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Determining of Geosynthetics Reinforcement Effects on California Bearing Ratio Value of Base Course Material

Assad Khrisat[1], Mohammad Awad[2]
([1]Email: 2370451@std.hu.edu.jo, [2] Email: **2370308**@std.hu.edu.jo)

Abstract:

Geosynthetics has been the most vital improvement in the field of geotechnical engineering. The main objective of this study is to determine geosynthetics reinforcement effects on. California Bearing Ratio value of base course materials. The selected base course samples with different types of geogrids and location of geogrid. To achieve the main goal of the research, 28 samples of soil with different base course samples. The influence of reinforcement type on the load-penetration curve and the relative performance of several geosynthetics types have also been examined. The three types of geogrids are Tri x 160, Tri x5, Biaxial SS30. The best samples are three layers of geogrid "Quarter of Sample's Height from Bottom and Top and Half of the Sample's Height" then two layers of geogrid "Quarter of Sample's Height from Bottom and Top", and one layer of geogrid "Sample's Height Over Three from Top". The best samples are the base course material with biaxial SS30. Based on the results of research, an increase in CBR value for most of the cases is due to placing the geogrid layers. Geogrid reinforcement is found to be most effective in the case of weak base course layer.

Keywords: Geosynthetics, Geogrid reinforcement, California Bearing Ratio (CBR), Base course material, Biaxial geogrid , Triaxial geogrid, Load–penetration curve, Pavement engineering, Ground improvement

INTRODUCTION

The improvement of weak soil and base course materials has long been a challenge in the field of geotechnical engineering. Soil layers play a fundamental role in supporting pavement structures, and their weakness can lead to rapid deterioration, instability, and costly maintenance. Over the past few decades, geosynthetics have emerged as an innovative and effective solution to these challenges, enhancing the subgrade and strengthening base course materials in both paved and unpaved roadways. Numerous studies have demonstrated that correctly installed geosynthetics significantly improve road performance by providing reinforcement, separation, filtration, and drainage functions in soil-related applications (Qian, Han et al. 2010, Rajesh, Sajja et al. 2016[1, 2]). Geosynthetics offers a cost-effective alternative for constructing durable pavements with reduced maintenance needs, especially in areas with weak or poor-quality soils. Their applications extend to critical geotechnical projects such as highways, railways, and airports. Geosynthetics encompasses a variety of products, including geogrids, geotextiles, and geo composites, each tailored to address transportation and geotechnical challenges. Among these, geogrids have garnered particular attention due to their ability to interlock with granular base materials, efficiently distribute stresses, and minimize deformation under load, thereby improving soil stability and load-bearing capacity. Enhancing the strength behavior of weak soils has been a priority for engineers, driving the development of various ground improvement techniques. These include replacing weak soils with stronger materials, increasing soil density, and incorporating reinforcements such as geogrids (Sharma and Kumar [3]). Research has shown that geogrid layers can significantly increase California Bearing Ratio (CBR) values—by more than threefold in some cases—when placed at optimal depths within the base course (Singh and Gill [4]). The California Bearing Ratio (CBR) test remains one of the most reliable methods for evaluating the strength and thickness of base course materials and soil subgrades. CBR values are critical for designing pavement thickness and assessing load-bearing performance under various conditions. The CBR value is influenced by factors such as soil type, index properties,

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permeability, optimal moisture content (OMC), and soaked/unsoaked conditions (Testing and Materials, Jayanthi, Soundara et al. [5, 6]). However, the impact of geogrid reinforcement on CBR values varies based on the type of geogrid, the number of layers, and their specific placement within the soil structure (Sheikh, Wani et al. Sheikh[7].).

This study aims to comprehensively investigate the effects of geosynthetics, particularly geogrids, on the performance of base courses and subgrades. Testing was conducted on unreinforced and reinforced systems, examining different geogrid types—such as Tri X 160, Tri X5, and Biaxial SS30—placed at varying depths within the base course layer. The objectives include determining the extent to which geogrid reinforcement enhances CBR values, analyzing load-penetration behavior, and identifying optimal reinforcement configurations. Results demonstrated that incorporating geosynthetics significantly improves system performance through their separation and reinforcement functions. Additionally, this study explored the effects of reinforcement type and placement strategies on the subgrade-aggregate composite system, considering scale effects in small-scale tests. By addressing these objectives, this research provides valuable insights for geotechnical engineers and practitioners seeking to design cost-effective, durable, and resilient pavement systems, particularly in challenging soil conditions.

Figure 1 California Bearing Ratio (CBR) Test

Improving weak soil and base course materials has been a long-standing problem in geotechnical engineering. Soil layers are the foundation of pavement structures and weakness in them can lead to rapid deterioration, instability and costly maintenance. Over the past few decades geosynthetics have emerged as an innovative solution to these problems, improving the subgrade and strengthening base course materials in both paved and unpaved roads. Many studies have shown that properly installed geosynthetics improve road performance by providing reinforcement, separation, filtration and drainage functions in soil related applications (Qian, Han et al. 2010, Rajesh, Sajja et al. 2016 [1, 2]).

. Geosynthetics is a cost-effective solution for building durable roads with low maintenance needs especially in areas with weak or poor quality of soil. Their applications are in critical geotechnical projects like highways, railways and airports. Geosynthetics includes various products like geogrids, geotextiles and geo composites, each designed to address transportation and geotechnical challenges. Among these geogrids have gained attention due to their ability to interlock with granular base materials, distribute stress efficiently and minimize deformation under load thus improving soil stability and load bearing capacity. Improving the strength of weak soils has been the goal of engineers and has led to development of various ground improvement techniques. These include replacing weak soils with stronger materials, increasing soil density and incorporating reinforcements like geogrids Sharma and Kumar(Sharma and Kumar [3]). Research has shown that geogrid layers can increase California Bearing Ratio (CBR) values by more than three times when placed at optimal depth in the base course (Singh and Gill [4]). The California Bearing Ratio (CBR) test is one of the most widely used methods to evaluate the strength and thickness of base course materials and soil subgrades. CBR values are crucial for designing pavement thickness and assessing load carrying capacity under various conditions. CBR value is affected by soil type, index properties, permeability, optimal moisture content (OMC) and soaked/unsoaked conditions (Testing and Materials, Jayanthi, Soundara et al. [5, 6]). But the effect of geogrid reinforcement on CBR values varies with type of geogrid, number of layers and their placement in the soil structure (Sheikh, Wani et al. [7]). This study aims to investigate the effects of geosynthetics, particularly geogrids on base courses and subgrades. Testing was done on unreinforced and reinforced systems, with different geogrid types (Tri X 160, Tri X5, Biaxial SS30) placed at different depths in the base course layer. The objectives are to determine the extent of geogrid reinforcement on CBR values, load penetration behavior and optimal reinforcement configuration. Results showed that geosynthetics improves the system performance through separation and reinforcement functions. This study also investigated the effect of reinforcement type and placement strategy on the subgrade-aggregate composite system and scale effects in small scale testing. By achieving these objectives, this research will provide valuable information for geotechnical engineers and practitioners to design cost effective, durable and resilient pavement systems especially in difficult soil conditions.

Geogrid Materials

A geogrid is a type of geosynthetics material with perforations large enough to enable the striking through of the surrounding soil, rock, or other geotechnical material. It consists of parallel sets of connected tensile ribs. When used with appropriately sized aggregate fillings, geogrid offers reinforcement, stabilization, and even filtration. They are frequently utilized in civil engineering applications and are made from polymers like polyester, polypropylene, and polyethylene.

Geogrids are a geosynthetic material used widely in civil engineering to improve soil stability and pavement performance. They are the go-to solution for weak or unstable ground. Here are the 3 main applications of geogrids: Geogrids stabilize work platforms over soft or compressible soils. These soils are often not suitable for construction due to low bearing capacity can be made stable by placing geogrids under granular fills. The geogrid distributes the loads effectively, minimizes soil deformation and provides a solid base for construction. Geogrids in pavement design increases the durability and performance of the road. By reinforcing the base course and subgrade layers, geogrids reduce rutting and cracking and extend the life of paved roads. This reduces long-term maintenance costs and provides smoother and safer roads. Geogrids allow engineers to achieve the required service life of the road while reducing the structural cross-section of both paved and unpaved roads. This means lower construction costs and less use of natural resources like aggregates. Geogrids make thinner layers of material work efficiently by distributing loads and reducing stress on the subgrade.

Types of Geogrids

Uniaxial geogrid: It is stretched only along longitudinal direction. Thus, the stress is transferred only along that axis, even the tensile strength is more in longitudinal direction when compared to transverse direction in uniaxial geogrid. Biaxial geogrid: It is stretched along two directions (longitudinal and transverse); thus, the stress is equally distributed along both directions. In biaxial geogrid the longitudinal direction is called machine direction (MD) and transverse direction is called cross machine direction (CMD). Since the strength is equal along both axis these geogrids are mostly preferred in construction. Triaxial geogrid: a next-generation enhancement to biaxial geogrid, have additional diagonal ribs that increase the product's in-plane stiffness. The triangular pattern is formed into a hexagon to improve how the product absorbs traffic loading forces. It creates a more efficient effect that delivers optimal in-service stress transfer from the aggregate to the geogrid, Triaxial geogrid have undergone extensive full-scale and field testing and have been calibrated within the more common pavement design methodologies, both for paved and unpaved roads Geogrid-Geotextile Composites: are comprised of both material types that are heat or sonically welded together to yield an effective reinforcement and separation element for very challenging subgrade soil conditions. When subgrade filtration-separation criteria cannot be met with adequately graded fill materials, Geogrid-Geotextile Composites are ideal for deploying. Such that underlying subgrade soils may be appropriately filtered, thus preventing contamination of the overlying granular fill.

Geogrids have become a game changer in geotechnical engineering, offering many benefits in soil reinforcement and ground stabilisation applications. Their design and functionality provide cost effective, durable and high performing infrastructure systems. Here are some of the key benefits of using geogrids in civil engineering applications: Geogrids can reduce aggregate layer thickness in unpaved roads by up to 50% without compromising the road. This reduces material costs and construction time, making geogrids a more sustainable option than traditional unreinforced designs. Geogrids in road and pavement design can reduce annual maintenance costs, especially for asphalt layers. By distributing loads and stabilising base layers, geogrids reduce wear and tear on pavements, resulting in over

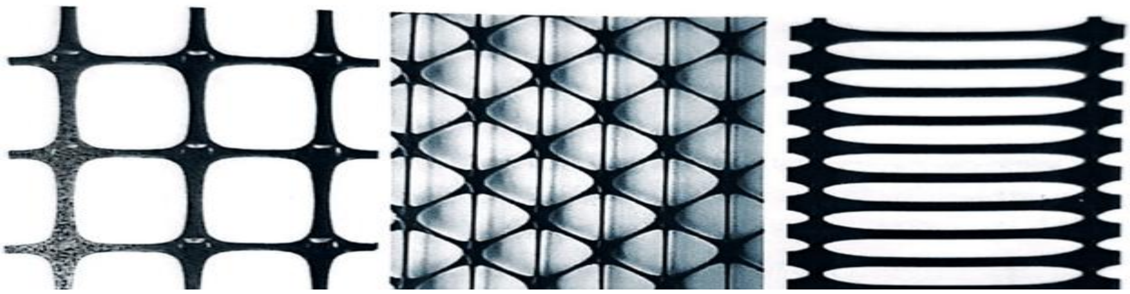


Figure 2 The Geogrid Types

50% savings in maintenance costs and extending the life of the infrastructure. Geogrids are great at stabilising slopes and reinforcing weak subgrades, which is especially useful in seismic zones. By increasing soil strength and bearing capacity, geogrids make infrastructure more resilient to seismic events, reducing the risk of landslides and slope failures. In rail engineering, geogrids stabilise rail ballast and the track bed. By increasing the bearing capacity of the rail ballast and minimising its movement and displacement, geogrids improve overall project performance. This stabilisation reduces maintenance over the life of the railway and reduces foundation material by up to 30%. Geogrids are a great alternative to poured concrete for load transfer and working platform applications. They reduce differential settlement in soft subgrades and provide a reliable and cost-effective solution for difficult soil conditions.

California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test, which measures the strength of base course materials and soil subgrades, is carried out in construction materials laboratories. When deciding on the pavement and foundation thicknesses for airport runways, highways and parking lots, taxiways, and other pavements, CBR test values are used. The basic procedure for the laboratory CBR test is to prepare a soil sample in a cylindrical steel mold, then press a plunger made of cylindrical steel with a nominal diameter of 50 mm into the sample at a regulated rate while measuring the force needed to penetrate the material[5]. California Bearing Ratio is defined "the percentage of stress a soil specimen can resist for a certain amount of penetration relative to the value of stress of which a standard soil could resist. Basically, the value is an indicator of the strength of the soil".

$$CBR = \frac{P_s}{P_{std}} X\ 100\%$$

Where P_s = Stress carried by site soil and P_{std} = Stress carried by standard soil.

Previous Studies

Abdi-Goudarzi, Ziaie-Moayed and Nazeri [8] analyzed the performance of soil-aggregate sections supplemented with three different geosynthetics materials. The primary subject of this study was a geocomposites material made of a nonwoven geotextile and a geogrid. Along with looking into this reinforcement, the functions of its parts (namely, geogrid and nonwoven geotextile) in sod-aggregate systems were also examined separately Is this day, the subgrade was selected from two sandy soils, one of which served as a case study. The measure used to gauge a specimen's strength was called the California Bearing Ratio (CBR) Making modified CBR mold allowed researchers to look into the scale effect of the standard CBR mold and geosynthetics anchors. Utilizing some foil, strain analysis was also completed. Foil strain gauges were used in the strain analysis to measure the strain mobilized in the geotextile in various reinforced portions. The load-penetration responses of the specimens greatly improved in the presence of both geocomposites and geogrids, whereas the inclusion effect of the geotextile was adverse. The reworked mold demonstrated improved reinforcing material functionality,

Singh and Gill [4] investigated the impact of geogrid reinforcement on the maximum dry density (MDD), optimal moisture content (OMC), California Bearing Ratio (CBR), and E-Value of subgrade soil. For this investigation, a geogrid type and a clayey soil type were chosen. According to the study, geogrid reinforcement significantly improves the sub-California grade's Bearing Ratio (CBR). When geogrid was positioned at 0.2H from the top of the specimen, the CBR increased to 9.4% from 2.9% in the absence of reinforcement (Geogrid). Sheikh et al.[7] investigated the geosynthetic behavior of reinforced Quarry Waste Bases (QWB) under vertical loading. The study found that the thickness of the infill material increases the strength and stiffness of roadway pavement. In this study, the artificial neural network was used to estimate the performance on the top of the footing surface while the different influential parameters take into consideration. Under static loading circumstances, the efficacy of geosynthetic (geocells and non-woven geotextile) reinforced quarry waste as an alternative base course material (BCM) was examined (plate load test-PLT). The bearing capacity (BC) rose from 450 to 840 kPa by increasing the geocell height from 100 to 150 mm. BC increased from 500 to 890 kPa when geocell and geotextile were used together. The geosynthetic reinforcement boosts the load-bearing capability of QWBs by 85 percent, according to the experimental data.

Cicek and Buyukakin[9] studied the influence of geotextile on bearing capacity ratio, geotextile thickness, and Cost of Pavement Layers using the California Bearing Ratio (CBR) test.

The tests included fourteen geotextile samples, the majority of which were made from recycled materials.

As a result, CBR tests were used to assess the physical attributes of geotextiles to determine the most effective form of geotextile, Microscope examinations were then used to investigate the interaction and adaptability between soil particles and geotextile kinds. AASTHO pavement thickness calculations were also performed, as well as cost analyses based on reinforced pavement design, either for the reinforced base or reinforced subbase layers. As a result of the research, it was discovered that the use of geotextile can improve CBR behavior, with bearing capacity ratio values nearly 3.5 times higher than unreinforced models. Each type of geotextile reinforcement has a distinct effect on the pavement layer, in general, they reduce pavement thickness and can be more cost-effective for long spans.

Duncan-Williams and Attoh-Okine[10] examined the strength characteristics change of different granular base materials reinforced with geogrid. This study's test aimed to evaluate the behavior of geosynthetics material when placed in four distinct soil samples with varying CBR values and subjected to stresses. The use of geosynthetics in soils reduces surface penetration and deformation while also improving the stress distribution over the soil sample. This indicates that adding reinforcing geosynthetics to soil improves its resistance to dynamic and cyclic loads. The results obtained that the addition of reinforcing geosynthetics materials to soils improves CBR and, as a result, soil strength. It means that geosynthetics reinforced soils in unpaved roads will perform better than non-reinforced soils, increasing loud carrying capacity and improving soil strength and CBR when using geosynthetics material, which is dependent on soil parameters and in situ CBR. Low CBR soils gain more in terms of enhanced strength than soils with higher CBR values.

Grygierek and Kawalec[11] studied the geogrid effect on the stabilization of unbound aggregate layers. The test results reported here should be regarded as preliminary. However, the greatest deformation of the geogrid observed under the primary loading was 1,270 m/m, which may already be seen at this point. The deformation increments significantly reduced in the next loading-unloading cycles, as shown. Deformations were smaller than those reported in cycles 2-6, i.e. < 10-4, should be predicted when considering the deformations in the base course during the use (traffic load) of the whole pavement system. As a result, a spectrum of so-called minor deformations can be seen in the road pavement layers, including the included geosynthetics. This remark reaffirms the need for geosynthetic materials used in pavements to have high initial stiffness for them to interact effectively with the pavement aggregates.

Çiçek and Buyukakin [12] investigated the different fiber types effects on cost analysis and road design. The California Bearing Ratio (CBR) experiments were used to determine the behavior of granular layer fills reinforced with discrete fibers, and the results were used to create read layer designs and cost estimates. Six distinct fiber kinds were used in the road layer in this investigation. and several layered approaches were examined, as well as an effective cost estimate as an original impact. With unreinforced road, stress-penetration curves were examined for various fiber types and layering methods, optimal configuration types were compared, and cost analysis was presented. Various fiber types and laying procedures can produce a variety of improvements. Because of the investigation, CBR test values for each fiber type employed in the study differ, and some test results reveal no improvement in the road's bearing capacity ratio for tiny penetration levels. It was discovered that as the penetration depth is increased, the bearing capacity ratios increase in size. As a result, the cost and layer thickness numbers for different reinforced road layer models varied. As a result, in real-world road construction, cost and performance analyses should be conducted to identify which fiber type is the most beneficial.

Goud et al.[13] studied the design and sustainability of flexible pavement reinforced by geogrids. The difference in performance between geogrid-reinforced and unreinforced pavement can be measured using the Layer Coefficient Ratio (LCR) or Traffic Benefit Ratio (TBR). Both LCR and TBR-based approaches to designing geogrid-reinforced base courses of pavements with specific purposes are proposed in this work. These objectives included designs focused on (a) reducing aggregate consumption and (b) lowering the overall cost of constructing geogrid- reinforced pavement. The LCR and TBR values for selected traffic, as well as the California Bearing Ratio (CBR) of subgrades, are used to create design charts. When employed over weak subgrades (CBR-5%), the benefits of reinforcing in pavement construction are found to be high. For example, a reduction in the aggregate layer thickness of 28-45 percent has been discovered. In addition, the embodied carbon (EC) created during the building of geogrid-reinforced and unreinforced pavements is compared to determining the sustainability of geogrid reinforced pavement. In comparison to unreinforced pavements, the EC of reinforced pavements was found to be lowered by as much as 58-85 1002 km.

Rashidian, Naini and Mirzakhanlari[14] studied the bearing capacity of reinforced specimens concerning the position and number of geotextile layers. The load penetration behavior of unreinforced granular soils as well as reinforced ones with nonwoven geotextile layers was investigated using the standard laboratory California Bearing Ratio (CBR) test (s). Seven distinct scenarios (one, two, and/or three layers of reinforcement in the bottom, middle, and/or top compacted soil layers) were used to install the reinforcements in samples. The results showed that adding the geotextile layer(s) increased bearing capacity in most scenarios, however, increasing the number of reinforcement layers did not necessarily increase the reinforced mass bearing capacity. It was also discovered that the efficiency of placing reinforcement layers to increase bearing capacity is higher for soil masses with higher fine content than for soil masses with lower fine content; even in some scenarios, the geotextile would decrease bearing capacity in comparison to the unreinforced sample for soil masses with lower fine content. Finite Element (FE) software was utilized to simulate the CBR tests in addition to laboratory testing. The findings of the FE analysis revealed that the ratio predicted to measure CBR value varies between 1.06-1.20 for lower fine content soils and 0.86-1.086 for greater fine content soils. After the FE model was confirmed, it was tested in software by replacing the nonwoven geotextile with a woven one to compare the two forms of reinforcement.

Data Collection

achieves the aim of this research 28 samples were prepared, each with different geosynthetics location, material type, testing setup and methodology. These samples were from weak base course materials to focus on the conditions of low strength soils. The testing involved systematic analysis of geosynthetics effect on soil performance under different configurations. Table 1 shows the properties of the base course material used in this study to give an idea of its composition and suitability for reinforcement. This comprehensive approach ensures the results accurately reflect the potential of geosynthetics to improve the strength and stability of weak base courses under various conditions.

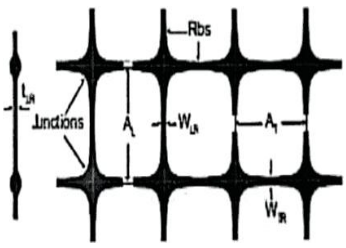


Figure 3 Biaxial geogrid.

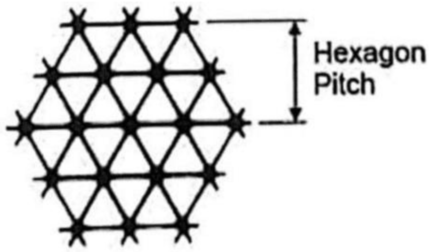


Figure 4 Triaxial geogrid.

Sample Perpetrations

The California Bearing Ratio (CBR) test is a widely used method to evaluate the strength of subgrade soils and base course materials for infrastructure projects like roads, highways and airport runways. Below is the step-by-step procedure to prepare and test soil specimens in the laboratory to get the CBR values. To ensure uniformity and consistency in testing, the soil sample is sieved through 19 mm sieve to remove oversized particles. 5 kg of the sieved soil is then weighed and mixed with water to achieve the optimum moisture content (OMC) or field moisture content. This step is very important to replicate the field conditions in the laboratory. Before filling the soil, the testing Mold and spacer disc are prepared to get accurate results and easy handling. A spacer disc is placed at the bottom of the Mold on the base plate, then a coarse filter paper on top of the disc. This will prevent soil loss during compaction. The soil-water mixture is then divided into 5 equal parts to make compaction uniform, as shown in Figure 6. To make removal of the sample after compaction smooth, the Mold is cleaned and lightly oiled. Compaction is done in layers. One-fifth of the prepared soil mixture is poured into the Mold. Each layer is compacted with 56 blows of 4.89 kg hammer to achieve the desired density.
. Before adding the next layer, the top surface of the compacted soil is lightly scratched to promote bonding between layers.

Table 1 The Characteristics of base material.

Aggregate Identification		Limestone Aggregate	
		Base Course	
		Test Results	Test Standard
Sieve Size		% Passing by Weight	
$1\,^{1}/_{2}$”		100%	ASTM C136-19.
1”			ASTM C117-17
$^{3}/_{4}$"		91%	
$^{1}/_{2}$"		80%	(Method A)
$^{3}/_{8}$"		66%	
No. 4		57%	
No. 10		39%	
No. 40		24%	
No. 200		14%	
$1\,^{1}/_{2}$”		11%	
Atterberg Limits	Liquid Limit	18	ASTM D 4318-17 CI.12 (Method A)
	Plastic Limit	16	
	Plasticity Index	2	
Modified Proctor	OMC (%)	6.9	ASTM D1557-12
	M.D.D (g/cm^3)	2.14	(Method C)
	Liquid Limit		
AASHTO Classification		A-1-a	AASHTO M 145

Table 2 Geogrid Characterization

Geogrid Reinforcement	TX160	TX5	SS30
Aperture Shape	Triangular	Triangular	Square
Strength (kN/m)	-	-	30
Radial Stiffness (kN/m)	290	250	-
Nominal Mass per Unit Area (g/m^2)	220	205	335
Nominal Gross Mass Unit (Kg)	66.5	62	67.5
Polymer Type	Polypropylene	Polypropylene	Polypropylene
Aperture Size (mm)	35 x 35 x 35	40 x 40 x 40	35 x 35

This is done for all 5 layers. After compaction of the 3rd layer, a collar is attached to the Mold to accommodate the remaining layers to make the process consistent and efficient. This is important to get reliable data in the next testing phase. After compaction is done, the collar is removed, and the excess soil is carefully struck off to make a smooth surface.

Specimen Setup

The Mold is inverted to remove the spacer disc and clamped to the base plate. A surcharge weight of 2.5 kg is placed on top of the compacted soil to simulate field conditions during testing. Once the prepared Mold is in the CBR testing machine, the penetration test is done to determine the bearing capacity of the soil. First the penetration plunger is placed on the soil surface. A seating load of 4 kg is applied to ensure the plunger is in contact with the compacted soil sample. At this stage the dial gauges are zeroed to ensure accurate reading throughout the test. The test proceeds by applying a load to the penetration plunger at a rate of 1.25 mm per minute. Load values are recorded at specific penetration depths of 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 7.5, 10 and 12.5 mm. These readings are important to determine the resistance of the soil to penetration and will give you the CBR value of the tested material. This data will help you determine if the soil is suitable for construction applications such as roadways, runways and other infrastructure projects. This ensures accurate measurement of CBR values and provides valuable data to assess the bearing capacity and strength of soils. The results will be used to design and thickness of pavements, foundations and other load bearing structures to ensure their durability and performance under different conditions.

Figure 5 Sample Preparation: Sift the soil sample through a 19 mm sieve, then take 5 kg of the sample and add water to it to obtain the ideal moisture.

Figure 6 Mold cleaning and oiling, placement of separator disc and filter paper, then filling the mold in five equal parts with the soil–water mixture.

Figure 7 Sample preparation with five-layer compaction using 56 blows per layer and leveling after collar removal.

Figure 8 The sample with geogrid.

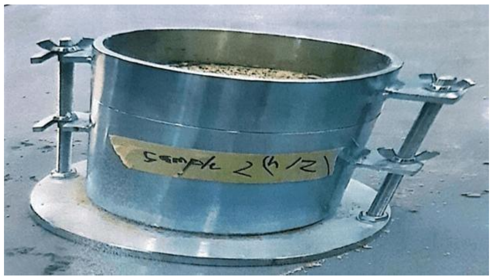
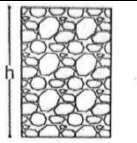
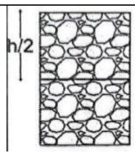
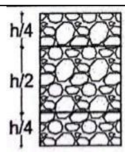
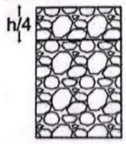
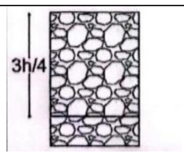
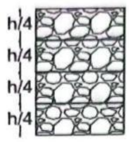
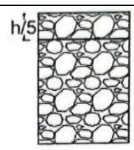
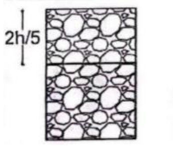
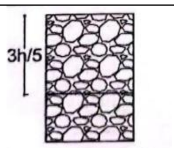
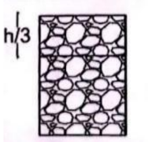


Figure 9 Sample Preparation: Bring the penetration plunger into contact with the soil and apply a seating load of 4 kg to establish contact.

The different base course samples were used in this study to achieve the main goal of research as shown in figure 6. The variation between samples depends on the location of geogrid and the type of geogrid.

Table 3 The Samples Description.

Sample No.	Sample Name	Sample Image	Geogrid Location	Geogrid Height
1	Control Sample		No Need Geogrid	-
2	Sample 2		Half of Sample's Height	5.82 cm from the top
3	Sample 3		Quarter of Height from Bottom and Top	The lower Layer 8.7 cm from the Top and the upper layer 2.91 cm from the top
4	Sample 4		Quarter of Sample's Height from Bottom	8.7 cm from the top
5	Sample 5		Quarter of Sample's Height from top	2.91 cm from the top
6	Sample 6		Quarter of Height from Bottom and Top and Half of the Sample Height	The lower layer 8.7 cm from the top, the middle layer 5.82 cm from top and the upper layer 2.91 cm from the top
7	Sample 7		Fifth of Sample's Height from Bottom	9.143 cm from the top
8	Sample 8		Two of Sample's Height Over Five from Bottom	6.3 cm from the top
9	Sample 9		Two of Sample's Height Over Five from Top	4.66 cm from the top
10	Sample 10		Sample's Height Over Three from Top	7.76 cm from the top

Results

The California bearing ratio test, also known as the CBR test, is known as the ratio of the test load to the standard load, expressed as a percentage for a specific depth of plunger penetration. In this method, the thickness of the pavement and its individual layers are determined by combining load penetration tests-performed in the lab or in-situ-with empirical design charts. This is one of the most frequently employed methods for designing flexible pavements. CBR values are used to calculate the thickness of each component of a pavement. It is observed how the penetration resistance, or test load, compares to plunger penetration. The standard load is the plunger's resistance to penetration into a standard sample of crushed stone for the appropriate penetration (Notes, 2022).

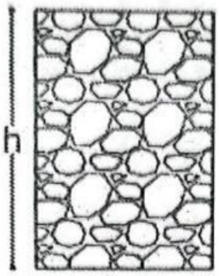


Figure 10 Control Sample Diagram

California Bearing Ratio Test Results is divided into three results of all samples such as water content, density, and load- penetration curve. All samples vary depending on type and location of geogrid material. Control Sample is sample without any geosynthetics material that used to check and compare between other samples. Water content was measured to check and control the moisture content of sample where it does not exceed the optimum water content in proctor test. Table 6 shows Molding moisture content of control sample.

Table 4 Molding Moisture Content Calculation

Molding Moisture Content	Weights
A. Mass of wet sample + pan	3371 g
B. Mass of dry sample + pan	3236 g
C. Mass of pan	1280 g
D. Mass, Moisture (A - B)	135 g
E. Mass, Dry (B - C)	1956 g
F. Moisture % (D/E) * 100	6.9 %

Density was measured to check and control the maximum dry density (MDD) of sample where it does not exceed MDD the in-proctor test. Table 5 shows density determination of control sample.

Table 5 Density Determination

1. Mold volume	2125 cm³
2. Mass of sample + Mold	21823 g
3. Mass of Mold	17490 g
4. Mass of Sample	4333 g
5. Unit wet mass	2.04 g/cm³
6. Moisture (OMC) %	6.90%
7. Unit dry mass	2.14 g/cm³

In this test the swelling index is not considered as the base course material has lower value. California Bearing Ratio (CBR) is the ratio of the load required to penetrate the material to a specified depth to the load required to penetrate crushed stone to the same depth. The test gives a composite measure of both stiffness modulus and shear strength rather than measuring either of them directly.
Penetration is done by applying a bearing load to the sample using a standard 50 mm diameter plunger at a rate of 1.27 mm/min. CBR is expressed as a percentage of the actual load required to cause the standard loads on crushed stone to penetrate 2.5 mm or 5.0 mm. A load-penetration curve is plotted and at penetrations of 2.5 mm and 5.0 mm the load values for normal crushed stone are 1.370 kg. (13.44 kN) and 2,055 kg. (20.15 kN) respectively.

Table 6 Load Penetration

Penetration (mm)	**Displacement (mm)**	**Load (kN)**	**CBR% after correction**
0	0	0	
0.64	0.64	0.69	
1.27	1.27	0.91	
1.9	1.9	0.83	
2.54	2.54	1.05	2
3.18	3.18	1.41	
3.81	3.81	1.63	
4.45	4.45	2.03	
5.08	5.08	2.46	3
7.62	7.62	4.63	
10.16	10.16	8.63	
Standard load at 2.5 cm = 13.2 kN	CBR% at 2.5 cm	**15.2**	
Standard load at 5.08 cm = 20 kN	CBR% at 5.8 cm	15.0	

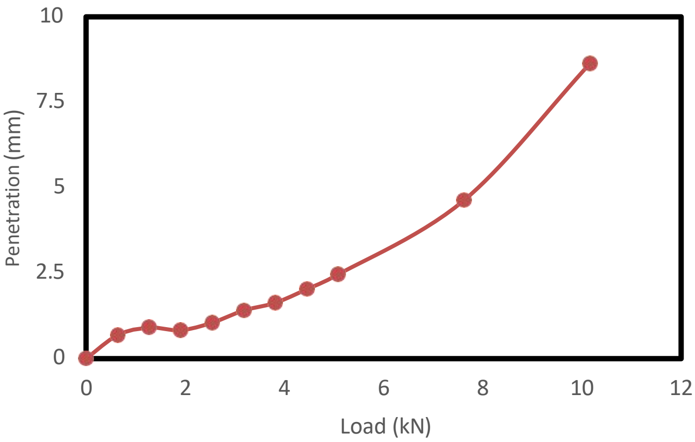


Figure 12 Load-Penetration Diagram.

Conclusion

This study investigates the effects of geosynthetics reinforcement (geogrids) on California Bearing Ratio (CBR) value of base course materials. It looks at how different types of geogrids and where they are placed in the base course sample will affect the mechanical properties of the material, particularly its resistance to penetration and overall stability of the road. 28 soil samples were used, each with different geogrid configurations, different types of reinforcement and location within the base course material. The three geosynthetics tested were Tri x 160, Tri x 5 and Biaxial SS30, each chosen for their known properties to improve soil stability. The reinforcement was placed in different configurations within the base course, including layers at specific points along the sample height. The configurations tested were three layers of geogrid at one-quarter of the sample height from both top and bottom, two layers at the same height and one layer at one-third of the sample height from top. These different configurations were to evaluate the effect of reinforcement location on the overall performance of the base course material, particularly on its CBR value.

The results showed that the presence of geogrid reinforcement increased the CBR value of the base course material. The three layer configuration where the geogrid was placed one-quarter of the sample height from both top and bottom was the most effective followed closely by the two-layer configuration where the geogrid was placed one-quarter of the height from top and bottom. The single layer configuration where the geogrid was placed one-third of the sample height from top also showed improvement in CBR values but to a lesser extent. Among the three types of geogrids tested, Biaxial SS30 geogrid showed the most significant improvement in CBR, strengthening the base course material and its load bearing capacity.

Geogrid reinforcement is most effective on weak base course materials which have low CBR values. By stabilizing

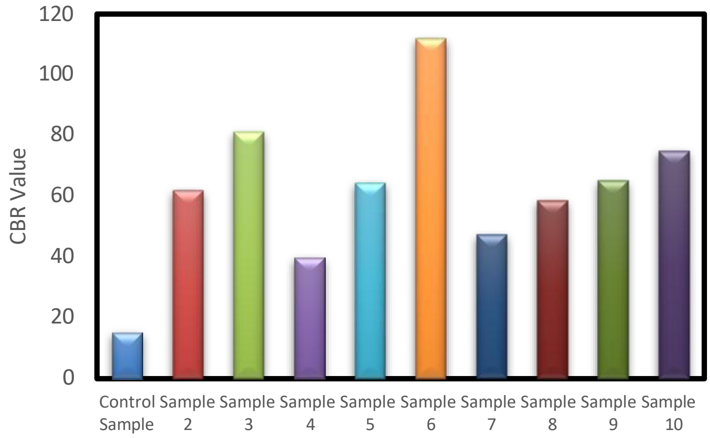


Figure 11 CBR Result (Tri x 5)

these materials, geogrids help to resist deformation under load and increase the overall life of the pavement structure. This is very useful for roads with high traffic and harsh environmental conditions where traditional unreinforced materials can't provide the required strength and stability.

And the research also looked at the bigger picture of using geosynthetics in pavement construction. Adding geogrid layers not only strengthens the base course material but also is a more cost-effective solution by reducing the amount of material needed for the pavement. By strengthening the base course material geogrids allow for thinner pavement layers without compromising the road. That means less material and less labor costs, a very economical solution for road construction projects especially in areas with limited resources.

Based on the research the study recommends the use of geosynthetics, specifically geogrids in base course applications to improve the stability and performance of roads. Geogrids in the pavement structure can give improved load bearing capacity, reduced maintenance costs and longer life of roads under heavy traffic. Geogrids can be more beneficial for projects that require long lasting infrastructure like highways and airport runways where the road structure has to withstand heavy wear and tear over time. In summary geosynthetic reinforcement, especially geogrids can improve base course material performance, pavement durability and reduce construction and maintenance cost. Geosynthetics in road design is the way to go, a more sustainable, cost effective and durable solution for modern infrastructure.

Future research can look into other geosynthetic materials, different types of fibers and innovative reinforcement techniques. It would also be good to study the effect of different soil types and road conditions on geogrid reinforcement. Comparative studies of other reinforcement methods and their performance under real world conditions will help to further optimize the use of geosynthetics in pavement construction. Large scale testing under actual environmental and traffic conditions will provide valuable data to validate laboratory test results and give deeper insights into the practical benefits of using geosynthetics in road infrastructure.

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