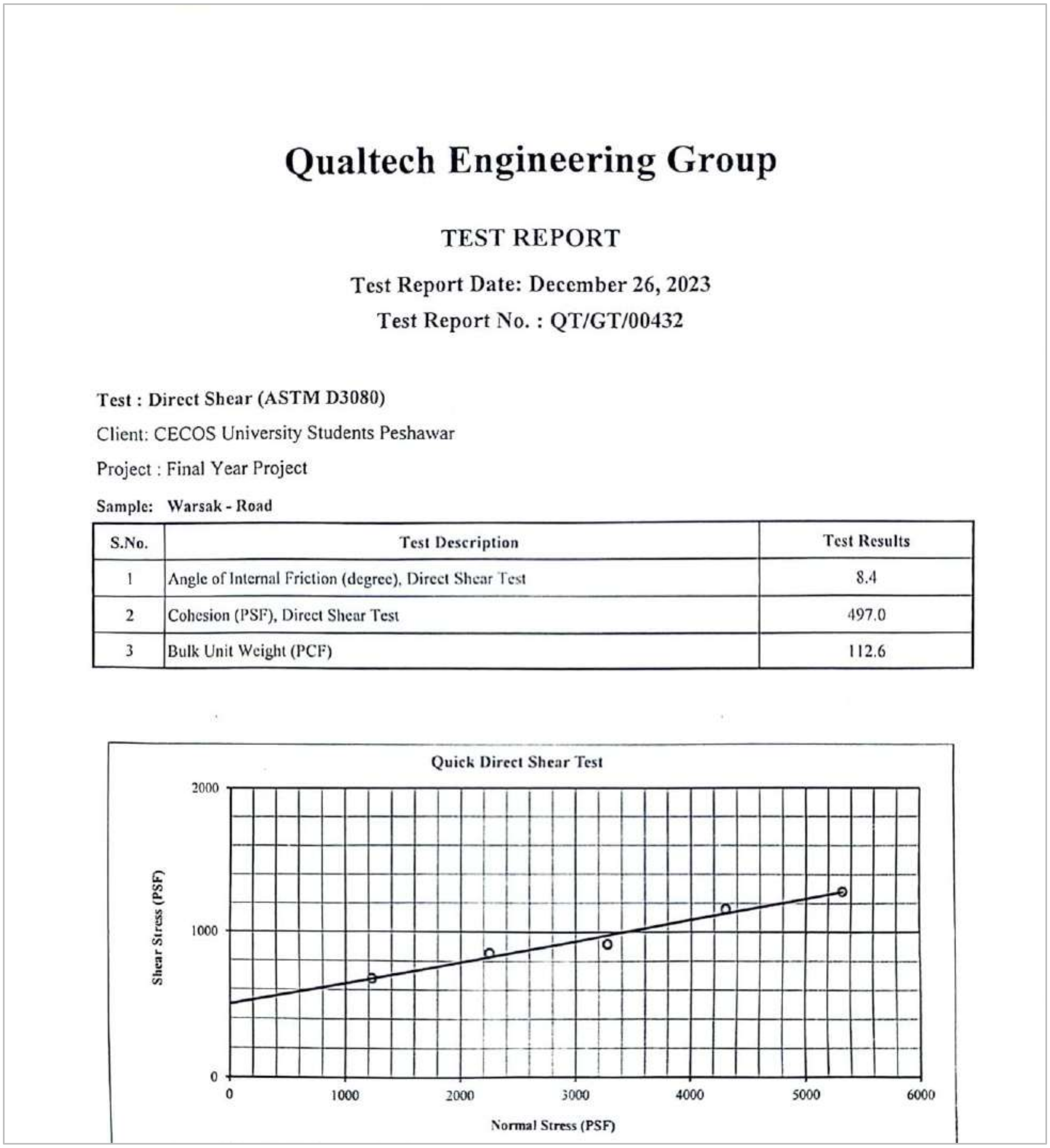
Annexure:

1. Direct Shear Test, Warsak Road, Ashaq Abad, Peshawar site



Qualtech Engineering Group

TEST REPORT

Test Report Date: December 26, 2023
Test Report No. : QT/GT/00432

Test : Direct Shear (ASTM D3080)

Client: CECOS University Students Peshawar

Project : Final Year Project

Sample: Warsak - Road

S.No.	Test Description	Test Results
1	Angle of Internal Friction (degree), Direct Shear Test	8.4
2	Cohesion (PSF), Direct Shear Test	497.0
3	Bulk Unit Weight (PCF)	112.6

Quick Direct Shear Test

2. Direct Shear Test, Naguman to Charsadda Road, Peshawar site