RUTTING POTENTIAL OF COIR GEOTEXTILES AS INTERFACE OVER POOR SUBGRADE FOR LOW VOLUME ROADS

Submitted in partial fulfilment of the requirements

for the award of the degree of

Doctor of Philosophy

by

D. HARINDER

701405

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, WARANGAL

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CERTIFICATE

This is to certify that the thesis entitled **"Rutting Potential of Coir Geotextiles as Interface Over Poor Subgrade for Low Volume Roads"** being submitted by **Mr. D. HARINDER** for the award of the degree of **DOCTOR OF PHILOSOPHY** to the Department of **Civil Engineering** of **NATIONAL INSTITUTE OF TECHNOLOGY, WARANGAL** is a record of bonafide research work carried out by him under my supervision and it has not been submitted elsewhere for award of any degree.

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APPROVAL SHEET

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DECLARATION

This is to certify that the work presented in the thesis entitled **“Rutting Potentialof Coir Geotextiles As Interface Over Poor Subgrade For Low Volume Roads”**, is a bonafide work done by me under the supervision of **Dr. S. Shankar**, Assistant Professor, Department of Civil Engineering, NIT, Warangal,Telangana, India and was not submitted elsewhere for the award of any degree. I declare that this written submission represents my ideas in my own words. I have adequately cited and referenced the original sources where other ideas or words have been included. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

D. Harinder

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Dedicated to

My Parents and Teachers

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D. Harinder

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GLOSSARY OF TERMS

LVRs	: Low Volume Roads
APT	: Accelerated Pavement Testing
(PMGSY)	: Pradhan Mantri Gram SadakYojana
AADT	: Annual Average Daily Traffic
SADC	: Southern African Development Community
ASTM	: American Society for Testing and Materials
CAGR	: Compound Annual Growth Rate
AASHO	: American Association of State Highway and Transportation officials
BC	: Block Cotton Soil
ABC	: Aggregate Base Course
LVDT	: Linear Variable Differential Transformer
CBR	: California Bearing Ratio
MDD	: Maximum Dry Density
OMC	: Optimum Moisture Content
UCS	: Unconfined Compressive strength
WTT	: Wheel Tracking Test
CC	: Coir Composite
GG	: Geogrid
NWCM	: Non-Woven Coir Mat
WCM	: Woven Coir Mat
NWCM	: Non-woven Coir Mat and
GW	: Well-Graded Gravel
SP	: Poorly Graded Sand Gravel
IS	: Indian Standard
DAQ	: Data Acquisition
LL	: Liquid Limit
PL	: Plastic Limit
PI	: Plasticity Index
SG	: Specific Gravity
FSI	:Free Swell Index
IRC	: Indian Road Congress (IRC)
ME	: Mechanistic-Empirical (ME)
CVPD	: Commercial Vehicle per Day
Cu	: Undrained Soil Cohesion
CBR_m	: Modified California Bearing Ration
E_s	: Young’s Modulus of Geotextile

ABSTRACT

Low Volume Roads (LVRs) constitute an integral component of the road system in all countries. Their importance extends to all aspects of the social and economic development of rural communities. India has a total road network of over 5.3 million kilometers in length, making it the second-largest road network in the world. This is about 80 percent of all types of roads in India. Given this, they often form the most crucial link in terms of providing access to educational, medical, recreational and commercial activities in local and regional areas.

The use of geosynthetics for engineering applications is not a new concept. The concept of reinforcing weak soils to enhance their load carrying capacity has been developing until present times, and the first textiles were used in road construction in the United States in 1926. After that, it has been practiced for centuries in various infrastructure projects and road construction. Geosynthetic materials include geotextiles Geonets, Geogrids, Geocells, and Geocomposites. Most of these materials become a permanent part of the road. The use of Geosynthetic materials has grown significantly in road construction for the past 40 years and trial construction over the past 15 years. In the pavement, they perform four essential functions, namely reinforcement; separation; drainage; and filtration. Today a variety of geosynthetic materials can be used in many engineering projects such as roads, railroads, dams, retaining walls, tunnels, landfills, recreation areas, etc. The construction of LVRs on weak subgrade soil within the sinking budget is a challenging task. Most of these roads are lower order roads and subjected to low traffic. Under such circumstances whenever the poor native subgrade soil found, it is mandated to adopt the soil stabilization techniques or ground improvement methods.

Coastal and river portion of India is predominantly blessed with clays and expansive soils. These soils behave very typically due to the presence of montmorillonite minerals. Further, they pose several problems in terms of swelling and shrinkage and contribute cause for various distresses. To address these issues one of the common and innovative techniques are promoting the usage of geotextiles. So, the utilisation of geotextiles has gained universal promises to enhance the weak subgrade soil and geotechnical engineering aspects.

A review of existing literature revealed that most of the experimental studies were conducted on polymeric geosynthetic to reinforce the weak subgrade soil; limited research is available on coir Geotextile applications for LVRs. The LVRs are usually the lower order roads in the world, where the traffic ranges from 100 vehicles per day to 5000 vehicles per day.

The coir geotextile is naturally available eco-friendly and abundant material. It is available in huge quantity in the coastal area and also Malaysia, Indonesia, Srilanka, etc. The coir geotextile has higher tensile strength, more extended durability high performance among the other natural geotextile material, the utilisation of coir geotextile mats in pavement and geotechnical applications having high demand. It also creates an opportunity for rural employment, saving of natural material such as aggregate, morrum soil in the pavement application. With this background, in the present study four types of the coir geotextile mats such as Non-Woven Coir Mat (NWCM), Woven Coir Mats (WCM), Coir Composite (CC) and Geogrid with Non-Woven Coir Mat (GG+NWCM) combinations were considered with a aim to evaluate their effectiveness and potential benefits in laboratory using the Wheel Tracking Test (WTT) setup and in-situ by constructing a test tracks in the field under Accelerated Pavement Testing (APT). The primary conclusion from the laboratory study is that the maximum and minimum rut depth was 37.0 mm and 13.0 mm was found at sub-base-I and sub-base-II with 200mm thickness of the fabricated mould. The placement of the coir geotextile mats with morrum soil showed more significant performance in terms of rut depth and No. of passes than the gravel soil sub-base. It is also concluded that the inclusion of coir-geotextile mats improved the No. of passes (1200 passes) in sub-base-II with 100mm layer thickness with 300 mm assemble of mould during reduction thickness of the sub-base material. The rut depth at sub-base-I and sub-base-III position are noticed with reinforcement and without reinforcement as 3.0 mm, 4.0 mm and 11.0 mm, 24.0 mm respectively. In addition, the gravel sub-base soil is more effective when providing the decreased thickness of the sub-base as per the design standard charts (225 mm). In the case of the reinforcement function, the composite material provided better reinforcement than the woven and non woven coir mats. From the test track study, it was noticed that the reduction (55mm to 40mm) of the sub-base layer thickness is more in case of gravel soil with different types of coir geotextile. The deformation in the gravel sub-base soil is less than the morrum sub-base soil. To summarize finally, it is noticed that test track studies are more reliable to quantify the performance of these materials than laboratory evaluation. The coir composites material are shown the better function (reinforcement and separation) than the woven coir geotextile, the thickness of pavement can be reduced up to 55 mm with provisions of coir geotextile mats.

Keywords: Coir Composite, woven coir mat, non-woven coir mat, and geogrid with non-woven coir mat, wheel tracking test, accelerated pavement test, reinforcement, separation, rutting.

Chapter 1
INTRODUCTION

1.1 General

India is the second-largest country in the world in terms of population. It consists of about 80% of Low Volume Roads (LVRs) network out of 5.3 million kilometers. LVRs provide accessibility to market centers, hospitals, and education facilities. The livelihood of rural communities hugely depends on these roads. Generally, these LVRs passes through the villages surrounded by the agricultural fields, which mostly consist of clayey soils. So, the construction of LVRs roads on such clayey soils faces several difficulties in terms of swelling and shrinkage and affects the performance of these roads. In this aspect, use of locally available materials plays a vital role in the construction of these roads.

The primary purpose of this road is to provide all-weather connectivity taking the traffic loads that are coming on it without causing an excessive deformation. Further, the subgrade is the bottom-most layer which acts as a foundation. If the subgrade is not possessing adequate required strength to withstand the traffic loads, it may lead to poor performance and results in premature failure of the pavement. This is true especially in the case clayey and expansive soils as the subgrade. Weak subgrade strength leads to several distress in pavements such as rutting and cracking etc.

In order to address the above problems, different designs, methods have been used to enhance the subgrade strength. Some of the conventional stabilization methods are lime stabilization, cement stabilization, and bitumen emulsion stabilization are adopted to enhance the strength of pavement layers. However, these are not economical for such low traffic roads. So, as an alternative, locally available materials are adopted. Among one of such materials is coir geotextiles. The use of coir geotextiles has been promoted in the recent past in India for the construction of LVR's. Some experimental and analytical studies have been conducted to assess and quantify the performance improvements associated with geotextiles in pavements. Studies show that the utilization of geotextiles at the subgrade and base course as the interface of LVRs increases the number of load repetitions before failure or decreases the thickness of the pavement layers (Al-Qadi et al. 1998;Al-Qadi et al. 1999. Al-Qadi et al.2003; Yang et al. 2007; Perkins et al. 1999; Meshram et al., 2013; IICF, 2016). These benefits are provided by separation, lateral restraint and reinforcement functions. Geotextiles is a separation layer prevent intermixing, promote vertical stress transfer on to the subgrade, and spread the applied load over a wider area.

Nowadays, it is challenging to construct roads under constrained funding; transportation professionals are continually seeking for an alternative, cost-effective materials, and construction process. As an alternative construction material, geosynthetic so offers a potentially economical solution for reinforcing roads built over soft subgrade soils. With this background, the current research is carried out to assess the rutting potential of coir geotextiles and quantify the benefits associated with different types of coir geotextiles in the laboratory as well as under Accelerated Pavement Testing (APT) facility for the construction of LVRs.

1.2 Low Volume Road Scenario in India

Till the launching of Pradhan Mantri Gram Sadak Yojana (PMGSY), the roads covered only 60%of villages/habitations in the country. Understanding the various direct and indirect roles that LVR's play, the Government of India on 25th December 2000 launched PMGSY, in order to provide road connectivity, through good, all-weather roads, to all rural habitations of the targeted population. At the commencement of PMGSY, it was estimated that about 3,30,000 habitations out of 8,25,000 habitations were without all-weather road connectivity, implying that about 40% of the habitations were cut-off from the mainstream development. Subsequently, it was proposed to take up 1,73,000 unconnected habitations of the population above 500 under the PMGSY. Under the program, 31,924unconnected habitations have been connected by constructing 85,405 km of roads since its inception up to March 2009. By the end of 2009-10, this was expected to go up to 66,802 unconnected villages to be connected with the total constructed road length going up to1,46,200 km. About 1,55,000 km of existing rural roads have also been upgraded. In 2018, against the sanctioned length of 6,58,143 km, 5,50,601 km of road length had been completed.

LVR's in India form a substantial portion of the total road network. Of 5.3 million kilometers of LVR's are formed in India. Because of this, they often form the most critical link in terms of providing access to educational, medical, recreational and commercial activities in local and regional areas. Universally, there is no exact definition for low volume roads (LVR's), but it could be defined primarily as tertiary roads that carry AADT of 200 to 500 vehicles per day (Oglesby 1985; Smith 1983; Gourley and Greening 1999; Hall and Bettis 2000; Southern African Development Community (SADC), 2003). Given the growing scarcity of pavement materials in different parts of the world in general and particularly in India, there is impulsion to adopt alternative materials in pavement construction, especially for low volume roads.

1.3 History and Importance of Coir Geotextiles

Geotextiles have emerged as new engineering materials with a wide variety of applications in civil engineering infrastructure developments. Geotextiles form one of the largest groups of Geosynthetics. Their rise in growth during the past 20 years has been nothing short of extraordinary. They consist of synthetic fibers rather than natural ones such as cotton and wool. Thus, biodegradation and subsequent short lifetime of such materials is not a problem. Geotextileshavereasonablygood mechanical properties and resistance to biodegradation (Faoun, 2012).Considering these factors, some vegetable fiber such as jute, flax, coir, hemp, and sisal have been chosen as the most promising materials as geotextiles. The Coir is a naturally available material, and itis extracted from the husk of coconuts. The American Society for Testing and Materials (ASTM) Committee D35 defined that, "Geosynthetics as a planar product, is manufactured from polymeric materials used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a man-made project, structure or system". Geosynthetics include geotextiles, geogrids, geonets, geomembrane, geosynthetic clay liners, geofoam, geocells, and geocomposites. The most popular geosynthetics used are the geotextiles and geomembrane. Fig.1.1 gives an idea of the utilization of geotextiles by application as presented below.

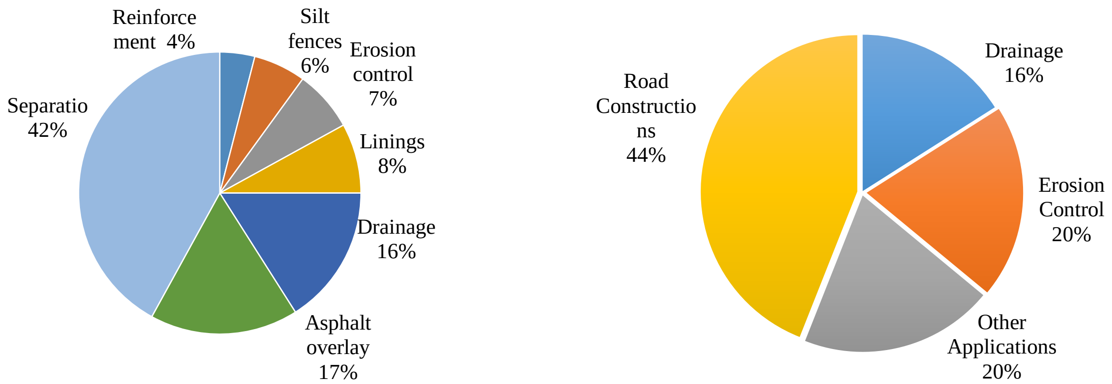


Figure 1.1 (a) Pavement Applications and (b) General applications
Source: India International Coir Fiber Report (2016) and Grand View Research Report (2014)

Figure 1.1. Shows the importance of geotextiles usage in pavements and general application respectively. It is a fact of the matter that there is considerable research is increased and focused on geotextiles and its applications in erosion control and roadways are expected to be a critical factor for market growth (Zornberg et al. 2013). Worldwide geotextile demand (for application in roads, erosion control and drainage) has grown at a Compound Annual Growth Rate (CAGR) of 8.9% from 2014 to 2020 and relies on achieving 4325 million m^2 by 2020. Obviously, natural fiber geotextiles will be useful, with an estimated CAGR of 9.1% from

2014 to2020; the Asia Pacific is expected to be the top regional market for the forecast period. Market revenue for European geotextiles is expected to reach US$1.97 billion by 2020 and growing at a CAGR of 9.6% from 2014 to 2020. In 2013, non-wovens were the most commonly used geotextiles, at an expected use rate of 1560 million m^2. Non-woven geotextile was the most favored among different geotextiles products because of their low cost and broad scope for application. Table 1 presents the functions of geotextiles.

Table 1.1Functions of geosynthetics

Type of Geosynthetics	**Separation**	**Reinforcement**	**Filtration**	**Drainage**	**Containment**
Geotextiles	√	√	√	√	-
Geogrids	-	√	-	-	-
Geonets	-	-	-	√	-
Geomembranes	-	-	-	-	√
Geocomposites	√	√	√	√	√

1.4 Problem Statement

The construction of LVR's using natural materials does not satisfy all the engineering properties of materials, especially in situations where subgrade is as clayey/black cotton soils. These soils are subjected to volume change behavior and offer to several settlement problems during the movement of traffic over it. The roads over such soil pose higher stress at the subgrade level. To keep the stresses within tolerance limits, geotextile mats are spread to act as load transfer medium over it. When BC soil subgrade is unprotected from the settlement characteristics, it imposes bearing capacity failure and initiates deeper ruts over the pavement due to its weak shear strength. Initiation of deeper ruts progressively create subsequent losses to the original pavement thickness, and these also penetrate into the BC soil subgrade. If it is not addressed, ultimately, a stage is reached where nothing can be done to prevent the diminishing thickness of the pavement layer. If this phenomenon remains unaccounted, then rutting will occur and progressively lead to failure of the pavement.

Given the above consideration, geosynthetics are introduced to prevent such problems for the pavement. Polymeric Geosynthetics/geotextile is used as reinforcement/separation, which prevents intermixing of particles, in turn, improves the behavior of the performance of pavement and geosynthetics. However, the natural geotextile mats studies were are not well established under the repeated loading condition. Among the natural geotextile such as coir, jute, hemp, sisal, etc., the coir geotextile possesses the higher tensile strength than the other types of the geotextile due to the presence of lignin and cellulose content in the coir fiber. These properties will improve the rigidity of the material and increase the tensile strength. This study addresses the same by making use of naturally available coir geotextile mats in LVRs. Based on the above mention advantages of the material; the current investigation is planed with four types of coir geotextile mats under repeated loading conditions (WTT and APT).

1.5 Need for the Study

An extensive literature study was carried out about the utilization of Geotextiles in the pavement as reinforcement, and separation functions. The literature survey reveals that the application of Geotextileenhances performance and also prolongs the life of the pavement. Geosynthetics have been used for the past few decades in the field of geotechnical and pavement engineering (Loulizi et al.1998). Several types of polymeric geosynthetics are used in the construction of highway engineering projects (Al-Qadi et al. 2009; Jersey et al. 2012; Ferrotti et al. 2011 and Khodaii et al. 2008). Since polymeric materials are now-available and high-cost materials, it may not be possible to use in developing countries. Hence, an alternate material is needed for the construction of LVR's. The use of coir geotextile, which has a non-polymeric form, is one of the most significant features of geosynthetics that can be used in LVRs.Coir materials have become popular and gained prominence in the construction of LVRs. It has been proved that the stabilization of pavement with geotextile provides better performance and is more effective than geo-grid (Loulizi et al. 1998). The coir geotextile has excellent potential to improve the strength of weak subgrade, and it is also a simple and easy method of earth reinforcement (Shaheem et al. 2013). Maliakal et al. (2013) stated that coir geotextile is a cost-effective method to improve the weak soil subgrade in developing countries and also addresses the benefits of coir geotextile in pavement construction.

India as a developing country, depends mainly on agro-based products and generates 70% rural employment through agriculture. To protect the traditional work and to employ the rural population, especially for the weaker section of the coastal belt, coir industries have been set up. India is one of the leading coir producing countries in the world, and these industries are found in south India. It is necessary to protect coir industries and meet the global challenges for the utilization of the new products from the existing products in the development of the road network. At present, the world is focusing on the replacement of chemicals and synthetic material to natural geotextiles to protect the environment. Due to lack of awareness and limited exposure in the country, coir geotextiles are not used in projects, even the decisionmakers and potential end-users are not aware of the application of this material in different areas of civil engineering. The various research studies witnessed that the durability performance of the coir geotextile is stable even after five years without any distress (IIFC, 2016)in the pavement. Sumi et al. (2018) studied the durability performance of the coir geotextile with scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis using the using Cashew Nut Shell Liquid (CNSL). The study noticed that the CNSL modified coir fiber is more effective than the un-coated coir fiber. The coated fiber effectively close the surface pores acts as barrier extended the life of the coir fiber. The current research is aimed to use the natural coir geotextiles material in pavements application without any treatment and asses the performance.

1.6 Objectives of the Study

The following are the objectives of the study, as presented below.

1) To evaluate the deformation characteristic and potential benefits of coir Geotextiles mats with different types of sub-base layers using the Wheel Tracking Test apparatus in the laboratory.
2) To investigate the effectiveness of reinforcement and separation function of the selected coir geotextiles mats in the laboratory.
3) To estimate the effectiveness and potential benefits of coir geotextiles mats with a different type of sub-base layer soil over the weak subgrade by constructing test tracks using the APT facility.
4) To study the deformation characteristics of coir geotextiles mats under repeated loading conditions with the help of the APT test.
5) To design low volume flexible pavement using coir geotextiles with minimum sub-base material layer thickness.

1.7 Scope of the work

The present study addresses the usage of coir geotextile mats to enhance the weak subgrade soils. The study evaluates the rutting potential and effectiveness of coir geotextile by considering the reinforcement and separation functions subjected to the repeated loading condition. The laboratory and in-situ investigation using wheel tracking test and accelerated pavement test respectively were carried out. The other essential tests, like California Bearing Ratio (CBR), compaction, tensile strength, were also done. This study is limited to make use of coir geotextile mats such as coir composite, geogrid with non-woven coir, woven coir and non-woven coir for subgrade and sub-base as interface and study the rutting potential of various coir geotextiles.

1.8 Organization of Thesis

This thesis comprises seven chapters, as indicated below.

Chapter -1 Introduction, problem statementand objective of the study.

Chapter- 2 Review of literature on coir Geotextiles and concluding remarks on literature.

Chapter- 3 Research approach adopted in the study.

Chapter- 4 Results from laboratory investigations.

Chapter- 5 Results from field investigations.

Chapter- 6 Design of low volume roads using coir Geotextiles.

Chapter -7 Conclusions and future scope of the study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

In the previous chapter, a detailed evolution of coir geotextiles and their utilization aspects are dealt. The current chapter deals with the specific uses, and the mechanism of coir geotextiles and earlier research works are discussed. The coir geotextile materials are available in different sizes and shapes. These materials are composed of lignin, and cellulose content which gives rigidity to the material. Due to these properties, it possesses higher tensile strength and is used as a separation and reinforcement function to improve the performance of the subgrade and other layers. The mechanism of separation and reinforcement are presented subsequently.

2.2 History of Geosynthetics

For several years various materials (like coir, jute, and hemp, etc.) have been mixed with soil in an attempt to improve its mechanical properties. In Roman days, such a technique was widely used to stabilize the pavement layers. These attempts were made using natural fibers, vegetation, etc. mixed with soil to improve road quality when roads were built on unstable/poor soil. The main problem with using natural materials in a buried environment is the biodegradation that occurs from micro-organisms in the soil. With the advent of polymers in the middle of the 20^{th} century, a much more stable material is available. The significant advantage of using geotextiles in any structure is to improve the performance, life of the structure and reduces the reflection cracking in asphalt overlays. While savings in material, reduction in labor cost and time, and reduces the reflection cracking in asphalt overlays.

2.2.1 Classification of Geosynthetics

Geosynthetics are broadly classified into five categories, as listed below:

- Geotextiles
- Geogrids
- Geonets
- Geomembranes and Geocomposites

2.2.2 Geotextiles

Geotextiles are continuous sheets of woven, non-woven, knitted or stitch-bonded fiber or yarns. The sheets are flexible and permeable and generally have the appearance of a fabric. Geotextiles are used for separation, filtration, drainage, reinforcement and erosion control applications. Most of the geotextiles available are manufactured from either polyester or polypropylene. Polypropylene is lighter than water (specific gravity of 0.9), strong and very durable. Polypropylene filaments and staple fibers are used in the manufacturing of woven yarns and non-woven geotextiles. High tenacity polyester fibers and yarns are also used in the manufacturing of geotextiles. There are two principal geotextile types, or structures: woven, and non-woven. Various types of geotextiles are shown in Figure 2.1

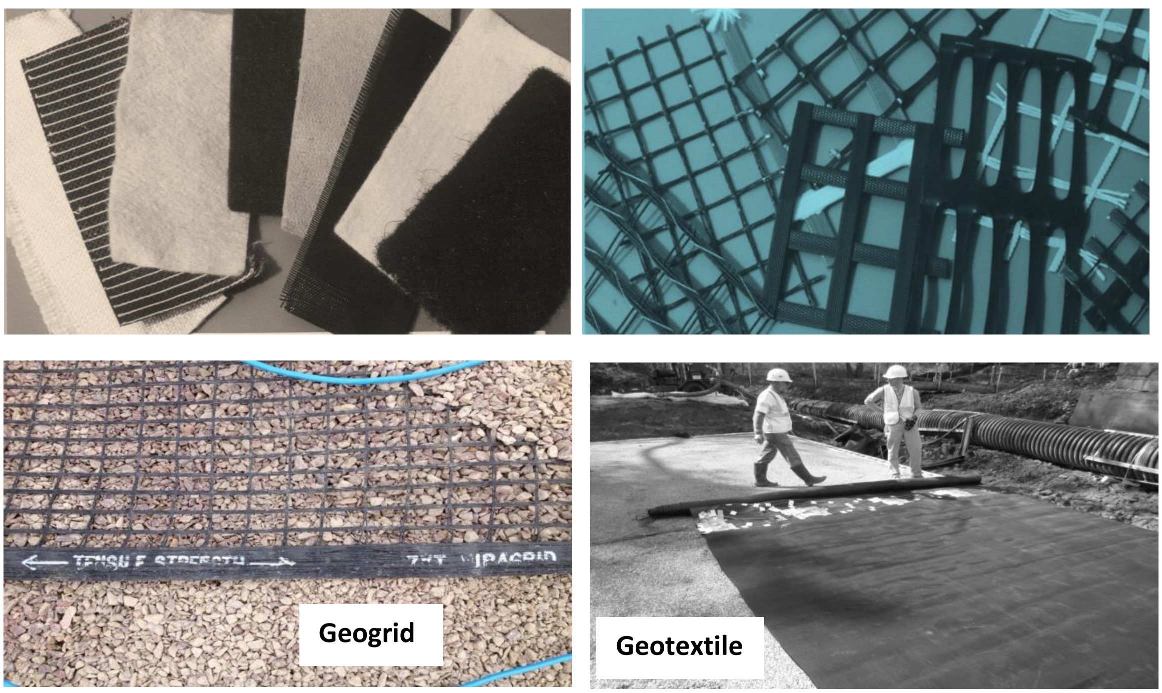


Figure 2.1 various types of geotextiles (Source: Zornberg et al. 2010)

2.2.3 Woven Geotextiles

Woven geotextiles are made from weaving monofilament, multifilament yarns. Weaving is a process of interlacing yarns to make a fabric. Slit film yarns can be further subdivided into flat tapes and fibrillated yarns. There are two steps in this process of making a woven geotextile: first, manufacture of the filaments or slitting the film to create yarns; and second, weaving the yarns to form the geotextile. Slit film fabrics are commonly used for sediment control, i.e. silt fence, and road stabilization applications but are poor choices for subsurface drainage and erosion control applications. Though the flat tape slit film yarns are quite stiff, they form a fabric that has relatively poor permeability.

2.2.4 Non-Woven Geotextiles

Non-woven geotextiles are manufactured from either staple fibers of length usually ranges 2.5 to 10 cm in length. The web then passes through a needle loom and another bonding machine interlocking the fibers/filaments. Non-woven geotextiles are highly desirable for subsurface drainage and erosion control applications as well as for road stabilization over wet moisture-sensitive soils. The non- woven geotextiles are further subdivided into various groups depending upon the method used.

2.2.5 Geogrids

Geogrids are single or multi-layer materials usually made from extruding and stretching high-density polyethylene or polypropylene or by weaving or knitting and coating high tenacity polyester yarns. The resulting grid structure possesses large openings that enhance interaction with the soil or aggregate. The principal application for geogrids is the reinforcement of soil. Geogrids are made from synthetic polymers, and the most widely used ones are polypropylene, high-density polythene, polyester and in some rare cases polyamide. Polypropylene is a polyolefin with the main characteristics of chemical resistance and low cost. Similarly, high-density polythene has the characteristics of chemical resistance, ultraviolet resistance, and excellent insulation properties.

High-density polyethylene /polypropylene grids are formed by punching small holes in a solid sheet of polymer and stretching the sheet in one or two directions causing holes of elongate to form grid apertures. Polyester geogrids consist of fibers that are knotted to form a well-defined grid pattern. High-density polythene/polypropylene geogrid and polyester fiber are stretched during their production. Both geogrids consists of longitudinal, transverse structural elements called ribs to effectively transfer loads. These fibers are stretched during their production, which causes the long molecular chains to realign in the direction of strain, thus giving the plastic much higher tensile strength. The various application of geosynthetics given in Table 2.1.

Table 2.1.Evolution of coir geotextiles in pavement applications

S.No	Application of Geotextiles in Pavements	Author and Year
1.	Woven cotton fabric was used as a separation function to stabilize the subgrade by mills and followed by a review of geotextile and its importance in pavement engineering by various researchers.	*Beckham and Mills (1935), Rankilor (1981), Jones (1982), Giroud (1986), Pilarczyk (2000), Holtz (2004), and Heerten (2015).*
2.	A patent was granted to British engineer namely. J. F. Hillen of Holland in 1968 for his works before 1964 (Koerner and Welsh, 1980)who demonstrated the use of high-strength woven geotextiles on soft saturated soils.	*H. J. F. Hillen of; Holland in 1968*
3.	One of the critical works was carried out by the US Federal Highway Administration, where the development of design and construction guidelines were developed for geotextile materials.	*Steward et al., 1977; Bell et al., 1975; Mohney, 1977; Steward et al., 1977; Bell and Steward, 1977).*
4.	In Europe, initially non-woven fabric was developed and used for the separation. Further, the woven geotextiles were used in Netherland for coastal protection works. Later, the manufacture of needle-punched nonwoven fabrics from continuous filaments was taken up.	*Koerner, R.M., Welsh, J.P., 1980; John et al. (1987); Giroud (1986)*
5.	Geotextiles can also be incorporated into granular base support layers to improve the long-term structural performance of pavement layers. The reinforcement mechanisms can potentially provide improvements as described initially and later for geotextile-reinforced unpaved roads.	*Bender and Barenberg (1978); Kinney and Barenberg (1982)*

6.	McGown, Professor at the University of Strathclyde was one of the earliest academicians who carried out works on geotextile testing and field implementation for unpaved roads in Scotland	*McGown and; Ozelton, 1973.*
7.	Application of non-woven geotextiles in unpaved roads, as a separation material and fabric, were used in the construction of walls and embankments. Similarly, in Canada, thick needle-punched nonwoven geotextiles have been used as filters/separators in railroad ballast. Table work on fabrics was done by various researchers to reinforce soft subgrade soils for highways in aspects of filtration and drainage.	*Kern, 1977; Puig et al., 1977; Raymond, 1982; Wandschneider (1986), (Wehr, 1986; Lieberenz and Piereder, 2013)*
8.	The study summarized that as a separator, all geotextiles could be used between a subgrade and granular base in paved and unpaved roads. A research report on pavement materials highlighted the demand for geotextiles in public and private sectors in various developed and developing countries for improvement in infrastructure using geotextiles.	*Kamal Uddin et al., 1998; Grandview Research, 2014.*
9.	Applications of geotextiles in pavements were presented as, between subgrade and stone base in unpaved roads and airfields, between subgrade and stone base in paved roads, etc. The study recommended that Geotextiles can be used effectively in drainage control. The best type of drainage geotextile is Nonwoven geotextiles and Geotextiles in conjunction with geonets and	*Koerner, 2012; Gourc et al., 1982; Koerner et al., 1984; Palmeira and Gardoni, 2002*

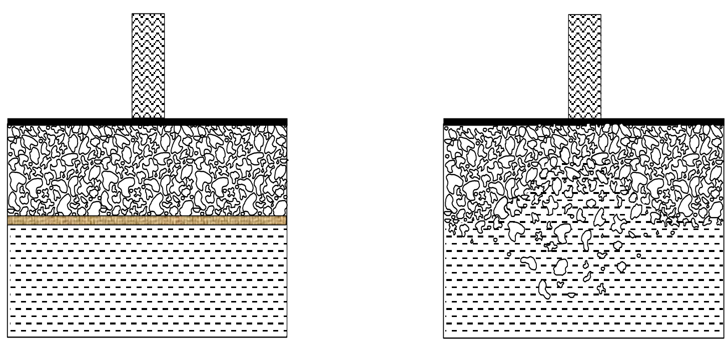
	geospacers.	
10.	Bender reported that the geotextile provides more even distribution of stress over the subgrade. Thompson explained the concepts of reinforcement of base layers in paved roads, on soft as well as firmer soil. They concluded the immense potential of geotextiles to reduce base course aggregate over weak subgrade soil at the interface. Later, Bender et al. developed an alternate method to evaluate the reinforcement mechanism in unpaved roads using the optimum depth method.	*Bender and Barenberg (1978), Thompson and Laad (1979); Haliburton and Baron (1983)*
11.	AASHTOallow the direct incorporation of geosynthetic reinforcement into the design Models In early 2000 for the Federal Highway	*AASHTO MEPDG-1, 2008.*
12.	They found that a composite of geogrid geotextile performed much better than geogrid by directly placing over the same nonwoven geotextile.	*Christopher and Schwartz (2010)*
13.	The authors extensively used geotextiles over four decades to construction the low-volume roads (unpaved) and improve their performance on weak subgrades. The study includes the function of geotextile (separation, reinforcement, and drainage) in the pavement layer. Authors describe the benefits of utilization of geotextiles in the laboratory and field study for unpaved low-volume roads that have been well documented in numerous case histories.	*Stewart et al., 1977; Bender and Al-Qadi et al., 1994; Austin and Coleman, 1993, Tsai, 1995; Fannin and Sigurdsson, 1996; Barenberg;1978; Haliburton and Barron, 1983; Christopher and Lacina, 2008; Cuelho and Perkins, 2009; Cuelho et al., 2014).*

2.3 Mechanism of Geotextiles in Pavement Application

The reinforcement and separation mechanism of the geotextile helps in dissipating the excess stress and strain obtained over the weak subgrade due to the traffic. The obtained stress is dissipated at the subgrade level by changing the direction of the crack, along with the underlying material from vertical to horizontal (White, 1991). Thicker geotextiles are used as stress-relieving material, which has a better absorption of stress than thinner material (Grzybowska et al.1996).

2.3.1 Separation function of Coir Geotextiles

Geotextiles are used to prevent road base materials from penetrating soft underlying soft subgrade soils and prevents fine-grained subgrade soils from being pumped into permeable granular road bases. Separation is the introduction of a flexible porous textile placed between dissimilar materials so that the integrity and functioning of both the materials can remain intact or be improved (Koerner 2012). The application of geotextile in pavements is mainly from considering the role of separation, reinforcement and drainage function. The phenomenon of separation function implies separating fine subgrade soil from the aggregates of the base course. It preserves the drainage and strength characteristics of the aggregate material. The effect of the separation mechanism is well presented by (Zornberg et al. 2011) is illustrated below in Fig 2.2.



(a) (b)

Figure 2.2 Separation function (a) with and (b) without geotextiles

For example, Fig 2.2 shows the weak subgrade and sub-base without the provision of coir geotextile mats. In this case, the sub-base material particles are penetrated the weak subgrade, which leads to higher stress over the weak subgrade. To reduce the stress over the subgrade, it consists of the diminishing thickness of the sub-base material. However, in another case, the incorporation of coir geotextiles will prevent the intermixing of subgrade soil with the material in sub-base layers. Geotextile fabrics with an appropriate porous structure form a barrier to control the migration of particles from one layer to another. As a filter, they allow fluids to flow through the fabric surface while preventing soil particles from transmitting liquid through the fabric. As separator, all geotextiles can be used between a subgrade and granular base in paved and unpaved roads and landing strips, between a subgrade and ballast in railroads, between drainage layers in poorly graded filter blankets, between old and new asphalt pavement layers, etc. (Uddin et al.1998).

2.3.2 Reinforcement function of Geotextiles

Geotextiles with fibers of suitable tensile moduli can effectively be used as reinforcing tension elements when embedded in compacted soils and aggregates. The concept of reinforcement is the synergistic improvement in the total system strength created by the introduction of a geotextile into the soil, as explained by (Koerner, 2012). Fig 2.3 explains the function of reinforcement with and without coir geotextiles. The concept of reinforcement of subgrade soil is similar to the reinforcement of the concrete with steel. The geotextile membrane affects a vital role in the reinforcement of the subgrade. Thus, the reinforcement function of the geotextile helps to construct roads over weak subgrade.

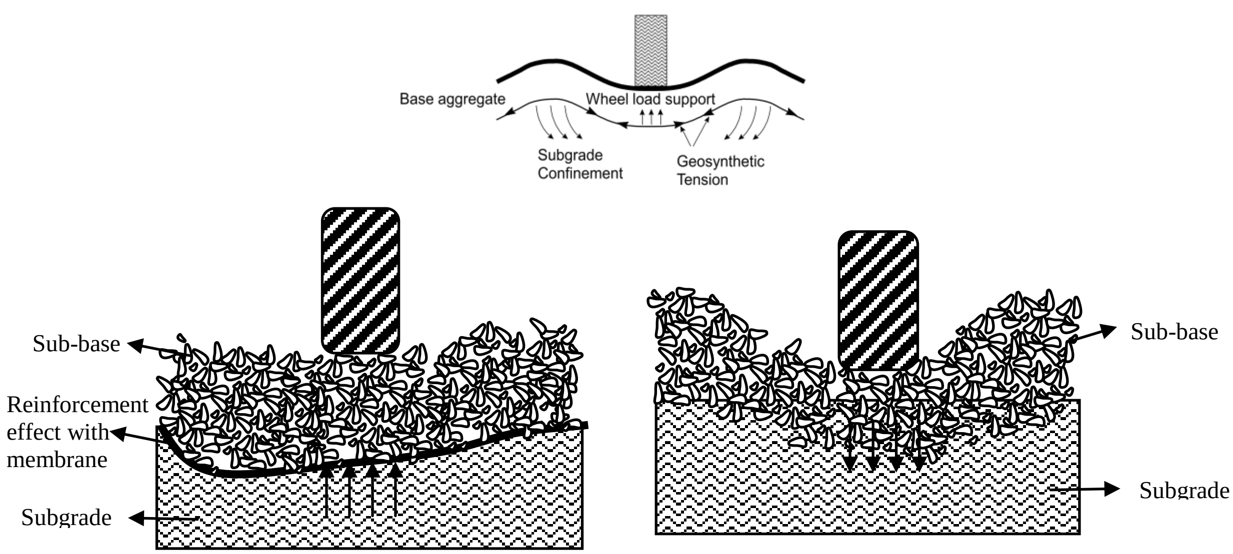


Figure 2.3 Lateral restraints through interfacial friction between geotextile and aggregate

Sayali et al. (2017) explained the mechanism of the geotextile in pavement construction. The study explains the reinforcement and separation mechanism using various types of geotextiles used in pavement construction. The study concluded that the separation function of the woven geotextile is better than that of non-woven geotextile due to the inappropriate opening size of the geotextile. Also, it is indicated that the permeable geotextile showed better drainage over weak subgrade soil. Zornberg(2017) examined the multiple applications of geotextiles functions in pavement applications, as presented below in Fig 2.4.

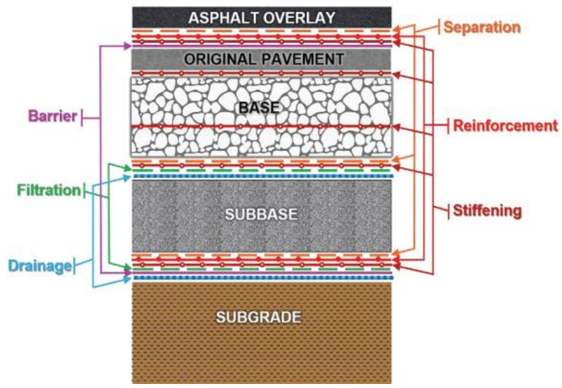


Figure 2.4 Multiple functions of geotextiles

Qurishee(2017) examined that the load of the reinforcement section over the weak subgrade is lower than the section without reinforcement. The salient feature of the study is that the geotextile materials could be successfully used as reinforcement, separation, filtration, and drainage function in the pavement placing at one-third position of the base layer. Geotextile and geogrid help in reducing the intermixing of two different materials and reduction in permanent deformation over subgrade. The study demonstrated that the provision of the geotextile helps in the reduction of the base course thickness from 20% to 40%. Fig 2.5 shows the relative load distribution character of the pavement with and without the reinforcement of geotextiles.

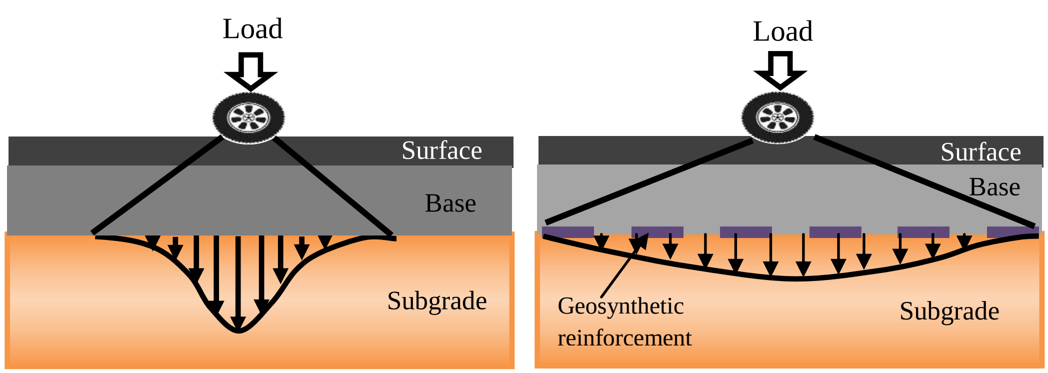


Figure 2.5 Relative Flexible pavement load distributions using Geosynthetics

2.4 Earlier Research Works on Geotextiles

Giroudand Noiray(1981) explained the benefits of geotextiles. The study revealed that the composite material such as geotextile and geogrid are performing better functions of separation and reinforcement in pavement engineering applications.

Satyanarayana et al. (1982) conducted a study to determine the strength and electrical resistivity properties of coir fibers. The volume resistivity of these fibers is noticed in the ranges of $1.3x10^5$ to $5.77x10^7$, this is due to the presence of cellulose (13%) and lignin (25%) contents in coir geotextiles material. Finally, the study recommended using the coir geotextile in pavement applications.

Koerner and Soong (1995) extensively discussed the use of geosynthetics in infrastructure development. They identified the five primary functions of geosynthetics:

- Separation
- Reinforcement
- Filtration
- Drainage, and barrier

Considering these primary functions, they have also presented several applications involving Geosynthetics in infrastructure remediation.

Perkins et al. (1997)used geosynthetics to reinforce the base course layers in flexible pavement sections to reduce the base course thickness and estimated the life-cycle cost analysis. This program involved the instrumentation of a full-scale pavement subjected to moving traffic loads. In order to examine the performance of the study, a pilot test section was constructed and monitored for approximately three months. The test section was constructed to establish a geosynthetic performance.

Zhao et al. (1997) conducted a field study over poor subgrade soil using multilayer geogrid. In this study, the geogrid was placed directly over the weak subgrade and compacted using the Caterpillar. It was noticed that the obtained stress is greatly reduced over the poor subgrade that improved the performance of the pavement structure. The multi-layer geogrid itself possess higher tensile strength and helps in the reduction of stress over the subgrade. The considered accelerated pavement test track details are shown in Table 2.2.

Table 2.2 Linear Aceelerated Pavement Test

Description of field test	Depth (m)	Width (m)	Length (m)
Dimension of APT	2.4	4.6	30

Loulizi et al. (1999) observed that the use of geosynthetics increased in the field of pavement construction and rehabilitation. Cancelli et al. (1999) demonstrated that the utilization of geosynthetics to reinforce flexible pavements. It has been documented that geosynthetics had extended (10-15yrs) of the durability of pavement service.

Famiyesin et al. (1998) focused on the numerical modeling aspects of cyclic loading on reinforced unbound pavements under plane-strain conditions. The study addressed non-linear material behavior of the aggregates, subgrade and pavement response to wheel loading. The study concluded that normal stresses under the geotextile are greatly reduced when compared with normal stresses in the aggregate. Cyclic loading has been accounted for the nonlinear behavior of pavement materials. The results indicated that advanced material models had been employed to explore the load-deformation response of reinforced unbound pavements. They suggest that the assumptions employed in some conventional design methods may be doubtful of their validity.

Kinney et al. (1998) discussed the benefits of using geogrids for base reinforcement to assess the rutting phenomenon in the field. The further test was chosen over a road stretch and divided it into three sections. The rutting of each section was measured along with the traffic load in two lanes; each of the lanes was subjected to different tyre pressures. The number of cycles required to reach a given level of rutting in one section divided by the number of cycles required in another section to reach the same level of rutting is defined as the Traffic Benefit Ratio (TBR). The TBR for reinforcement was between 2 and 10and TBR for tire pressure was 0.5 to 7. TBR varies depending on the type of geogrid and the thickness of the base course material. The decrease in rutting affected the thickness of the base course, and it may be due to lower tyre pressure to increase rutting. The decrease in rutting caused by reinforcement, therefore, is a function of the properties of the geogrid and the thickness of the base course.

Rao et al. (2000) pointed out that the degradation of coir depends on the medium of embedment and climatic conditions. It is also reported that it retains 80% of its tensile strength after six months of embankment in clay soil subgrade.

DeMerchant et al. (2002) examined in the laboratory with a plate load test to determine the effect of geogrid reinforcement on lightweight aggregate beds for subgrade modulus. The study also investigated the effects of loading settlement behavior of the aggregate considering several layers of geogrid, the width of the geogrid and its position. The study considered various parameters such as soil density, the width of soil reinforcement, the position of the geogrid layer, and the number of geogrid layers and the tensile strength of the geogrid. The study concluded that the reduction of stress and settlement of the pavement section is lower in the geogrid reinforcement section. It is noticed that the application of geosynthetics reduced stress and enhanced pavement performance.

Leng et al. (2002) investigated the characteristics of geogrid-reinforced aggregates over soft subgrade soil through a laboratory-testing program while considering the vertical deformation of the sample. They conducted nine cyclic plate load tests with varying base layer thickness and reinforcement type. The test sections were composed of Aggregate Base Course (ABC) and foundation soil with two different thicknesses of base course layer (152 mm and 254 mm) along with two types of geosynthetic reinforcement grades (BX1 and BX2). They concluded that reinforcement improved the deformation and stress aspects as reinforcement inclusion leads to decreased surface deformation, improved stress distribution being transferred to the subgrade and slow degradation of the ABC layer. The inclusion of geogrid improved the shear resistance at the interface because increased confinement reduces the lateral spread of the base course. The study concluded that ABC degraded under cyclic loading is manifested by an increase in wider of distribution stresses at the interface between ABC and the subgrade with an increasing number of cycles.

Gurung (2003**)** studied the tensile response of an unbound granular base layer in the laboratory using geosynthetics. Two types of geosynthetics were used: Namely G1 and G2 and geogrid. The G1 geotextile has the specification of thickness of 3.5mm, mass 310 $g/m^{2,}$ and tensile strength 25.2 kN/m. G2 geotextile has specification of 5.2mm , 500 g/m^2 , 40.1kN/m. The author developed a test set-up that consists of a test box, a motor and digital data logging components. Fig 2.6 shows the test box setup 300mm wide x 225mm deep x 600mm long, which is split across the middle, where the separation between two halves of the underlying support simulates subgrade crack. While the subgrade crack is opened at a constant rate of displacement, the transducers (load cells, LVDT) mounted on either side of the box recorded the displacements and forces. The use of geosynthetics increased the tensile strength of the unbound granular base layer. The tensile strength of the pavement reinforced with geogrid was higher than the pavement reinforced with geotextile. The high tensile strength of geogrid reinforcement to the pavement section has shown a significant influence on the behavior of the pavement surface under traffic loading and environmental consideration. The results are manifested using data acquisition (Labtech Notebook Version 7.1).

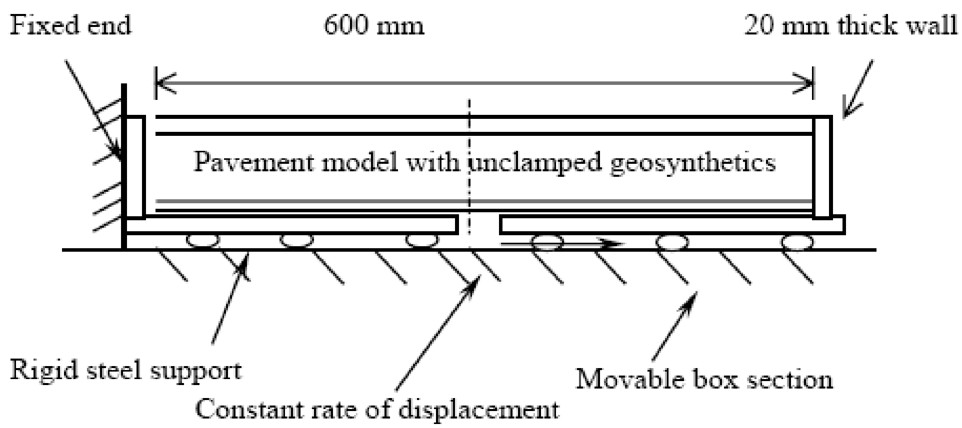


Figure 2.6 Longitudinal section of the pavement test box (Gurung, 2003).

Raymond et al. (2003) discussed the effect of geogrid reinforcement on unbound aggregates. In their study, optimal location and number of geogrid layers have not been considered. They considered two types of loading repeated and static loading. The aggregate layers are subjected to both repeated and static loading. A test tank was prepared in the laboratory of size 900mm long x 200 mm wide x 325mm deep. They observed that under repeated loading, the doubly reinforced deposit was found to be superior to a singly reinforced one in reducing settlement.

Rao et al. (2005) characterized the tensile strength behavior of four types of coir geotextile such as two woven, one non-woven and coir fiber specified coir yarns. Table 2.3 shows the tensile strength of the coir geotextile. The study concluded that the inclusion of the coir fiber increases the shear strength parameter of cohesionless soil. thus increased the performance of sand specimens. The study indicated that the mixture can be utilized in rural roads to enhance the strength of the subgrade.

Table 2.3 Tensile strength properties of woven coir geotextile

Coir geotextile	Mass per unit area (gsm)	Tensile strength (kN/m)
Type B	610	11.45
Type C	1335	31.5
Type D	750	2.76

Aran (2006) evaluated the performance of pavements on-base reinforcement with biaxial geogrid. They considered five test sections of which three sections were reinforced with the geogrids base at different depths of the base layer while the other two sections were kept as control sections with no reinforcement. The use of geogrids led to a reduction in pavement thickness. Field evaluations were performed on the test control sections and determined the effectiveness of geogrid applications with several pavement cracks, rutting, and deflections. The tests consisted of deflection measurements, rut measurements and crack surveys. It was found that short-term evaluations of pavement performance for the test and control sections were almost the same. The pavement sections and subgrades at both test site locations were stiff and appeared to have a significant effect on the pavement performance. The thinner test sections reinforced with geogrid provided a comparable level of pavement performance to the control sections. Further long-term evaluations were performed to determine the performance of the pavements. Fig 2.7 shows the typical cross-section of a two-layer subgrade reinforced with geosynthetic material.

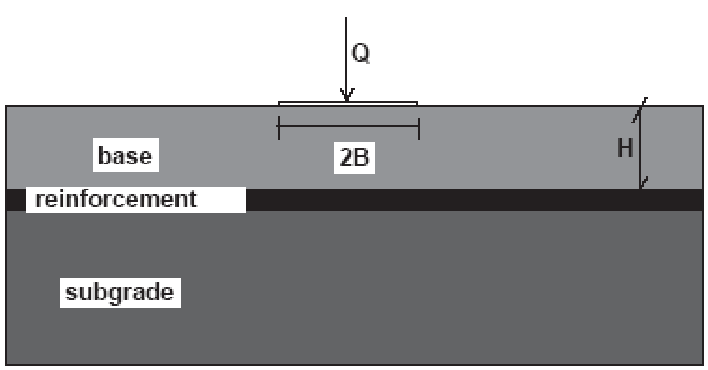


Figure 2.7 Typical cross-section of two-layer subgrade reinforced with geosynthetics

Raji et al. (2011) conducted a study using fly ash and coir geotextile over weak subgrade. The study aims to enhance the properties of the weak subgrade Block Cotton soil (BC). The salient observations from the study were that California Bearing Ratio(CBR) of reinforced soil with geotextile increased up to 12% and it stabilized with 5% fly ash, and 2.5% cement, soil reinforced with geotextile was found to be performing better. The maximum observed rut depth in reinforced soil with geotextile at 1000 number of repetitions was 10.6mm. The inclusion of coir geotextile improved the CBR value and the addition of fly ash reduced the swelling of the BC soil.

Tingle et al. (2007) discussed the empirical design methods for geosynthetic reinforced low volume roads. They considered two types of geosynthetics, such as geotextiles and geogrids. For many years, geosynthetic materials are used to improve the quality of low-volume roads to reduce the amount of aggregate required or to extend the service life of the pavement. This study discusses the use of geotextiles and geogrids in unpaved roads when compared to conventional design approaches, and discusses the advantages and limitations of current design methods, and seek directions for future research efforts to improve the implementation of geosynthetic technologies. Design methods are compared by performing designs with different methods for a variety of site conditions. They concluded that the laboratory and field experiments had improved the performance of geosynthetic-reinforced unpaved roads in terms of reduced aggregate requirements and increased traffic service life. In terms of material costs alone, geotextile is generally preferred for CBR of subgrade soil less than 2. Consideration of additional factors including hauling costs, installation costs, construction labor costs, road maintenance costs, and user costs are required to obtain real cost-benefit analysis to determine the suitability of a project for geosynthetic inclusions.

Babu et al. (2007) studied the strength, swelling, and compressibility of clay soil using the tri-axial shear tests with the provision of coir geotextile. The focus of this study is on the mechanism of strength development of BC soil with the incorporation of coir geotextile. The study concluded that the deviator stress failure increases as fiber content increases and deviator stress increases with an increase in diameter. The provision of the coir geotextile helped in controlling swelling and increasing the compressive strength of black cotton soil.

Mwasha et al. (2009) examined the service life of the pavement by replacing naturally available geotextile material with polymeric geotextile. The study aims to improve subgrade soil properties. One of the critical outcomes of this study is that they developed specifications for the standardization of geotextile fiber material for soil reinforcement. Further, the study suggested that the use of coir geotextile in pavements provided additional strength and extended the service life of the pavement.

Subaida et al. (2009) evaluated the performance of unpaved roads reinforced with woven coir geotextiles in the laboratory. It is noticed that the primary function of the woven coir geotextile serves as reinforcement material. Fig 2.8 shows coir geotextiles used in the study along with two types of woven coir geotextiles used (MMA2 and MMA3). The following variables were considered:

- Geotextile type (MMA2 and MMA3),
- Geotextile placement position in the base layer (mid-depth of the base course, and base course – subgrade interface),
- Base course thickness (167 mm and 267 mm to represent thin and thick pavement sections of 250 mm and 400 mm respectively, using a scale factor of 2/3).

From the study, considerable improvement in bearing capacity was observed when coir geotextiles were placed within the base course at all levels of deformations. The plastic surface deformation under repeated loading was greatly reduced by the inclusion of coir geotextiles within the base course irrespective of the base course thickness.

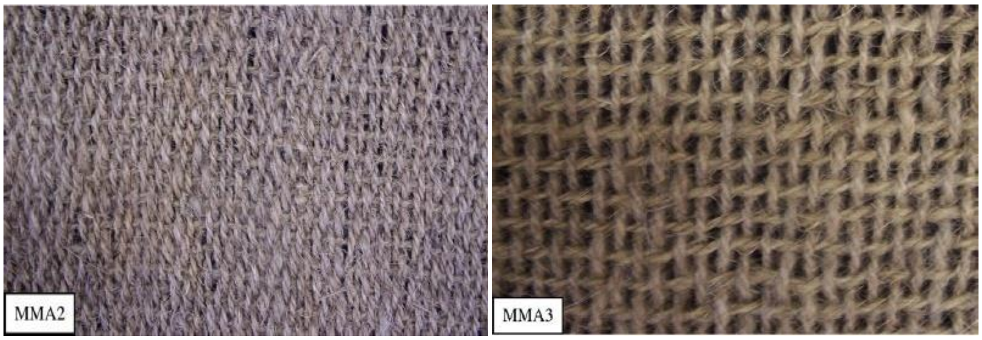


Figure 2.8 View of woven geotextiles (Subaida et al., 2009)

Kwon et al. (2009) analyze the geogrid base reinforced flexible pavements using the full-scall pavement section and developed a mechanistic response model at the University of Illinois. The test section divided into three categories based on the aggregate base course thickness ranging from 20.3 to 45.7 cm. The entire test section surface was spread with Hot-Asphalt Mix (HMA) of the thickness of 7.6 cm. The model thus developed was used in the Finite Element Method (FEM) of nonlinear and stress-dependent behavior of pavement foundation geo-materials, in unbound aggregates, fine-grained soils and anisotropic behavior of the granular base layer.

Binduet al. (2011) evaluated the shear strength and compressibility of clay soil in the laboratory using the coir geotextile. The stress and strain of marine clay with and without coir geotextile were determined in the present study. The study concludes that the provisions of coir geotextile significantly increase the shear strength and reduce the compressibility of the pavement layer. It is evident he incorporation of coir geotextile enhances the weak subgrade and improve the serviceability of the pavement.

Kumar et al. (2012) studied the performance of woven and nonwoven geotextile as an interface between the soft subgrade and unbound gravel in unpaved roads. The results of the study showed that the reinforcement ratio increases with an increase in penetration. It was noticed that the reinforcement section showed better performance on the pavement. Moreover, it concluded that the inclusion of geotextile offers excellent resistance, even at lower penetration. Also, Prashanthet al. (2012) experimented and recommended that the coir may be used as a filtration material in the construction of pavements, highways, and railways.

Manickam et al. (2011) listed the advantages of natural materials such as rice husk, jute sticks, cotton stalks, banana, and coir materials. In order to reduce the loose disposal, the study was carried out to make use of natural material in various filed of application. The investigation was carried out to determine the relax density under varying pressure and moisture content. From the study, it is evident that the coir geotextile can be briquette effectively at a pressure of 258.14 bar and the moisture content of 18%.

Artidteang et al. (2012) examined the performance of plain, knot-plain, and hexagonal patterns using the following tests such as tensile strength tests, direct shear tests, and pullout tests. The results of the study indicated that plain patterns are the most appropriate pattern for soil reinforcement application.

Kuriakose et al. (2012) studied the mechanical behavior of coir geotextile fiber. The study was carried out with reinforcement and without the reinforcement of non-woven and treated composites coir geotextile material. The study reported that treated coir fiber increases the tensile strength compared to polyester and untreated woven coir composites. The study concluded that the treated coir fiber enhances life and provides new life to the pavement.

Jairaj et al. (2013) conducted a study to evaluate BC soil characteristics with the reinforcement of coir geotextile using undrained triaxial test. The test was performed in the laboratory using coir geotextile as reinforcement material in the form of prototype models on a square footing supported on highly compressible clayey soil. It was observed that the reinforcement model with coir geotextile witnessed an increase in compressive strength and the shear strength of BCsoil. It was revealed that the increase in the length of coir fiber increases cohesion and angle of internal friction. The study concluded that the provision of the coir reinforced layer significantly increases the bearing capacity of clay soil and the ultimate bearing capacity of the reinforced section showed better performance without geotextile material.

Singh et al. (2013) investigated the influence of coir fiber on shear strength parameters and stiffness modules of fly ash. The test sample was compacted and prepared at Maximum Dry Density (MDD)and Optimum Moisture Content (OMC) with and without randomly distributed coir fiber. It was noticed that the preparation of identical samples of coir fiber reinforced fly ash beyond 1% of fiber content was not possible, and optimum fiber content is mentioned as 1% and the value of stiffness modulus and shear strength parameter of fly ash increase with an increase in fiber content, and maximum values are obtained at optimum fiber content of 1%. The study concluded that the optimum percentages of the coir geotextile are more effective to improve the CBR and the confinement of the poor subgrade soil.

Meshram et al.(2013)demonstrated the type of coir geotextile along with their properties, function, and application for the construction of flexible pavements. The study describes the properties of the geotextile for road construction. The author stated that in India, around 30% of the roads are constructed overboil, and the problem with BC soil is low shear strength, low compressibility, and low swell-shrink. To address the problem of BC soil subgrade, coir geotextile can be used effectively because of its active functions of separation and reinforcement. It also provides an effective inter-layer between the subgrade and base-course layers of the pavement while improving the confinement.

Sapuan et al. (2005) determined the tensile and flexural strengths of coconut fiber reinforced epoxy composites material. The objective of this study was to assess the suitability of natural material in the pavements and the replacement of polymeric geotextiles. The authors addressed the development of new material in engineering applications, as well as the treatment of coir fiber to improve the interfacial bonding between soil-fiber composite. The study concluded that the inclusion of coir geotextile improved the strength of the weak subgrade and extended the performance of the pavements.

Maurya et al. (2015) summarised the benefits, properties, and application of coir geotextiles through scientific data. The author indicated that the utilization of coir geotextile enhances the strength of all types of soil and also improves the stiffness of the material. Also, it was suggested that the types of coir geotextile and its length affect the strength of weak soil material in geotechnical and in pavement constructions.

Singh and Mittal (2014) conducted a laboratory study to determine the soil properties with natural fiber. The test is performed using CBR and UCS with and without the reinforcement of coir geotextile. The stabilization effects are studied in soaked and unsoaked conditions. The study indicated that the coir is naturally available materials that could be used in the sub-base for flexible and rigid pavement. The test results are significantly improved the CBR and UCS values with soil with an increasing percentage of the coir (0.25, 0.5, 0.75, 1 and 1.25) fiber. It is concluded the 1% of coir fiber is the optimum percentage of soaked CBR value.

Adams et al. (2016)made a laboratory study to investigate the effect of reinforcement with one and two layers and quantified the effects in terms of CBR values. It has been observed that multi-layer geogrid shows better strength over single layer reinforcement. The study concluded that suitable placement of coir geotextile as a single-layer might be sufficient in the same situation rather than the multi-layer geogrid. Also, Zornberg (2017) explained the function and application of geosynthetics in pavement engineering. Annu et al. (2018) investigated the effect of separation function using geotextile over the expansive soil subgrade. The study indicated that geotextile is a powerful and economical method of fixing the expansive soil in pavement engineering.

Houlsby et al. (1990) reported that the use of geosynthetics in pavement construction increases the bearing capacity factor of subgrade soil for better performance of roads in order to reduce the settlement characteristic of subgrade soil. This study describes the universal factors in enhancing the subgrade capacity.

Zhao et al. (1997)conducted a field performance study over the weak subgrade soil using multilayer geogrid. The multi-layer geogrid reinforcement enhances the weak subgrade to withstand traffic loading. This is obtained due to the tensile strength of multi-layer geogrid. It is also noticed that the multi-layer geogrid adds strength to the weak subgrade. In this study, the geogrid was placed directly over the weak subgrade; the stress of the pavement is reduced at the subgrade level and improves the performance of the pavement structure.

Leng (2002) investigated the behavior of geogrid between the subgrade and baselayer in unpaved roads. The provision of Geosynthetics reinforcement reduced the stress and strain distribution transferred to the subgrade. This study indicated that Geosynthetics reduces the degradation of the base layer and deformation, and improves the performance of unpaved roads.

Yang and al-Qadi et al. (2007) described the use of natural geotextile as an alternate and cost-effective material in pavements. The study aimed to improve the secondary flexible pavement roads through initial construction, rehabilitation, prevention of accidents, and limiting fuel consumption. The author developed a design method to evaluate the cost-benefits provided by geotextiles. Ashwani et al. (2006) conducted a test to study the performance of locally available material and the impact they exercised on pavement thickness. The study concluded that locally available materials were effectively utilized for the construction of LVR’s.

Brandon et al. (1996) carried out a study to evaluate the geo-grid and geotextile in pavement construction. It was noticed that geosynthetic stabilization of the pavement section significantly increases the pavement life and reduces the rutting of the pavement compared with an un-reinforced section of the pavement. The study concluded that geosynthetic stabilization of the pavement section significantly increases the pavement resistance while also reducing the rutting of pavement as compared with the un-reinforced section of the pavement section.

Al-Qadi et al. (2008) described the performance of the geogrid and reported that geogrid is very useful in reducing the horizontal shear deformation at the optimum placement location within the aggregate layers.

Virgili et al. (2009) focused on a better understanding of the influence of geosynthetic reinforcement materials. The study was carried out with three different types of geosynthetics reinforcement system. The author reported that geosynthetics are utilized successfully in asphalt pavement, which is used to enhance tensile resistance. Further, it was reported that geosynthetics are effective in reducing the local tensile stress concentration while helping to prevent pre-mature failures of the pavement.

Khodaii et al. (2009)measured the effect of geosynthetics in retarding the reflection cracking and to increase the service life of the pavements. The study indicated that reflection cracking propagation reduction depends on the position of materials. It also revealed that placing geosynthetics at a distance1/3rdfrom the bottom of the pavement increased the stiffness of old pavements.

Zamora and Barraza et al. (2010) focused on the durability characteristic of geosynthetics in a semi interlayer zone. The study was conducted with a dynamics test that simulated the passing of traffic load on the road surface. It is observed that Stresswasapplied between two layers of the reinforcement section with an anti-reflecting cracking system. The results of the investigation showed high resistance to repeated loading cycles with the reinforcement section. It was revealed that high stiffness modulus showed better performance. The study concludes that the inclusion of the geogrid system reduced the cracks and withstood between three and six times more cycles than other geosynthetics materials. Palmeira et al. (2010) evaluated the effectiveness of geosynthetic reinforcement over weak subgrade soil under the cyclic loading condition. The rut depth of the cyclic loading was fixed at each stage as 25mm. This study described the reinforcement section of the pavement with more cyclic loading compared to the un-reinforced section. The reinforced section was reducing the stress and strain at the subgrade level, controlling the settlement of the pavement and preventing the permanent cracks of the pavement.

Qian and Han et al. (2011) quantified the performance pavement with geosynthetics at the interface of base and subgrade under cyclic loading. The main aim of the study was to address pavement deformation and vertical stress over the subgrade. It was evidenced that with the inclusion of geosynthetics at the interface, pavement layers showed a reduction in pavement deformation and vertical stress in the subgrade, respectively. The study concluded that there was a reduction in the permanent deformation and vertical stress between the base and sub-base, while it improved the performance of the base over weak subgrade.

Dutta et al. (2012) conducted an experimental study with and without treated coir geotextile using unconfined compressive test. The coir fiber content varied from 0.4 to 1.6%. The experimental work indicated that compressive strength was higher with carbon tetrachloride treatment and bore higher strains at failure compared to clay. Better performance was registered with treated coir fiber when compared to dry fiber. The use of coir fiber in soil provides reinforcement; in addition to this, the use of coir geotextile addresses environmental concerns positively.

Jersey et al. (2012) evaluated the performance of the pavement in the form of reinforced and un-reinforced sections. The rut depth of this section is measured at various traffic levels. It is noticed that rutting occurs more in the unreinforced pavement section as compared to reinforced pavements. Initial stiffness was low, but after a noticeable drop, stiffness in the pavement, geosynthetic reinforcement reduced the rutting. The Traffic benefit ratio indicates that extension of the service life of the pavement with reinforcement of the geosynthetics.

Hejazi et al. (2012) demonstrated the function and application of geosynthetics to enhance the engineering characteristics of the soil. The author addressed the benefits of the reinforcement section with geosynthetics. It is concluded that the reinforced section of the pavement extended the service life and performance of the pavement. It also describes the application of geosynthetics on pavements with a different function.

Deepak et al. (2013) reported that during the last few decades; research had been conducted on various aspects of low volume roads resulting in innovative and unconventional approaches to road construction using various innovative materials. Among this material, Coir waste is a by-product available after extracting fiber from the coconut husks. Being dumped in bulk, it causes environmental hazards and another menace. This investigation assessed the usefulness of coir waste as an admixture in fly ash; especially for the construction of LVR’s.

Biren et al. (2013) studied the mechanical properties of red mud filled with coir fiber, reinforced polymer composites at the various stages with red mud as filler material. They found better tensile strength at 20% of red mud. The flexural strength of coir polyester composites increased up to a specific limit and then decreased. It also noticed that density was increased by increasing the percentage of red mud content due to the metal content of red mud.

Mitra (2013) explained the advantages of geotextiles and their properties. It was found that geotextiles material is permeable textile materials. This is commonly used in civil engineering and geotechnical applications like erosion control, soil stabilization, reinforcement, separation, and drainage. The study concludes that the use of the geotextile in pavement application enhances the poor subgrade in the form of separation and reinforcement function.

Adams et al. (2014) studied the performance of the LVR's to reinforcement with geogrid materials and established their effectiveness for low volume roads. The study indicates that the use of geosynthetics in the pavement over poor subgrade soil tends to reduce sub-base thickness with increasing traffic volume. The study was recommended for the placement position of geogrid at the top of the sub-base layer as itis more useful to enhance the performance of pavements.

Bongardeet al. (2014) described the importance, application, and advantage of naturally available biodegradable material along with their properties and their classification. These materials are readily available, cheap, renewable, biodegradable and eco-friendly. Mali et al. (2014) conducted a laboratory study to understand the behavior of cohesive soils reinforced with coir fibers, polypropylene fibers and scrap tire rubber fiber using triaxial, direct shear, and unconfined compression tests.

Maurya et al. (2015) summarised the benefits, properties, and application of coir geotextiles through the scientific data. The author indicated that the utilization of coir geotextile enhances the strength of all types of soil and also improves the stiffness of the material. The study indicates that the types of coir geotextile and its length affect the strength of the weak soil material in geotechnical and pavement aspects. Also, Adams et al. (2016) attempted to study the effect of reinforcement with one layer, and two layers and strength were measured in terms of CBR values. It was observed that the multi-layer geogrid shown a better strength over the single-layer reinforced. Annu et al. (2018) explained the separation function and the utilization of the geotextile over the expansive soil subgrade.

Sireesha et al. (2018) evaluated the compressibility characteristics of clay using synthetic fiber in the laboratory. The study was conducted with adding of varying percentages of the fiber from 0.5 to 2 with 6mm and 12mm length. It is observed that the 12mm length of fiber is better in interaction with clay. The study concluded that the adding of 6mm and 12mm length of fiber increase shearing resistance as 31 % and 51 % at 1.5 percentages of synthetic fiber. The study indicates that the incorporation of fiber-enhanced clay soil properties and improved the performance of pavements. Han et al. (2019) discussed the application of geosynthetics in transportation engineering. Cardile et al. (2019) studied the soil-geosynthetics interface behavior under cyclic load test. The author noticed that the decreasing of the interface parameter was studied using the pullout mechanism of the soil-geogrid. The study concluded that the cyclic loading passes increased with decreasing the vertical stress under the pull-out cyclic loading test. The study indicates that the inclusion of geogrid helped in the reduction of stress and improved the cyclic loading passes. The following Table 2.4 shows the comparative studies between the coir geotextile and jute geotextile.

Table 2.4 shows the comparative studies between the geotextile

S.No	Types of geotextile	Reinforcement /separation function	Earlier studies
1	Coir geotextile	Studied the performance and the long term durability of the coir geotextile while considering the reinforcement and separation function of the coir geotextile in LVRs.	Beena (2016), Agarwal et al. (2016), Rajagopal and Veeraragavan (2015).
2	Jute geotextile	The performance evaluation of the jute geotextile was carried out while constructing the field trial test. The study considered the reinforcement parameter of the jute geotextile while other studies separation functions of the jute geotextile.	Khan et al. (2014), Ghosh (2015), Annu and Verma (2018).

2.5 Summary of Literature Review

Based on the comprehensive literature review, the following summary is presented.

- Composite materials such as geotextile and geogrid are performing better functions in the form of separation and reinforcement in pavement engineering applications.
- Woven and non-woven coir geotextile is extensively used as separation and reinforcement material in pavement application. The non-woven coir geotextile had a better separation function to prevent the intermixing of material.
- Better reductions of stresses are found with geotextile material over the weak subgrade and found as lower settlements of the pavement structure.
- Even though some benefits have been reported by using woven coir geotextiles as reinforcement treated as limited life geotextile.
- Research is a focus on the development of new and suitable material for engineering applications in pavement according to the requirement.
- Coir geotextiles used as a cost-effective method to enhance the weak subgrade and improve the performance of the pavement, and also it extends the service life of the pavement.

2.6 Research Gaps

Based on the comprehensive literature review, the following research gaps are observed.

- Several studies were conducted in the laboratory using polymeric geotextile, and few studies were available with natural geotextile as separation and reinforcement material.
- The studies were not available with a combination of coir geotextile and geogrid in pavement applications to address the reinforcement and separation function.
- A few studies were conducted in the field using polymeric geotextile and limited studies with natural geotextile.
- Laboratory studies proved that h/3 position of mats is more significant than h/2 and h/4 position with specific mould. Studies focused on the use of coir geotextile as separation material only.
- A combination of laboratory and in-situ studies with different types of naturally available geotextile along with various types of sub-base layer material was not available or not recorded in the literature.

- The present study was planned in such a way to evaluate the performance and potential benefits of coir geotextile mats under the repeated loading condition in the laboratory as well as in the field. The reinforcement function of the material is considered an important parameter during the study.

2.7 Summary

This chapter summarises the history and mechanism of geotextiles in pavements. Further, it also dealt with various laboratory and field studies conducted by various researchers and identified gaps presented the gaps in the literature.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 General

In the current chapter, a detailed methodology adopted is discussed. The study was carried out in three stages. The first stage of the methodology deals with determining the basic properties of the material and evaluation of coir geotextile using the Wheel Tracking Test (WTT). The second stage of the methodology involves the in-situ test track using Accelerated Pavement Testing (APT). The third stage of the methodology is to design the flexible pavement using coir geotextiles.

3.2 Study Approach

Coir geotextiles

Four types of coir geotextile materials namelyCoir Composite (CC), a combination of Geogrid (GG), Non-Woven Coir Mat (NWCM), Woven Coir Mat (WCM), and Non-woven Coir Mat (NWCM) were used. These materials were used as an interface between the subgrade and the sub-base layer.

Figure 3.1 Fabricated moulds used in the study

Figure 3.2 BC Soil as subgrade

With the help of fabricated mould as shown above in Fig 1, a two-layer pavement model system was prepared, one using reinforcement section with coir geotextile mats and the other without, in the laboratory. The model pavement sections are tested in the laboratory for deformation (Rutting) characteristics using a WTT setup **(**Reddy and Moorthy 2005). The second stage of methodology was adopted in the field using APT study. Based on the laboratory evaluation, in-situ test track studies were planned using APT track Finally, the design of flexible pavement using the coir geotextile is worked out.

3.3 Research methodology

Figure 3.3 depicts the step by step procedure adopted in the present study.

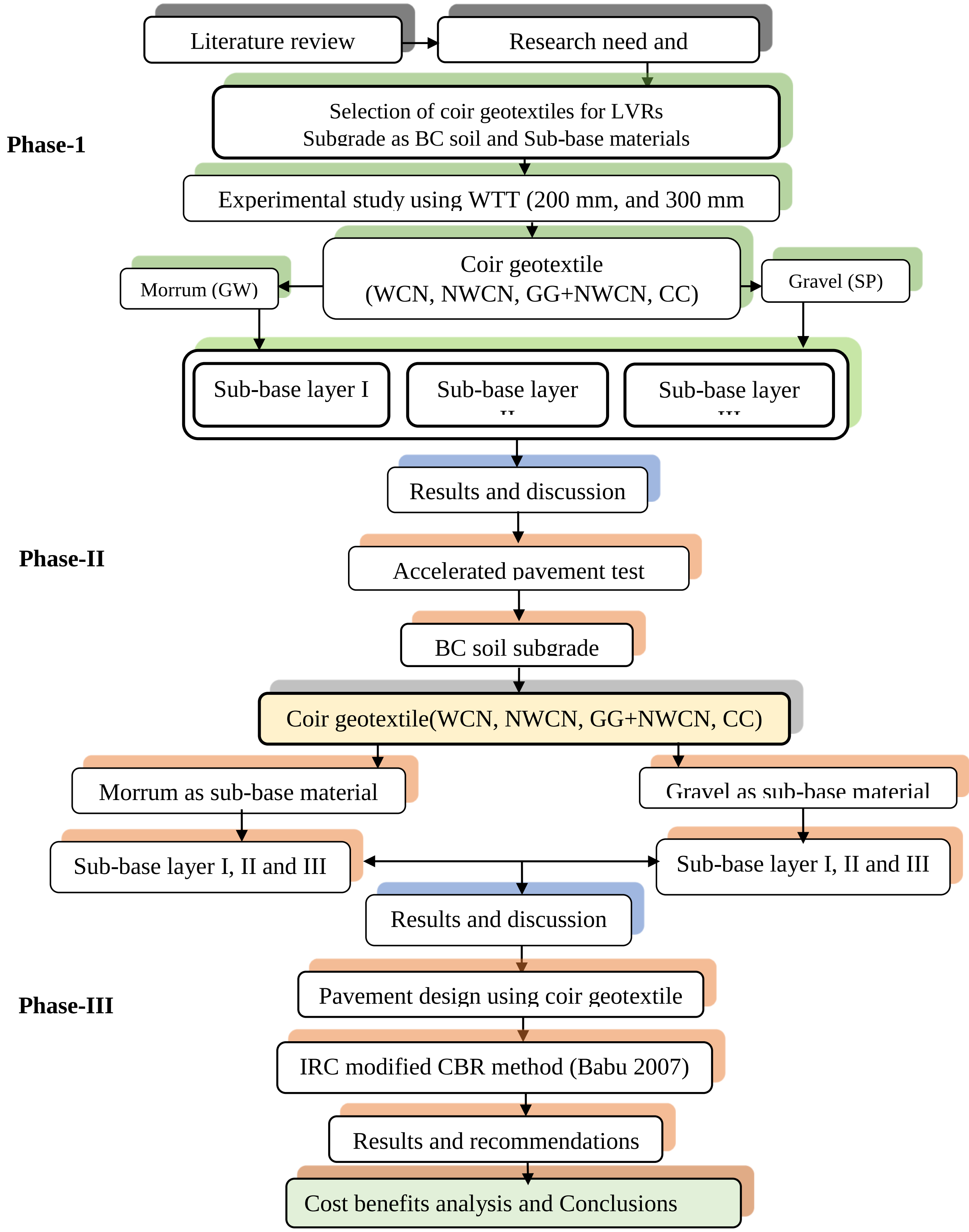


Figure 3.3Adopted research methodology

3.3.1 Stage-I: Laboratory Study using WTT

In stage–I, the adopted methodology consists of an extensive literature review on coir geotextile. The application and function of geotextile along with their mechanism in pavement engineering is described. Based on that, the gaps in the literature were identified, and the objective of the present investigation was formulated. To determine the stated objective of the present study, the material was selected. In this study, four types of coir geotextile have been used such asWCM (woven coir geotextile mats), NWCM (Non-woven coir geotextile mats), CC (coir composite mats) and the combination of GG+NWCM (Geogrid + Non-woven coir geotextile mats). Also, two-types of sub-base material such as gravel, morrum, and subgrade as Black Cotton (BC) soil are chosen to perform the laboratory as well as a field study. The basic engineering properties of the material were determined in the laboratory as per Indian Standard (IS) methods.

The experimental study was carried out to determine the effectiveness and potential benefits of the various coir geotextile with fabricated mould. A detailed laboratory study was carried out with two types of fabricated mould of specifications 300mmx300mmx200mm and 300mmx300mmx300mm. The fabricated mould sample with the experimental setup is shown in Fig 3.4.

Figure 3.4 Experimental setup with fabricated mould

The coir geotextile was placed as an interface between the subgrade and sub-base layer over the problematic subgrade (CBR< 2). The subgrade and sub-base, along with the coir mats, are incorporated in the mould in order to maintain the similar thickness of the subgrade and sub-base. In this, (sub-base layer I) the subgrade and the sub-base are maintained at 100mm thickness from the top of the mould. The coir geotextile is placed over the subgrade along with the two types of sub-base layer material, as shown in Fig 3.5. The study aimed to reduce the sub-base thickness by incorporating the coir geotextile in the mould so that the subgrade thickness is increased up to 133.3 mm due to the practical constraints and limitations of the instrument. In this case, the sub-base was provided as 66.6 mm with two types of sub-base material, and it is shown in Fig 3.6. Similarly, the placement of coir geotextile mats at the sub-base layer III are shown in Fig 3.7. The performance data of the materials is obtained using the data acquisition system, and the data were analysed in a detailed manner.

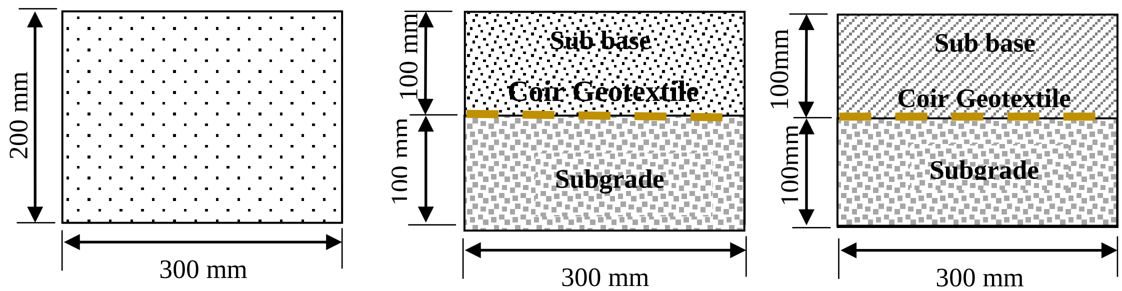


Figure 3.5 Inclusion of coir geotextile at sub-base layer I with 200mm thickness mould

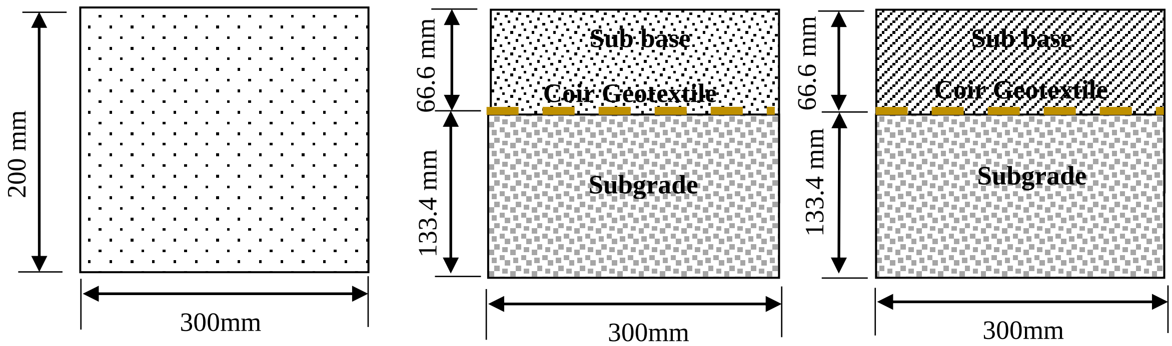


Figure 3.6Inclusion of coir geotextile at sub-base layer II with200mm thickness mould

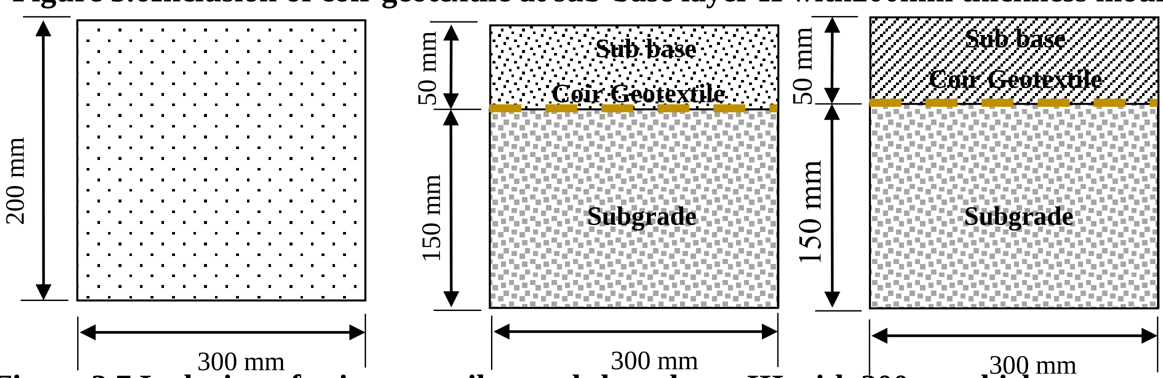


Figure 3.7 Inclusion of coir geotextile at sub-base layer III with 200mm thickness mould

Simultaneously, maintaining the constant subgrade and sub-base layer thickness, the coir geotextiles are provided in the fabricated mould in 300mm x 300mm x 300mm. The incorporation of the coir geotextile mats in the 300mm thickness of the fabricated mould at a subgrade thickness of 150mm and subbase thickness of 150mmis shown in Fig 3.8. The position of the coir geotextile mats was raised up to 200mm thickness of subgrade and sub-base thickness is kept as 100mm with two types of soil, as shown in Fig 3.9. Providing the coir mats at 225mm thickness with 75mm of the sub-base layer is shown in Fig 3.10.

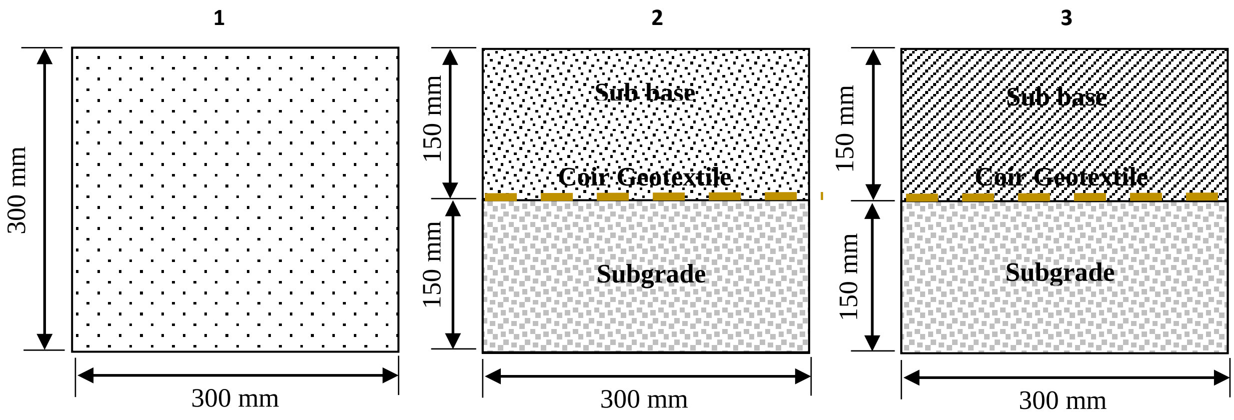


Figure 3.8Inclusion of coir geotextile at sub-base layer I with300mm thickness

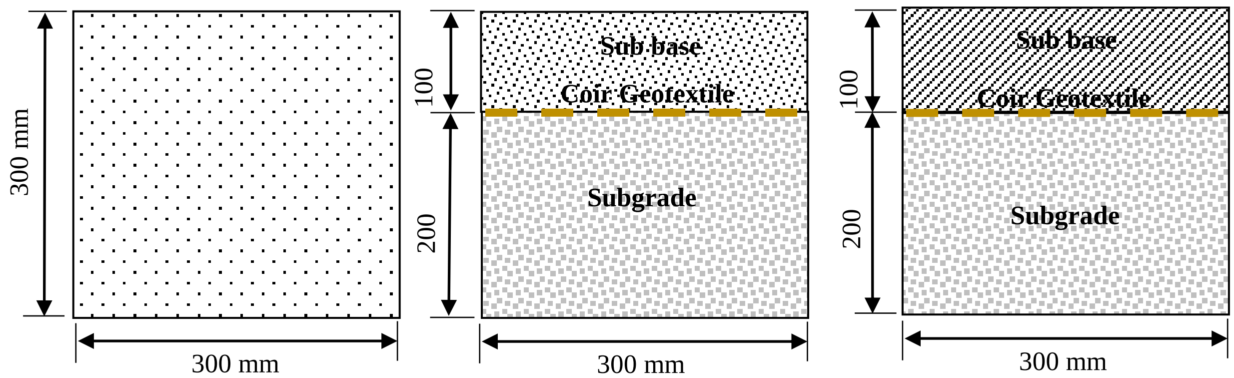


Figure 3.9Inclusion of coir geotextile at sub-base layer II with 300mm thickness

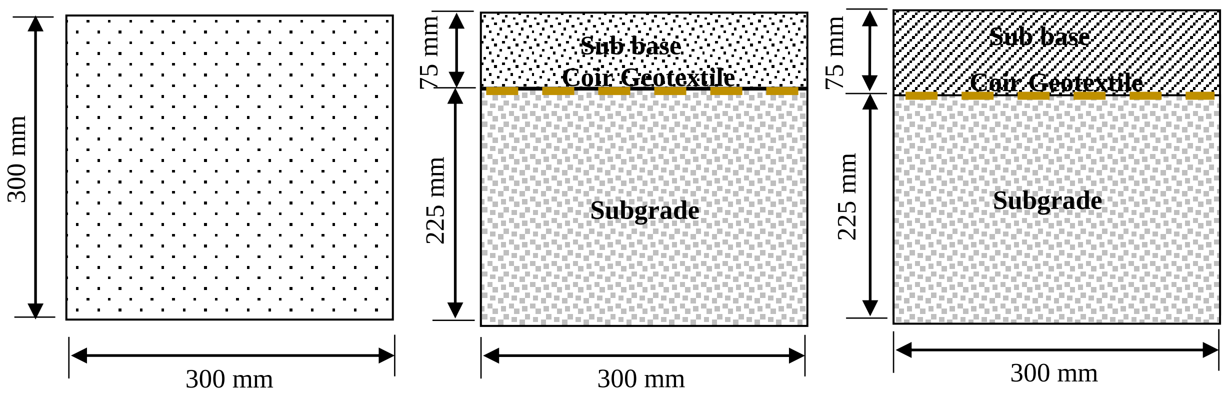


Figure 3.10 Inclusion of Coir geotextile at sub-base layer IIIwith 300mm thickness

3.3.2 Stage-II: In-Situ Test Tack Studies

The test track was conducted to determine the effectiveness and potential benefits of the coir geotextile mats. The study was carried out to evaluate the realistic pavement condition. The test track was planned according to the single-lane road, and a circular test track was constructed at NIT Warangal (Heeralal2013). The equipment used for testing has the inner diameter of the wheel as 1.8m, the outer diameter of the wheel is 2m, and the radius is 3.6m. The loading gearbox was fitted over the tyre to apply the varying loads.

The first test track section is constructed without reinforcement, and the remaining sections of the test track were reinforced with different types of geotextile mats. Fig 3.12 shows the cross-section details of the test track. The test track was divided into eight sections. The length of each track is about 1m. Moreover, the types of geotextiles incorporated to construct the APT track are mentioned in Fig 3.13.

Figure 3.11 View of constructed APT track

Figure 3.12 View of the Constructed Circular APT track

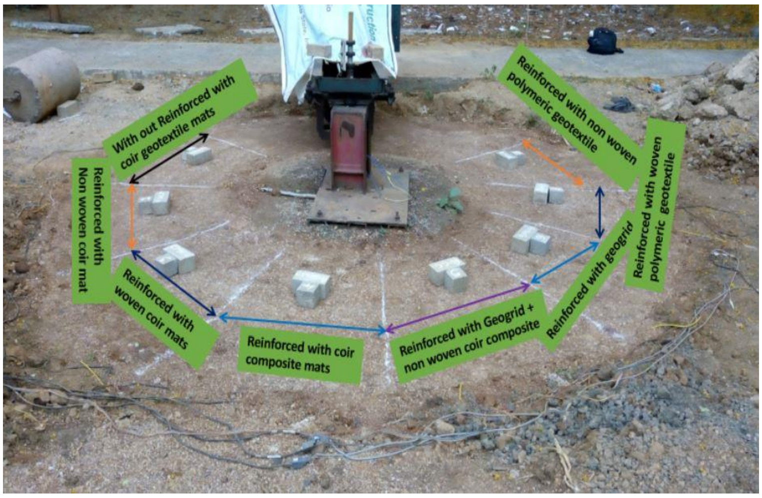


Figure 3.13 View of dividing Circular test track into different sections

The ground was cleaned around the test track, and the single-lane road is prepared. The test track was marked ina circular shape. The inner and outer wheel radius of the test track was 1.8m and 3.6m. The inner wheel (1.8 m) and outer wheel (2.0 m) from the center of the base plate. The natural ground was excavated up to a depth of 520 mm to 550 mm. The subgrade (300mm) was prepared using the BC soil. After placing the soil, it was compacted using the 200kg capacity of the roller. It was pulverized and made into particles of size 4.75 mm passing. The pulverized BC soil was placed in the test track, water was sprayed over the BC soil and compacted at OMC. The sub-base soil was compacted in order to attain the maximum density of the APT. The design thickness of the subgrade was kept as 300 mm, the variable thickness of the sub-base layer with the inclusion of 100mm to 120mm thickness of coir mats. The test track was prepared as a two-layer pavement system such as subgrade and sub-base for T2 traffic category (30000-60000 ESAL) as per IRC:SP:72-2015 has been adopted.

Figure 3.14 View of prepared subgrade without coir geotextile

Fig 3.14 shows the BC soil subgrade without compaction. The subgrade is prepared and compacted at OMC condition to attain maximum density with the roller compaction. Fig 3.15 shows the preparation of BC soil subgrade with roller compaction.

Over the prepared subgrade, the load cells and strain gauges were installed at eight sections. The distance between the load cells was kept as 1m. The distance between the load cell and strain gauge was 30 cm. Fig 3.16 shows the installation of the sensor, load cell and strain gauge. In the present setup, there is no provision to conduct the experiment at variable speed.

Figure 3.15 Compaction of BC soil subgrade with roller compaction

Figure 3.16 Installation of load cells and strain gauge into the subgrade

Figure 3.17 Anchoring of coir geotextile mats over the subgrade

After fixation of load cell and strain gauges, four types of coir geotextile mats were placed for the reinforcement of section and anchored with the help of 2.5 (2 ½) feet of mild steel wire. The anchoring of the mats is shown in Fig 3.17.

After proper provision of coir geotextile mats, morrum soil was spread over the entire test track. Water was sprinkled to attain the OMC of the sub-base material, as shown in Fig 3.18. The prepared sub-base layer thickness was measured before and after the test. Fig 3.19 shows the application of roller compaction over sub-base material. The compacted sub-base is shown in Fig 3.20. The rut depth of the test track was measured after the test. The thickness of the sub-base soil was placed as120mm (Sub-base layer 1), 150mm (Sub-base layer 2) and then 180mm (Sub-base layer 3) in the test track. The APT was made to revolve for T2 traffic category (60000 repetitions) for each sub-base layer. The stress and strain of the material were evaluated using the DAQ system. Fig 3.21 shows the APT during the test.

Figure 3.18 Sprinklingof water over sub-base

Figure 3.19 Compaction of sub-base material using the roller

Figure 3.20 View of the finished base layer for geotextile installation

Figure 3.21 View of APT test track during the study

Further, the load cell and strain at the top of the subgrade was measured with the help of Data Acquisition DAQ system. In the first case, morrum soil was spread over the mats with a thickness of 120mm. The rut depth, stress, and strain are observed for 60000 passes. Similarly, the thickness of sub-base II and sub-base III material is taken as 150mm and 180mm of morrum, respectively. Similarly, morrum sub-base material was replaced with gravel as sub-base soil. The variable thickness of the sub-base material was placed over the anchored coir geotextile mats. Fig 3.22 shows the preparation of the test track with gravel as a sub-base material. The stress and strain over subgrade were measured directly with the help of load cell and strain gauge sensor at each section using the DAQ system. In addition to this, the rut depth was measured by LVDT as well as manually at each section. The DAQ system is associated with modules, compact DAQ, and Lab view system software. The modules provide different responses such as strain, load, stress, and temperature et.during the test program.

Figure 3.22 Test track with gravel as a sub-base layer

The prepared test track before the test and after the test is shown in Fig 3.23 and 3.24, respectively. APT was revolved over the prepared sub-base test track with 720rpm with an electric motor. Similarly, a test was performed changing the sub-base material as morrum (GW) and gravel (SP) in the test track. Based on the laboratory study, 55kg load was applied in the entire test track to correlate laboratory study with an in-situ test track.

Figure 3.23 View of APT before the test with gravel material

Figure 3.24 View of APT test track after the test

The pneumatic tyre loading was arranged systematically to run over the prepared test track. The gearbox of the assemble helped in repetition using an electrical motor. The carrier was attached to the APT assemble in which a suitable load can be placed over the tyre. The complete assemble system of APT was revolves at a rate of 12 passes/ minute with the applied load 55kg. The applied tyre pressures

3.3.3 Stage III: Design of Flexible Pavement

The third stage of the methodology is to design the flexible pavement using coir geotextile. The design was adopted as per the field and laboratory study; then it is compared with standard pavement thickness. The benefits of coir geotextile into the LVR's while reduction of sub-base thickness are discussed. It is evident that coir geotextile mats reduce the thickness of the sub-base layer. The conventional pavement thickness cross-section and the adopted pavement cross-section with coir geotextile are present. Fig 3.25 shows the without reinforcement section of the pavement and Fig 3.26 shows the reinforced pavement section with sub-base layer thickness I.

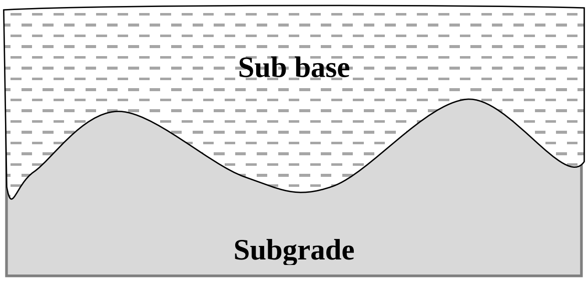


Figure 3.25 Without reinforcement section

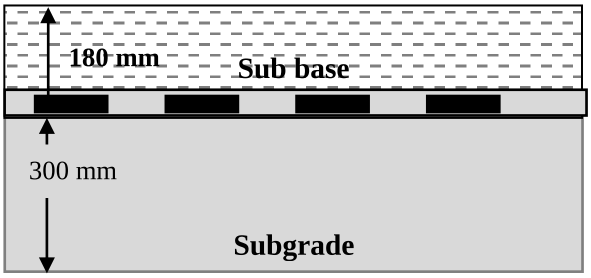


Figure 3.26 Reinforcement section with sub-base I

Similarly, Figures 3.27 and 3.28 show the sub-base layer thickness II and III, respectively. In this case, the reduction of thickness is presented with coir geotextile. It is concluded that the coir composite material with 120mm will also perform better reduction over the subgrade.

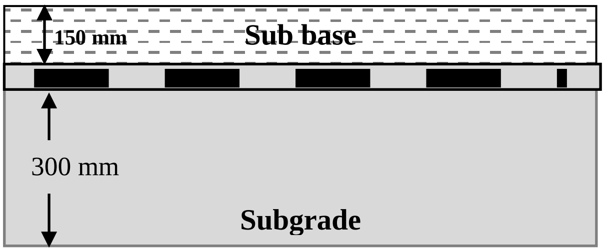


Figure 3.27 Reinforcement section with sub-base II

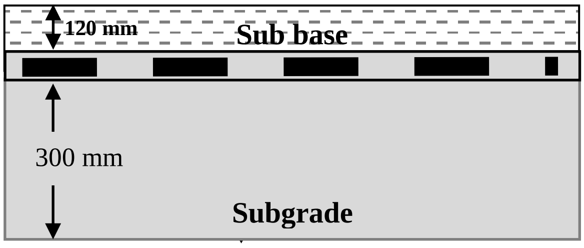


Figure 3.28 Reinforcement section with sub -base III

3.4 Data Acquisition System

Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as stress, strain, temperature, pressure, or sound with a computer in the pavement structure. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution. Data acquisition systems, abbreviated by the acronyms DAS or DAQ, typically convert analog waveforms into digital values for processing. The components of data acquisition systems include. The kind of data acquisition system used in the study is shown in Figure 3.29 below.

The hardware details used in the study are as follows:

NI - Compact DAQ Chassis (Model-9178), main device which will be connected to the PC, having 8-Slot, USB Compact DAQ Chassis. The DAQ-9178 is a Compact DAQ USB chassis designed for small, portable sensor measurement systems. The chassis provides the plug-and-play simplicity of USB to sensor and electrical measurements. It also controls the timing, synchronization, and data transfer between C Series I/O modules and an external host. One can use this chassis with a combination of C Series I/O modules to create a mix of analog I/O, digital I/O, and counter/timer measurements. The cDAQ-9178 also has four 32-bit general-purpose counters/timers.

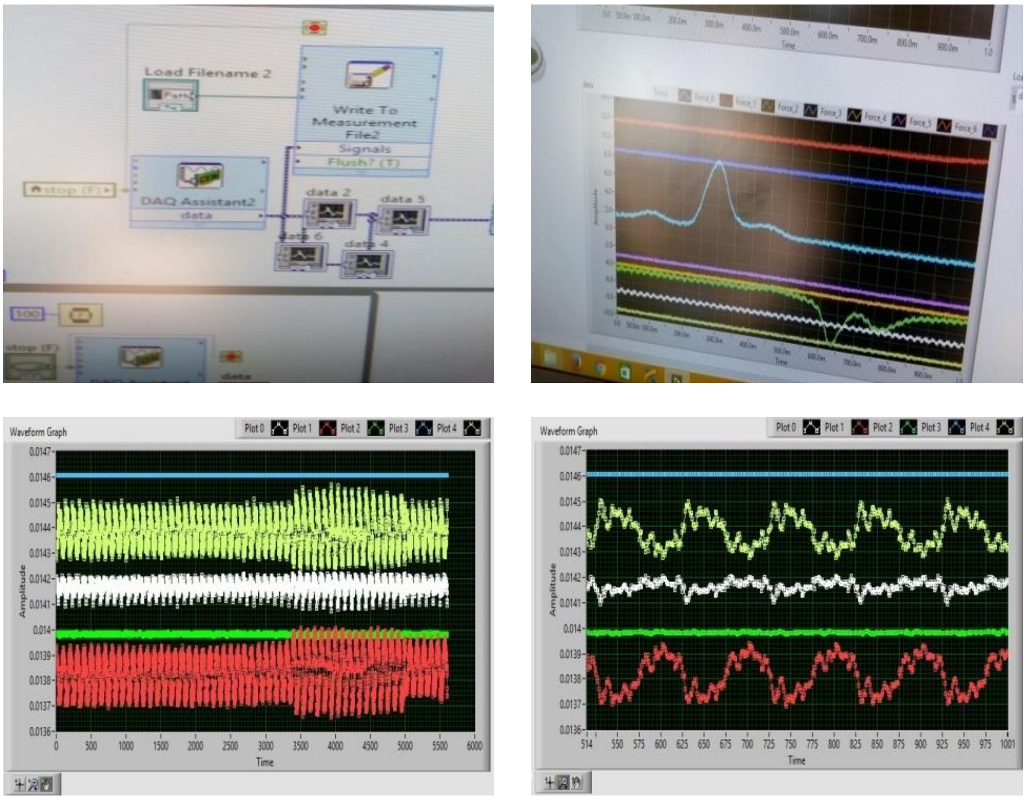


Figure 3.29 Screenshots of data captured during the study

3.5 Summary

This chapter summarises the proposed methodology adopted in the laboratory and in-situ evaluation, along with the materials used.

CHAPTER 4
EXPERIMENTAL EVALUATION OF COIR GEOTEXTILES

4.1 General

This chapter briefly describes the laboratory tests on coir geotextile with the help of Wheel Tracking Test (WTT) apparatus, rut depth potential of various types of coir geotextile results and analysis are presented. The current investigation is carried out based on a two-layer pavement model system using two types of fabricated moulds.

4.2 Materials and Tests

The materials used in the study are Black Cotton (BC) soil, morrum soil (GW), gravel soil (SP) and four types of the coir geotextile

4.2.1 Subgrade Soil

Black Cotton Soil (BC) was used as the subgrade. The color of BC soil is light to deep black in colour and medium to high plastic. The subgrade of pavement withstands the increased traffic load with the reduction of the maintenance cost. It was noticed that the BC soil subgrade possesses several problems to the pavement in the form of rutting, reflection cracks and unevenness, etc. This phenomenon occurs due to the presence of cohesive fine particles (mantomortolite), which shows high swelling and shrinkage properties during the wet and dry season. The undrained Cu value of subgrade soil is found as 30. The properties of the subgrade soils are determined in the laboratory and presented in Table 4.1.

Table 4.1 Properties of subgrade soil

Property	Obtained value
Liquid Limit (LL %)	58
Plastic Limit (PL %)	27
Plasticity Index (PI %)	34
Specific Gravity (SG)	2.61
Optimum Moisture Content (OMC %)	17
Maximum Dry Density (kg/m^3)	1.7
Free swell Index (FSI %)	77
California Bearing Ratio (CBR %)	1.0
Soil Classification	CH
Unit weight (kN/m^3)	18
Undrained sugrade soil cohesion (Cu)	

4.2.2 Sub-base Material

Two types of sub-base layer material were used in the present study, such as sandy gravel (SP) and morrum (GW) soil. The sub-base material were collected in surrounding of NIT, Warangal campus, and the collected material was characterized and found that the material was within the specification of the Ministry of Rural Development (MoRD), India. The basic index properties of the sandy gravel as a sub-base layer material was determined and presented in Table 4.2. The sandy gravel materials CBR values are determined as 21% and 45% in soaked and un-soaked conditions at 7.2% of optimum moisture content.

Table 4.2 Properties of gravel soil

Property	Obtained Value	Method
Liquid Limit (%)	NP	IS 2720 Part 5
Plastic Limit (%)	NP	
Plasticity Index (%)	NP	
Specific Gravity	2.63	IS 2720 Part 3
Optimum Moisture Content (OMC %)	7.2	IS 2720 Part 7
Maximum Dry Density (MDD g/cc)	2.21	
Free Swell Index (%)	14.41	IS 2720 Part 40
Soil Classification	SP	
California Bearing Ratio (%)	45	IS 2720 Part 16
Soaked CBR (%)	21	
Shear Parameter (c and ϕ)	0 and 31°	IS 2720 Part 13

Table 4. 3 show the properties of morrum soil. The CBR values are noticed as 26% and 54% in soaked and un-soaked condition at 9.6% of OMC.

Table 4.3 Properties of morrum soil

Property	Obtained value	Method
Gravel Content (%)	16.40	
Sand Content (%)	78.00	
Silt and Clay content (%)	5.60	
Liquid Limit	7.27	IS 2720 Part 5
Plastic Limit	2.63	
Optimum Moisture Content (OMC %)	9.60	IS 2720 Part 7
Maximum Dry Density (MDD g/cc)	2.01	
Soil Classification	GW	
California Bearing Ratio (%)	54	IS 2720 Part 16
Soaked CBR (%)	26	
Shear Parameter (c and ϕ)	5 and 34°	IS 2720 Part 13

4.2.3 Coir Geotextile

Coir-geotextiles are naturally available biodegradable materials; they are abundantly available in the southern part of the country (India), Srilanka and Indonesia (Meshram et al. 2013). The various types of coir geotextile mats are available as per field requirements.

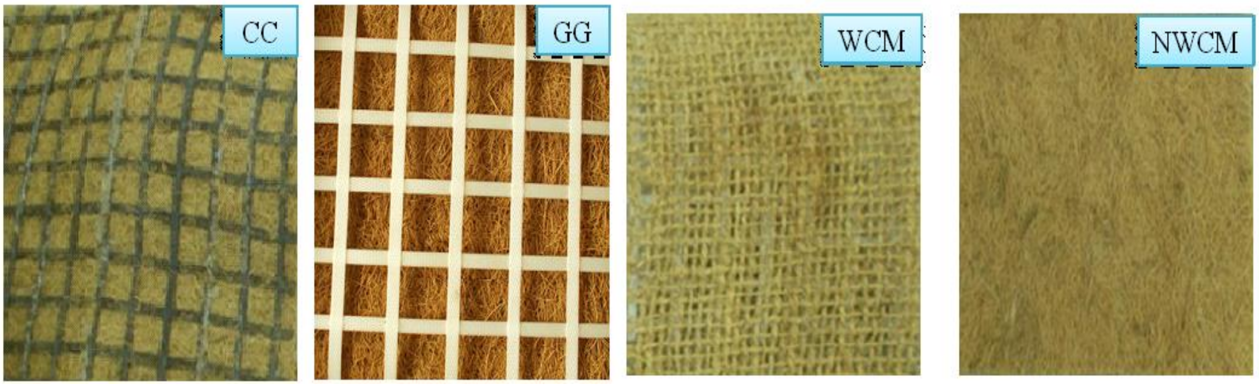


Figure 4.1 Various types of coir geotextile used in the study

Fig. 4.1 shows various types of coir geotextiles adopted in the study. The combination of NWCM with geogrid (GG in white color) is having a rigid nature with 20mm^2. The WCM showed better performance in separation function than the CC and GG, due to its smaller opening size with 3-4 mm^2. The NWCM is provided without opening size with a thickness of 10-1.20 mm. The coir geotextile possesses the tensile elements below the sub-base (Beena et al. 2016) to enhance the poor subgrade soil.

Table 4.4 Physical properties of the coir geotextile

Description (items)	Obtained value	Test Method
Diameter (mm)	0.12	
Length (cm)	28	
Thickness (mm)	0.3	
Density (g/cc)	1.38	IS 15868: Parts 1-6, IS 15869 (2008).
Water absorption (%)	5.2	
Breaking elongation (%)	27	
Swelling in water	4.3	
Tenacity (g/tex)	8	
Rigidity of modulus	1.87	

Coir geotextile mats are made from the coir fiber which is extracted from the husk of the coconut. These mats are available in the form of woven and non-oven coir geotextiles with a different mesh size of the opening with different yarn thicknesses. The physical properties of the coir geotextile are determined in the laboratory as per the is 15868: Parts 1-6, and IS 15869 (2008).

Similarly, the chemical properties of coir geotextiles are evaluated and presented in Table 4.5. The lignin and the cellulose properties were determined using Transmission Electron Microscopy (TEM). Higher lignin content was found in the coir geotextile (Khalil et al. 2006; Verma et al. 2013) among the other natural geotextile. These properties of the coir geotextile improve the rigidity of the material to increase the tensile strength.

Table 4.5 Chemical properties of coir geotextile

Description (items)	Obtained value
Lignin (%)	42.47
Cellulose (%)	39.21
Hemi-cellulose (%)	0.21
Pectin’s (%)	2.80
Ash (%)	2.1
Water -Soluble (%)	5

Table 4.6 shows the tensile properties of the coir geotextile mats. The tests are conducted based on ASTM D6637 test protocol. The WCM mats have the lowest tensile strength. The NWCM does not show tensile strength. The CC mats show higher tensile strength such as 4.84kN than the other types of the material. The tensile strength of woven coir mats was noticed as 2.97 kN, and Young's modulus of the same material was 5.559N/m^2.

Table 4.6 Tensile strength properties of the coir geotextile

Type of Geotextile	Load (kN)	Area (mm^2)	Tensile Strength N/mm^2	E= Stress/ Strain(Mpa)
Woven Coir Mat	2.97	20	14.85	5.559
Coir Composite	4.84	21	23.04	13.35
Geogrid	3.83	20	19.15	14.56
Non-Woven Coir Mat	-	-	-	-

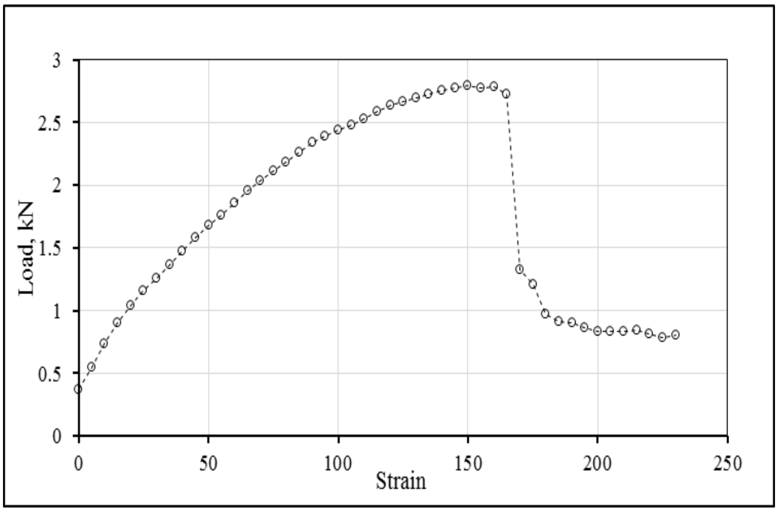


Figure 4.2 Load and strain rate of Woven coir geotextile

Among the other types of coir geotextile mats, WCM showed lower tensile strength. It is indicated that the obtained tension in the material reaches the maximum value, and then suddenly fails in case of WCM. This is obtained in the material without supporting the geogrid. Fig 4.2 shows the load vs strain rate of the woven coir geotextile.

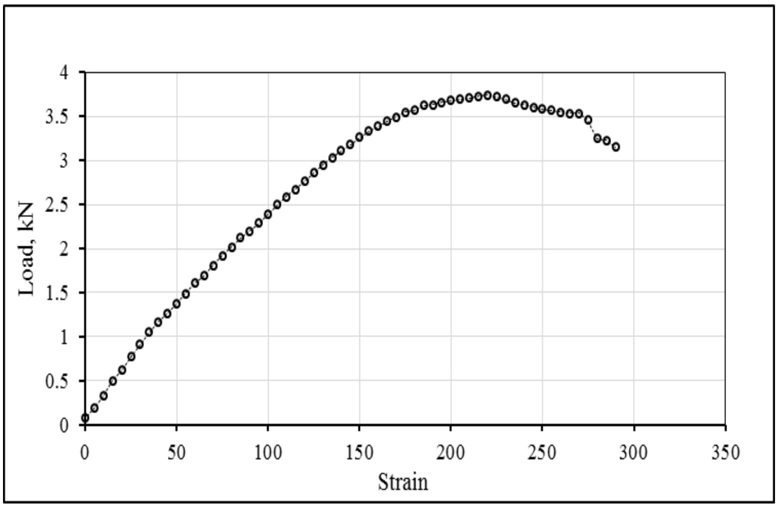


Figure 4.3 Load and strain rate of coir composite

The CC mats show a higher tensile strength due to the flexible nature of geogrids. Due to these properties, the tensile strength slowly increases and then decreases. This phenomenon helps in the slow settlement of the pavement layer. Fig 4.3 shows the load vs strain rate of the coir composite mats

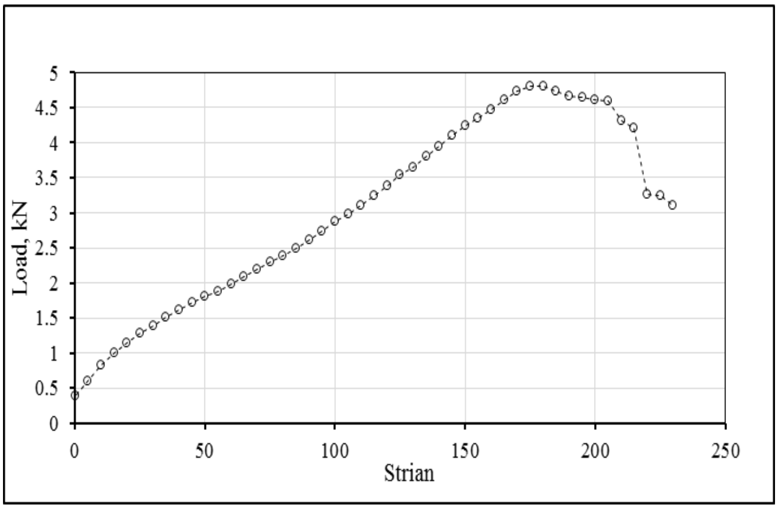


Figure 4.4 Load and strain rate of geogrid

Tensile strength of the GG mats obtained as 3.83kN/m^2, parabolic incremental of tensile strength was observed. After reaching the maximum tensile strength, it fails suddenly due to the rigid nature of the material. This failed phenomenon leads to the peak in the performance of the coir geotextile. Fig 4.4 shows the load vs strain rate of the woven coir geotextile. Initial and secant modulus of geotextile and geogrid is shown in Table 4.7

Table 4.7 initial and secant modulus of the geotextile

Types of geotextile	Initial modulus (kN/m)	Secant modulus (kN/m)
Woven Coir Mat	12.10	750
Coir Composite	45	1500
Geogrid	47.5	1800

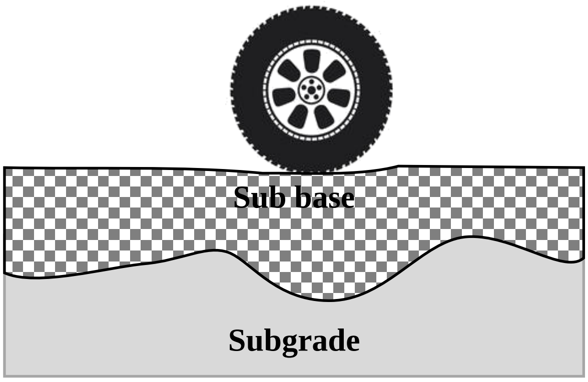


Figure 4.5 Pavement without coir geotextile

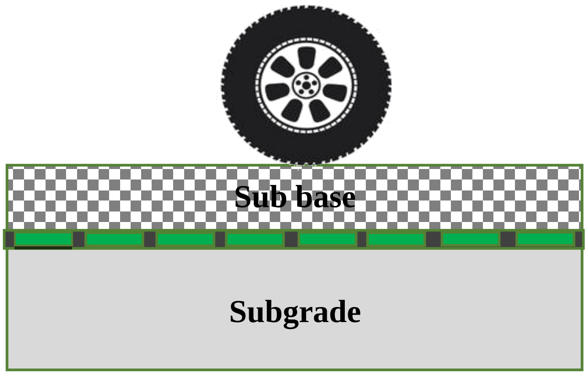


Figure 4.6 Pavement layer coir geotextile (seperation)

The mechanism of the geotextile plays a key role to enhance the performance pavement structure. It was observed that the NWCM provides better performance in separation function, but at the same time, it is weak in tension. When NWCM was attached with geogrid (flexible and rigid), it showed proper separation and reinforcement to the pavement. In other cases, the

WCM shows the proper separation function due to its smaller opening size than the geogrid. The pavement response shows without coir geotextile mats in the pavement layer, as shown in Fig 4.5. The inclusion of the composite mat possesses the dual function in the form of separation and reinforcement, which are shown in Fig 4.6. Hence, the provision of composite mats improves performance and extends the serviceability of the pavement.

4.3 Laboratory Experimental Program

The pavement model layer has been made in the laboratory with a different contact pressure of moving load using Wheel Tracking Test (WTT) set up to simulate the field condition. The height of the loading lever arm of the WTT apparatus has been raised using the fabricated angle sections. The available permissible limits of rut depth are 50mm for the LVR's as per the (Rural roads manual). The sample was tested under 40mm rut depth, due to the practical constraints and maximum possible limits of the equipment in the laboratory. The maximum load applied on the two-layer pavement model was 55kg (0.055 ton) through a moving wheel of diameter 200mm and the width of 50mm of a solid rubber tyre. The experimental setup used in the study is shown in Fig 4.7.

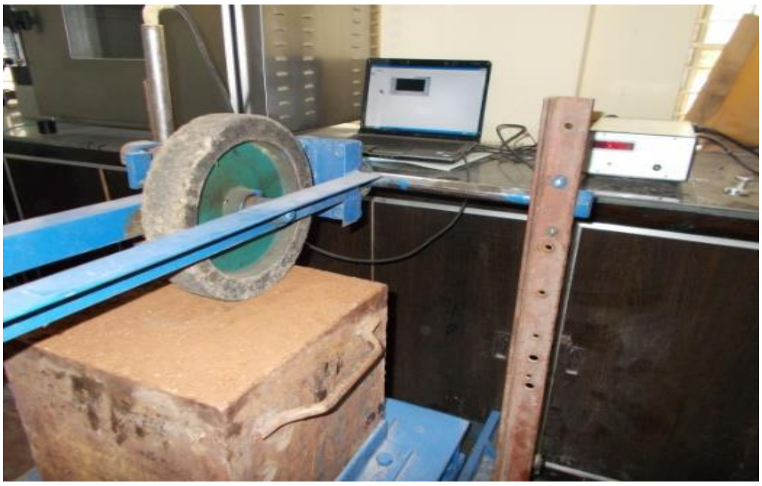


Figure 4.7 Experimental setup with a 300mm thickness of the mould

4.4 Sample Preparation Procedure

Subgrade was prepared and two types of sub-base with varying thickness of the pavement layer as per the modified California Bearing Ratio (CBR) test. The prepared sample was fitted in the wheel tracking test below the rigid rubber tire. The types of geotextiles were placed in two types of mild steel tank at a position of Sub-base layer I, Sub-base layer II and Sub-base layer III to evaluate the performance of coir geotextile along with the type of sub-base layer material. The subgrade is compacted and prepared at OMC. The four types of geotextiles are placed and appropriately anchored over the subgrade. The two types of sub-base materials such as GW and SP are placed with and without coir geotextile mats. The cross-section details of the two-layer pavement with the two types of the sub-base soil are shown in below Fig 4.8. The thickness of 100mm is taken as sub-base layer with gravel as sub-base material in 200mm thickness of the mould.

Similarly, the sub-base layer thickness was provided as 66.6mm from the top of the mould. The cross-section details of the subgrade and sub-base layer material are shown in Fig 4.9. The thickness of 66.6 mm of the sub-base layer is provided in a 200mm thickness of mould with and without coir geotextile.

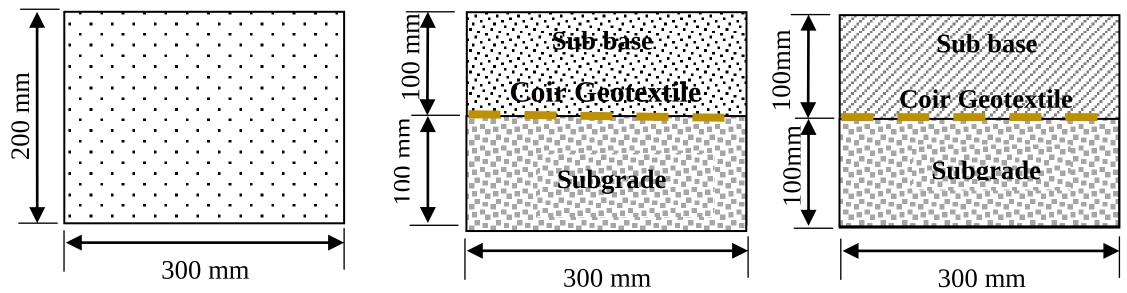


Figure 4.8 Reinforced and unreinforced pavement model layer at the sub-base layer I

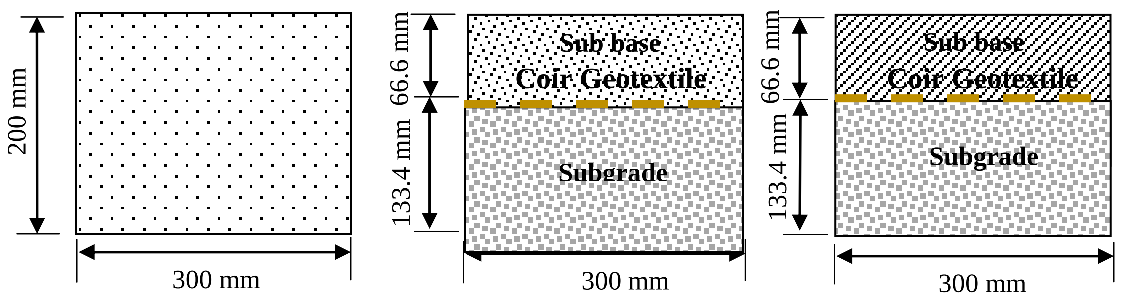


Figure 4.9 Reinforced and unreinforced pavement model layers at sub-base layer II

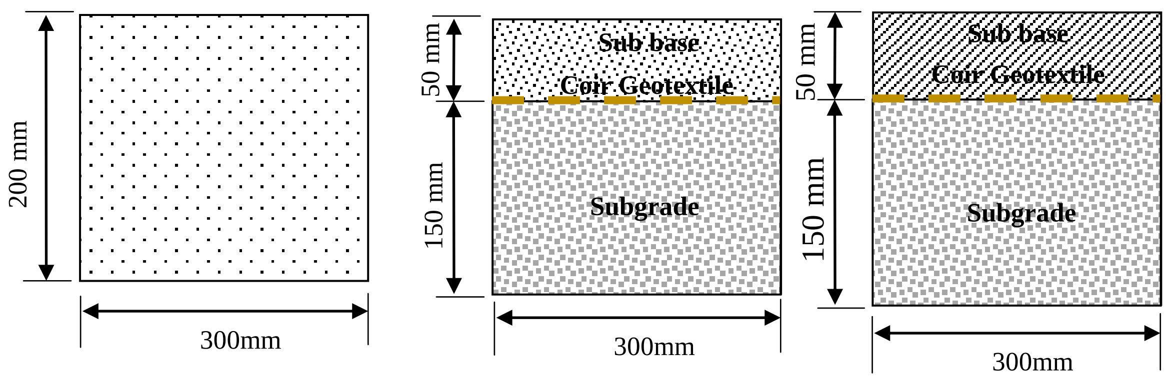


Figure 4.10 Reinforced and unreinforced pavement model layer at sub-base layer III

Similarly, the reduction of the sub-base layer thickness of 66.6mm is provided from the top of the mould. The thickness of the subgrade and sub-base layer material is shown in Fig 4.10. The rut depth of the reinforced and unreinforced samples is noted with respect to their number of wheel passes. Fig 4.8 shows the position of coir geotextile mats at the sub-base layer I with two types of sub-base material. the incorporation of geotextile at sub-base layer II and sub-base layer III shows in Fig 4.9 represents and Fig 4.10 respectively.

Table 4.8 shows the variable number of wheel passes with different types of coir geotextile mats in the same position. It depends on the position of the coir mats and also the types of the coir geotextile along with types of sub-base soil. The maximum 850 wheel passes are obtained at 40mm rut depth which is at a sub-base layer III with reinforcement of CC. The minimum number of 100 wheel passes was observed with an un-reinforced model layer.

Table 4.8. Rut depth of coir geotextile in 200 mm thickness mould and wheel passes

Pavement model section with 300mm x 300mm x 200mm	Position of coir mats	No. of wheel passes (N)	Observed rut depth (mm)
BC subgrade and without coir mat	Sub-base layer I (100mm thickness)	280	40.0
BC subgrade and coir composite		350	40.0
BC subgrade and Geogrid + non-woven coir mat		190	40.0
BC subgrade and woven coir mat		290	40.0
BC subgrade and non-woven coir mat		150	40.0
BC subgrade and without coir mat	Sub-base layer II (66mm thickness)	300	40.0
BC subgrade and coir composite		390	40.0
BC subgrade and Geogrid + non-woven coir mat		430	40.0
BC subgrade and woven coir mat		350	40.0
BC subgrade and non-woven coir mat		300	40.0
BC subgrade and without coir mat	Sub-base layer III (50mm thickness)	290	40.0
BC subgrade and coir composite		800	40.0
BC subgrade and Geogrid + non-woven coir mat		650	40.0
BC subgrade and woven coir mat		580	40.0
BC subgrade and non-woven coir mat		270	40.0

The lower number of wheel passes are observed in the case of an unreinforced model layer. This is due to the coir geotextile mats at sub-base layer III positions that will take the maximum load that is transferred towards the edges. However, in the case of Sub-base layer II and Sub-base layer I position of coir mats, it was noticed that the maximum wheel load is reduced with a provision of the higher thickness of sub-base layer material with coir geotextile mats. The provision of coir geotextile mats at a position of Sub-base layer I in the pavement model layer acts as unreinforced with SP as the sub-base layer material. From the laboratory work, it is observed that the better reinforcement occurred at the thickness of sub-base layer III positions when compared with the thickness of the Sub-base layer II and Sub-base layer I position of coir geotextiles.

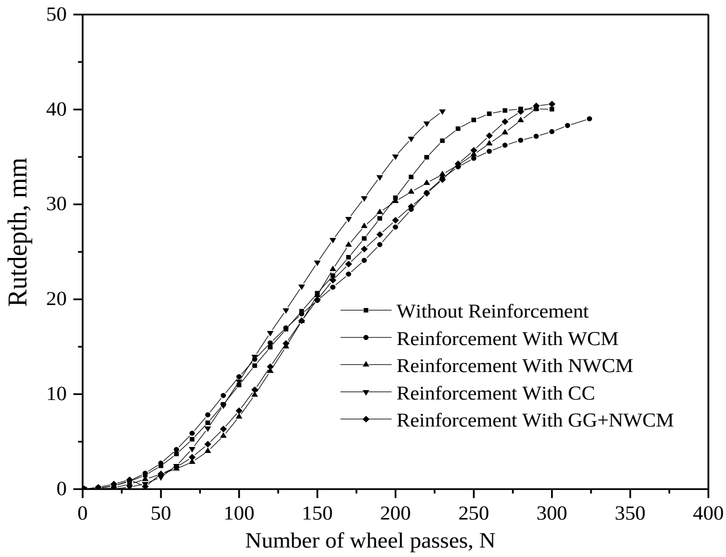


Figure 4. 11 Rut depth and number of wheel passes at Sub-base layer I Gravel (SP)

Fig 4.11 shows the number of wheel passes and rut depth of sub-base layer III positions of coir geotextile mats from the top of sub-base. It was noticed that the coir composite geotextile (GG+NWCM) had several wheels passes at Sub-base layer III as compared with other types of coir geotextile mats. The difference observed is not much higher at the position of sub-base layer I with reinforcement of coir mats. The GG+NWCM coir composite mats increase the number of wheel passes at the Sub-base layer I position with the sandy gravel due to a higher thickness of sub-base soil. The sandy gravel (SP) soil has lower CBR values due to the non-cohesive particles of sub-base layer soil (SP). It shows the lower CBR and higher rut depth. Fig 4.11 shows the rut depth, and several wheels passes at the Sub-base layer I position with sandy gravel (SP) material.

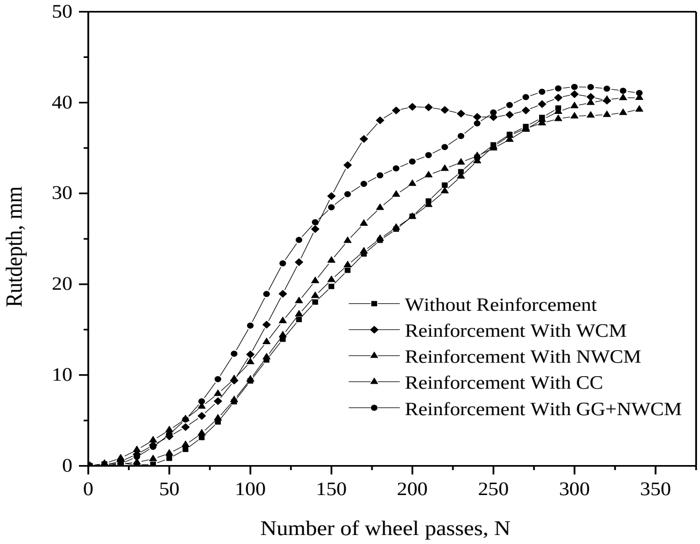


Figure 4.12 Rut depth and number of wheel passes at Sub-base layer II gravel (SP)

The inclusion of coir composite geotextile mats were kept at (150mm) from top of sub-base layer II and the coir geotextile mats ensure the multi-function in pavement application such as reinforcement, separation, and drainage (Ali khodii Imadi, 2009). At 40mm rut depth, the maximum number of 350 wheel passes occur, with reinforcement of GG and NWCM (combination). It color that the woven coir geotextile mats act as reinforcement material, and the non-woven mats purely act as separation material. When the non-woven coir mats attached to the geogrid give the additional reinforcement to the pavement structure, it increases the passes. The higher secant modulus of geogrid (GG with NWCM) shows as better reinforcement (IS 15871. 2009) due to its tensile strength. It is revealed that the coir geotextile provides better separation and reinforcement (IS 15871. 2009) function to the pavement over the weak subgrade. Hence, it is evident that the application of coir mats enhances the strength of weak subgrade and improves pavement performance. The rut depth, along with a number of wheel passes at sub-base layer II is shown in Fig 4.12.

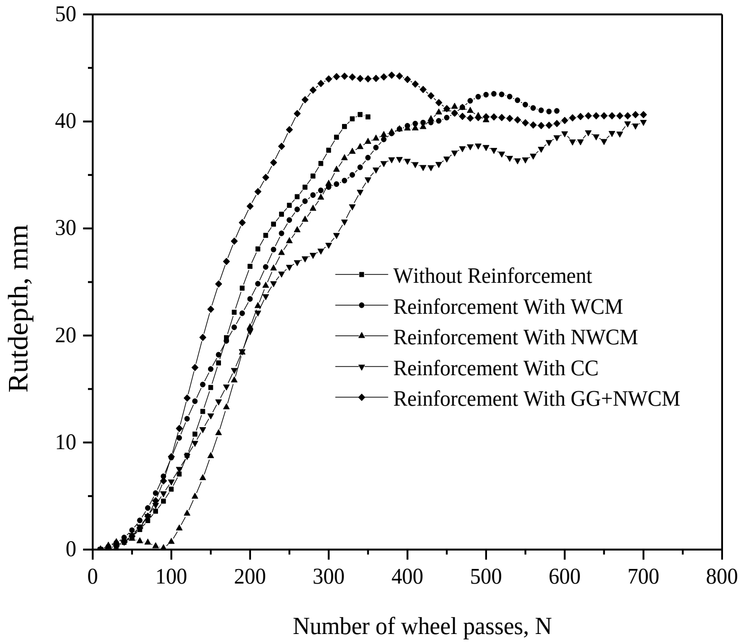


Figure 4.13 Rut depth and number of wheel passes at Sub-base layer III gravel (SP)

In order to reduce the sub-base layer thickness from the top of the mould, the coir geotextile is incorporated with 50mm gravel material. It was also noticed that the reduction of wheel passes occurred with higher thickness of sub-base layer material. However, in this case, the provision of the coir mat leads to the maximum wheel load transferred towards the edges of the pavement. It was concluded that the provision of coir geotextile mats gives the additional reinforcement to the pavement and also provides the separation (IS 15871. 2009) of subgrade and sub-base layer material. The provision of coir geotextile at Sub-base layer II shows better performance than the sub-base layer I and II. The uniformly graded sub-base layer material is having non-cohesive fines than the morrum soils. Due to non-cohesive properties, it showed lower shear strength and CBR values. The reduction of passes obtained at this position is due to the uplift pressure of geogrid and coir geotextile mats (GG+NWCM). This uplift force occurs more in the case of sandy gravel as a sub-base material. From the laboratory test, it was observed that the provision of coir geotextile mats increases the wheel passes and service life of the pavement. The obtained number of wheel passes at Sub-base layer III with GG+NWCM coir mats is shown in Fig 4.13.

Similarly, to evaluate the effectiveness of coir mats, an attempt is made in the laboratory using the fabricated mould size of 300mm x 300mm x 300mm. The sample is prepared with and without incorporation of coir geotextile mats at a position of Sub-base layer I (Fig 4.14) Sub-base layer II (Fig 1.15), and Sub-base layer III (Fig 4.16) position as per the modified CBR protocol. The rut depth of fabricated mould is noted with respect to their number of wheel passes.

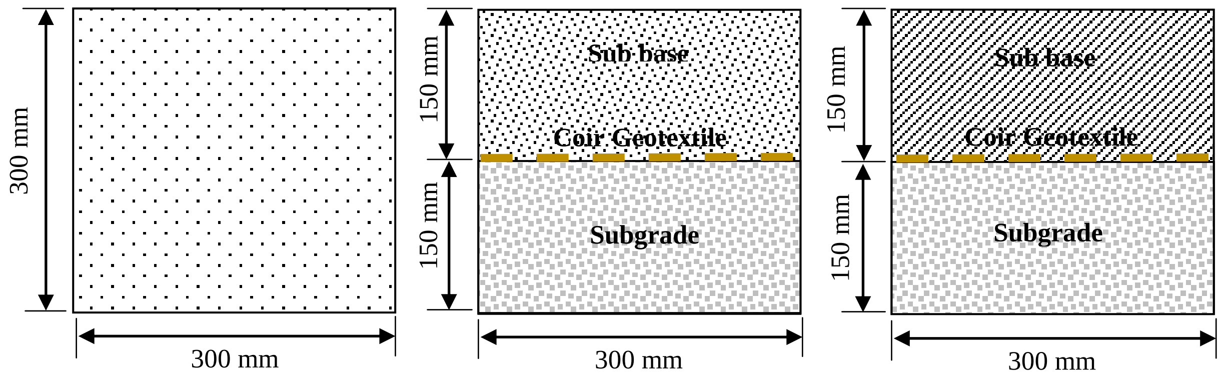


Figure 4.14 Placement of coir mats at Sub-base layer I with 300 thickness mould

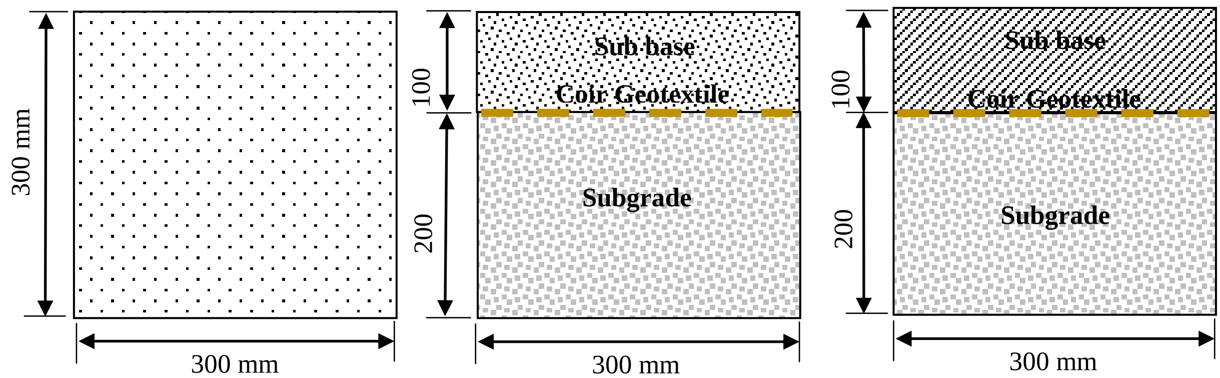


Figure 4.15 Placement of coir mats at Sub-base layer II with 300 thickness mould

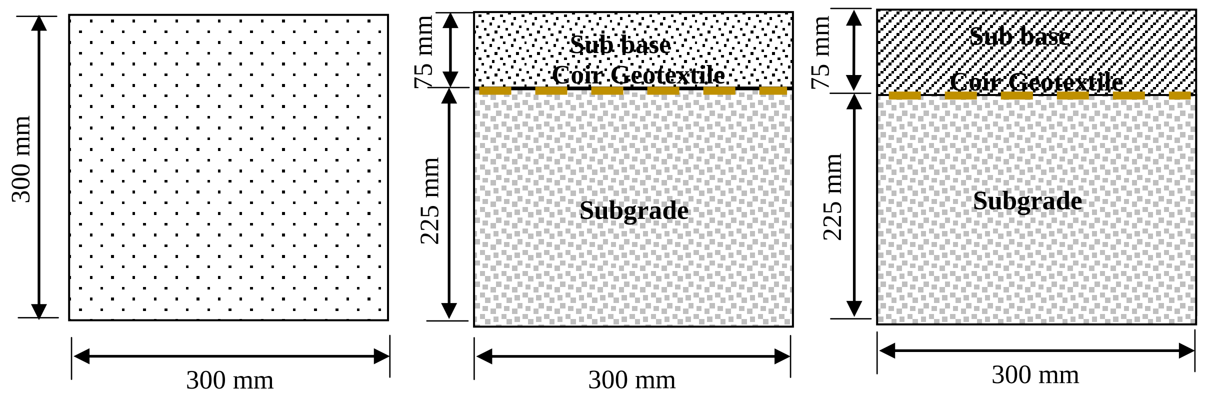


Figure 4.16 Placement of coir mats at Sub-base layer III with 300 thickness mould

The mould is prepared in order to maintain the constant thickness of subgrade and sub-base material. In this case, sub-base material is taken as gravel material. The coir geotextile mats provide a place of Sub-base layer I, Sub-base layer II and Sub-base layer III positions in the fabricated mould. The thickness details of the pavement section such as subgrade and sub-base, are shown in Fig 4.14, 4.15 and 4.16 at sub-base layer I, sub-base layer II and sub-base layer III, respectively. The rut depth, along with the position of coir mats and number of wheel passes are given in Table 4.9. The obtained rut depth was compared between the two type of the sub-base material and four types of the coir geotextile mats at the same position.

Table 4.9. Results of rut depth for with gravel soil in 300 mm thickness of the mould

Pavement model section with 300mmx300mmx300mm	Position of coir mats	No. of wheel passes (N)	Observed rut depth (mm)
BC subgrade and without coir mat	Sub-base layer I (150 mm thickness)	670	40.0
BC subgrade and coir composite		1400	40.0
BC subgrade and Geogrid + non-woven coir mat		1500	40.0
BC subgrade and woven coir mat		948	40.0
BC subgrade and non-woven coir mat		700	40.0
BC subgrade and without coir mat	Sub-base layer II (100 mm thickness)	170	40.0
BC subgrade and coir composite		420	40.0
BC subgrade and Geogrid + non-woven coir mat		480	40.0
BC subgrade and woven coir mat		356	40.0
BC subgrade and non-woven coir mat		190	40.0
BC subgrade and without coir mat	Sub-base layer III (75 mm thickness)	345	40.0
BC subgrade and coir composite		1040	40.0
BC subgrade and Geogrid + non-woven coir mat		1160	40.0
BC subgrade and woven coir mat		490	40.0
BC subgrade and non-woven coir mat		408	40.0

Table 4.8 shows the observed number of passes at different Sub-base layers. The position of CC and GG+NWCM coir geotextile shows 1400 and 1500 passes respectively with higher thickness of sub-base material at same rut depth. The reduction of wheel passes was noticed with reinforcement of NWCM at Sub-base layer II positions. The unreinforced pavement model system has 670 wheel passes at Sub-base layer III. This is obtained due to the poor performance of the layer material with the inclusion of coir geotextile mats.

Figure 4.17 shows the rut depth, and the number of wheel passes with sandy gravel soil at the Sub-base layer I. In this case, the coir geotextile mats are provided at 150mm of thickness from the top of the mould. The sub-base material is placed as gravel soil over the coir geotextile mats. It shows that the number of passes is more than the Sub-base layer II and Sub-base layer III positions at all the position. It is observed that higher passes occur due to 150mm higher thickness of sub-base layer material such as sub-base layer III with the inclusion of coir geotextile. The provision of coir mats at this position shows the low impact while improving the performance of the pavement. It is revealed that the confinement of coir geotextile mats with gravel is very poor, to improve the wheel passes.

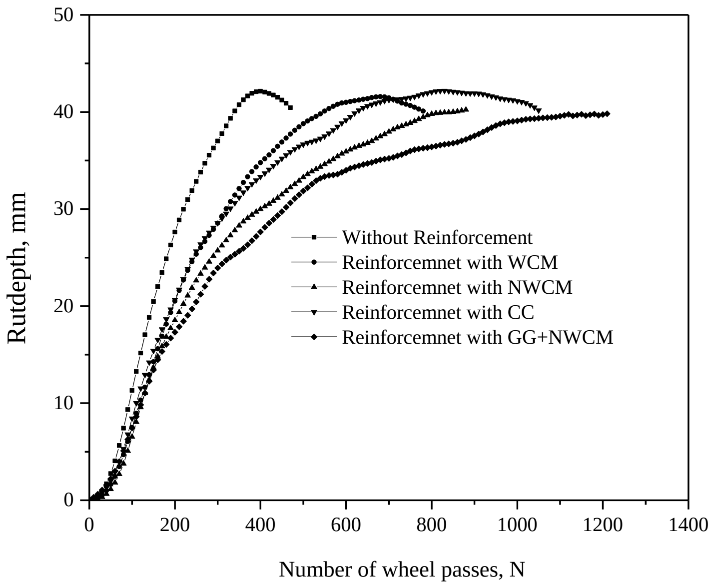


Figure 4.17 Rut depth and number of wheel passes at Sub-base layer I gravel (SP)

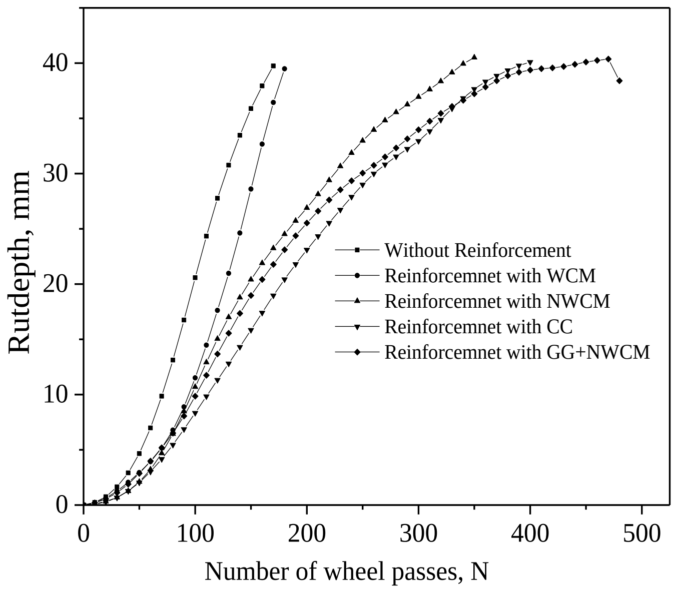


Figure 4.18 Rut depth and number of wheel passes at Sub-base layer II gravel (SP)

Similarly, the coir mats are placed at sub-base layer III in order to reduce the thickness of the sub-base layer materials from the top of the sub-base. In this case, it is observed that the wheel passes are reduced up to 120-130 and with and without reinforcement section at 40mm rut depth. It is observed that rut depth occurs due to the presence of non-cohesive fine particles of sub-base layer material. The provision of coir mats in the fabricated mould at Sub-base layer II from the bottom of the wheel shows the lower number of passes. It is due to shear failure in sub-base material such as gravel (non-cohesive) soil. It was noticed that the performance of the coir mats depends on the strength of the sub-base soil. The presence of cohesive soil (SP) along with the coir geotextile tends to reduce the passes and performance of the material. So that the appropriate and suitable types of the sub-base layer soil are used to enhance the pavement and coir geotextile material. Further, the morrum soil is chosen as a sub-base material. The rut depth and the number of passes at sub-base layer II with gravel material are shown in Fig 4.18.

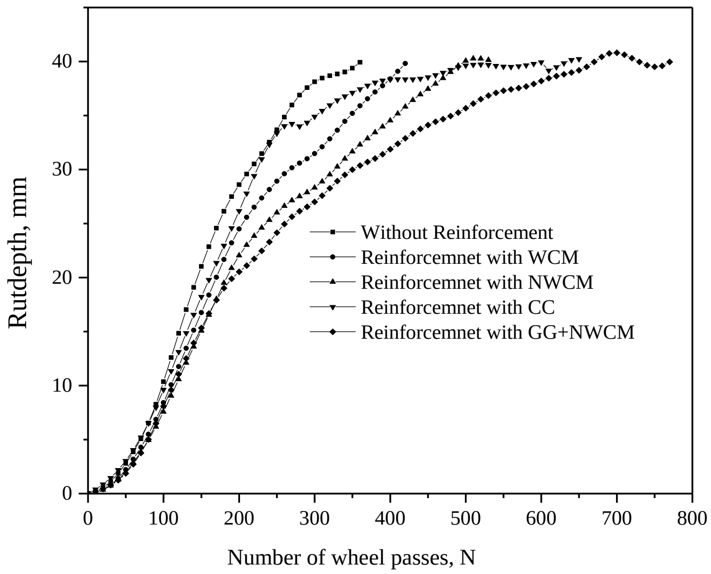


Figure 4.19 Rut depth and number of wheel passes at Sub-base layer III gravel (SP)

In this case, coir geotextile mats are incorporated at sub-base layer III with gravel as sub-base material from the top of the sub-base, with the reduction of the sub-base layer, coir mats are provided near wheel load. So that it acts as a tension member and the maximum stress will be taken by the coir mats. It was noticed that obtained stress is reduced by coir geotextile mats. The thicknesses of coir mats play a crucial role to improve the load-bearing capacity of the pavement. The higher the thickness of coir mats (CC, GG+NWCM, and NWCM) it reduces the rut depth. It provides additional strength to the pavement and reduces the vertical deformation. This reduction of vertical stress helps in slow settlement due to the function of reinforcement and separation. The provision of the coir geotextile mat at the Sub-base layer III positions, the rut depth and the number of wheel passes are shown in Fig 4.19.

The reinforcement of coir geotextile mats placed at the position of Sub-base layer I, Sub-base layer II and Sub-base layer III positions as per the modified CBR protocol. The rut depth of fabricated mould is noticed with respect to their number of wheel passes. The rut depth and position of coir mats along with the number of wheel passes are given in table 4.9.

Table 4.10 shows the rut depth of reinforced and unreinforced section, noticed at different layer thickness. The maximum and minimum rut depth of the unreinforced and reinforced section is 37mm and 8mm respectively at Sub-base layer III from the bottom of the sub-base layer. The reinforcement with coir geotextile mats at Sub-base layer III and Sub-base layer I position in the mould from the bottom reduces the rut depth up to 8mm and 4mm respectively.

Table 4.10 Results of rut depth for morrum soil in 200 mm thickness mould

Pavement model section with 300mmx300mmx200mm	Position of coir mats	Observed rut depth (mm)	No. of wheel passes (N)
BC subgrade and without coir mat	Sub-base layer I (100 mm thickness)	13.0	30800
BC subgrade and coir composite		6.0	30200
BC subgrade and Geogrid + non-woven coir mat		4.0	31450
BC subgrade and woven coir mat		8.0	30100
BC subgrade and non-woven coir mat		11.0	31400
BC subgrade and without coir mat	Sub-base layer II (66 mm thickness)	28.0	29900
BC subgrade and coir composite		11.0	31000
BC subgrade and Geogrid + non-woven coir mat		6.0	30600
BC subgrade and woven coir mat		15.0	31000
BC subgrade and non-woven coir mat		21.0	30000
BC subgrade and without coir mat	Sub-base layer III (50 mm thickness)	37.0	30900
BC subgrade and coir composite		13.0	29500
BC subgrade and Geogrid + non-woven coir mat		8.0	29500
BC subgrade and woven coir mat		18.0	30100
BC subgrade and non-woven coir mat		28.0	30200

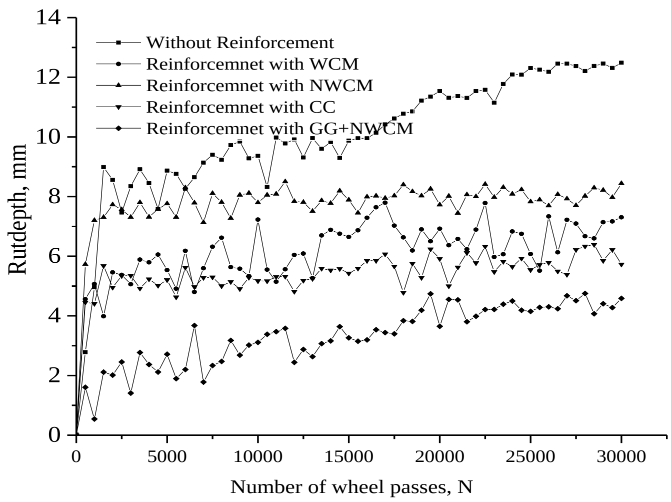


Figure 4.20 Rut depth and number of wheel passes at Sub-base layer I with 200mm of morrum (GW)

Fig 4.20 shows the incorporation of coir geotextile mats with morrum as sub-base material layer I (100mm) from top of the sub-base layer. The rut depth of reinforced and unreinforced section of pavement is observed as 13mm to 4mm respectively. The obtained reduction of the rut depth is noticed with GG+NWCM, due to the thickness of coir mats and the rigid geogrid attached, which gives them additional strength, so that it improves the passes and performance of the pavement which reaches up to 31,450 passes (T1-30, 000 as per the IRC: 37-2001) repetitions with reinforcement of GG+NWCM.

Similarly, without the reinforcement, the model layer showed the rut depth of 13 mm at 30800 passes with the morrum as the sub-base layer material. It is evident that the performance of the coir geotextile mats provides additional strength to the pavement and extend the service life of the pavement. The provision of coir mats with the presence of cohesive fine particles gives the confinement to coir mats and improves the wheel passes. The incorporation of coir mats at Sub-base layer I with morrum sub-base soil along with rut depth and the number of wheel passes is given in Fig 4.20.

Fig 4.21 below shows the rut depth and wheel passes at the Sub-base layer II position. In this case, the coir geotextile mats are kept at sub-base layer II from the top of the mould. It is observed that the unreinforced and reinforced section pavement model shows the rut depth of 28mm and 6mm, respectively, at the same position. The obtained reduction of rut depth is more significant with composite material (CC, and GG+NWCM). The WCM reinforcement pavement section shows that WCM and NWCM are having the rut depth of 15mm and 21m, respectively. It is observed that the thickness of the NWCM mats helps in the reduction of the rut depth along with attached geogrid.

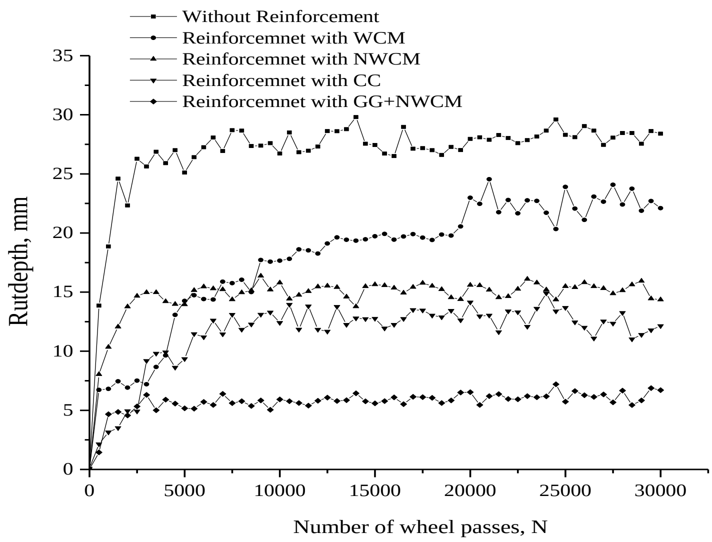


Figure 4.21 Rut depth and No. of wheel passes at Sub-base layer II with 200mm of morrum (GW)

The reinforcement model layer rut depth decreases while increasing the thickness of the sub-base material along with the incorporation of coir geotextile mats. It is found that the provision of coir mats shows better performance in the reduction of rut depth and helps in increasing the passes and service life of the pavement.

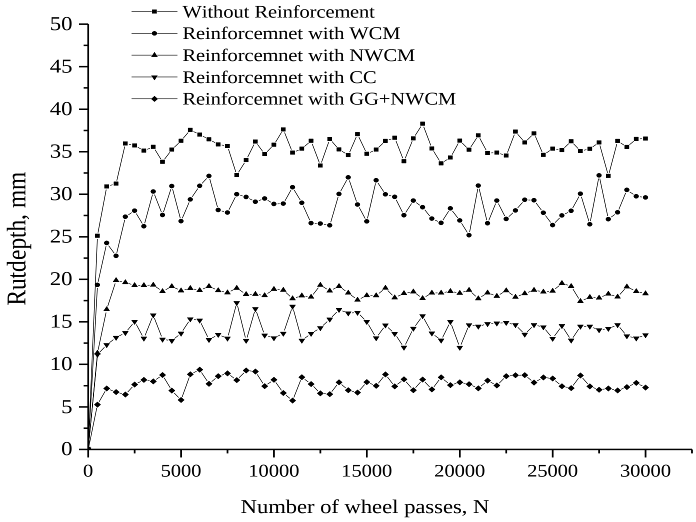


Figure 4.22 Rut depth and number of wheel passes at Sub-base layer III with 200mm of morrum (GW)

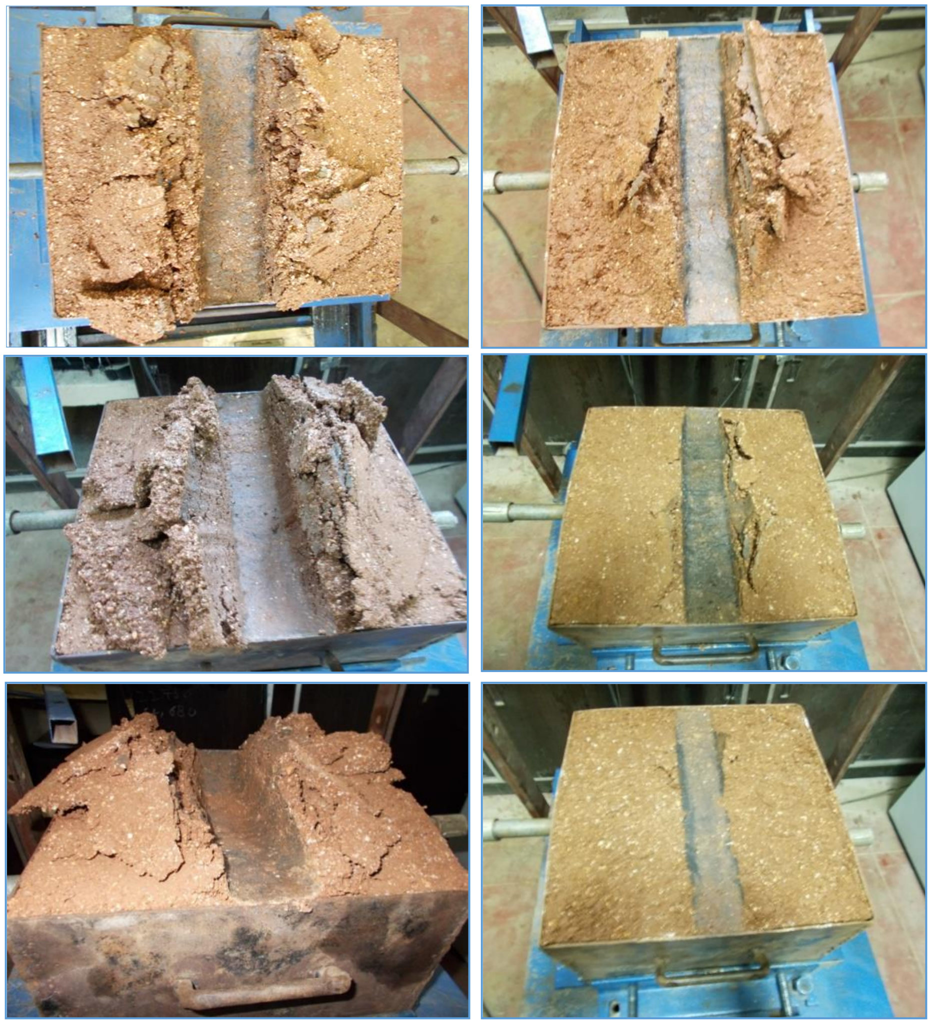


Fig 4.23 Rut depth of tested sample at sub-base layer I, II, III without and with reinforcement respectively

Similarly, the coir mats are provided in order to reduce the thickness of sub-base layer material at sub-base layer III from the top of the sub-base layer. From Fig 4.22, it is noticed that the two-layer unreinforced pavement model section is showing that the rut depth of 37mm for the unreinforced section, which is higher than the Sub-base layer I and Sub-base layer II positions of unreinforced sections. The provision of the coir mats at the Sub-base layer III position with morrum sub-base soil reduces the load at the top of the subgrade due to the coir mats. It is noticed that the unreinforced section of pavement showed 37mm of rut depth, due to the reduction of the sub-base layer and without coir mats. However, at the same position maximum reduction of rut depth at this position was noticed as 6mm with GG+NWC.

Similarly, the reduction of rut depth was also available with the type of coir (WCN, NWCM, CC, and GG+NWCM) geotextile in descending order. In that case, the thickness of the coir geotextile mats plays a key role while reduction of the rut depth. Images of laboratory study with and without the reinforcement of the coir geotextile at Sub-base layer I, Sub-base layer II and Sub-base layer III positions with a thickness of 200mm assemble of mould are shown below.

Figure 23 shows the snapshots of experimental studies with reinforcement and reinforcement. The above images, show rut depth at sub-base layer of I, II and III respectively at no reinforcement section.

Table 4.11 Results of rut depth for morrum soil in 300 mm thickness mould

Pavement model section with 300mmx300mmx300mm	Position of Coir Mats	Observed Rut depth (mm)	No. of wheel passes (N)
BC subgrade and without coir mat	Sub-base layer I (150 mm thickness)	11.0	60056
BC subgrade and coir composite		5.0	60200
BC subgrade and Geogrid + non-woven coir mat		3.0	60060
BC subgrade and woven coir mat		6.0	60240
BC subgrade and non-woven coir mat		8.0	60540
BC subgrade and without coir mat	Sub-base layer II (100 mm thickness)	18.0	60250
BC subgrade and coir composite		6.0	60076
BC subgrade and Geogrid + non-woven coir mat		4.0	60256
BC subgrade and woven coir mat		8.0	61870
BC subgrade and non-woven coir mat		11.0	60620
BC subgrade and without coir mat	Sub-base layer III (75 mm thickness)	24.0	60400
BC subgrade and coir composite		8.0	60348
BC subgrade and Geogrid + non-woven coir mat		5.0	60240
BC subgrade and woven coir mat		12.0	60320
BC subgrade and non-woven coir mat		18.0	60200

In order to reduce the thickness of sub-base material with the incorporation of coir geotextile mats, the fabricated mould is prepared at the thickness of 150mm, 100mm and 50mm as sub-base layer. In this case, the laboratory study was planned with the fabricated mould of size 300mm x 300mm x 300mm. The pavement model system consists of subgrade, which has BC soil and sub-base with morrum soil(GW), respectively. The rut depth of fabricated mould is noted with respect to their number of wheel passes. The rut depth and position of coir geotextile mats along with the number of wheel passes are given in table 4.11.

Fig 4.24 shows the performance of coir geotextile mats at sub-base layer I from the top of the sub-base material. It was noticed that the rut depth of 3mm and 11mm of pavement model occurred respectively with and without the reinforcement of coir geotextile. The reinforcement of GG+NWCM shows the 3mm of rut depth at 60, 000 passes. In the case of WCM, the higher rut-depth occurred due to the lower thickness of coir geotextile mats (3mm) than the NWCM. It is noticed that the incorporation of coir geotextile mats at this position (Sub-base layer I) shows less impact due to the provision of the higher thickness of sub-base soil than the sub-base layer II and III. The rut depth and the number of wheels passes along with four types of coir geotextiles mats is shown in Fig 4.24.

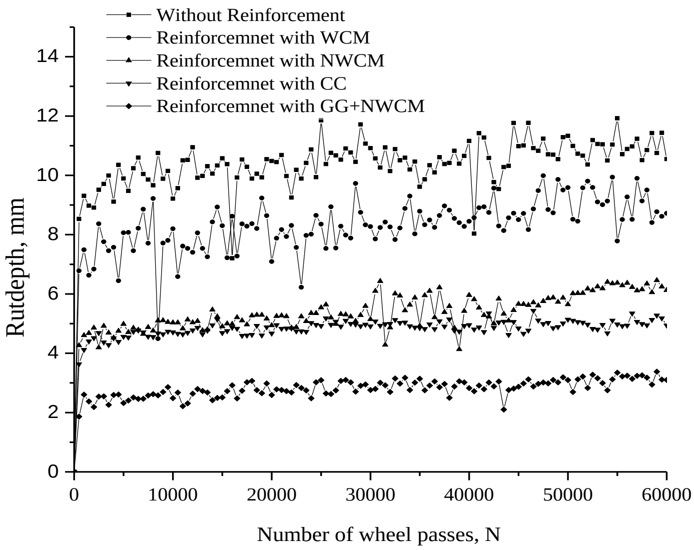


Figure 4.24 Rut depth and number of wheel passes at Sub-base layer I with 300mm of morrum (GW)

In order to reduce the thickness of the sub-base layer, the coir geotextile mats are at sub-base layer II. The rut depth of 18mm was found in case of the unreinforced section, which reduced up to 4mm with GG+NWCM. Similarly, the reduction of rut depth with CC and NWCM is 6mm and 7mm, respectively. It is observed that coir geotextile mats with morrum as sub-base material are more significant than the gravel as a sub-base material. With the reduction of sub-base thickness, the obtained stress is reduced over the subgrade with coir geotextile mats. This phenomenon helps in decreasing the sub-base layer thickness (saving of natural material) while increasing the wheel passes. It is evident that the coir geotextile provides better performance during a long time to the LVR's. The rut depth and a number of wheel passes at the Sub-base layer II position with morrum soil are shown in Figure 4.25.

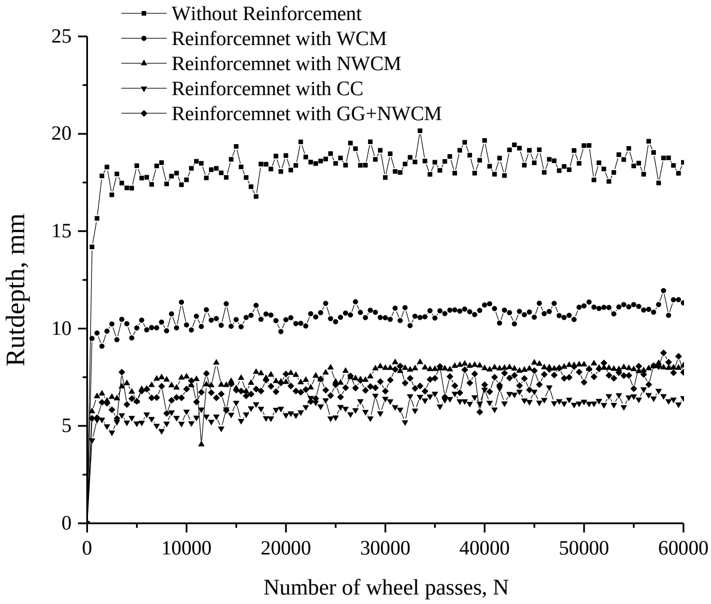


Figure 4.25 Rut depth and number of wheel passes at Sub-base layer II with 300mm of morrum (GW)

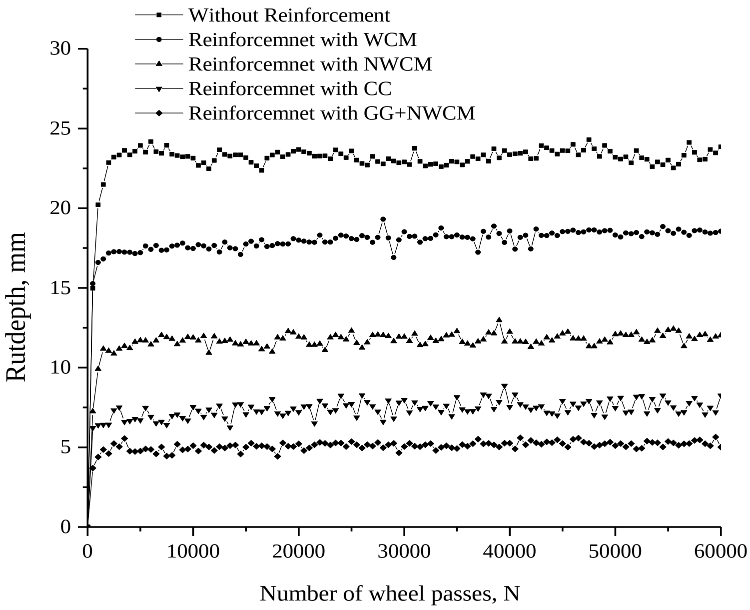


Figure 4.26 Rut depth and number of wheel passes at Sub-base layer III with 300mm of morrum (GW)

Similarly, the coir geotextile mats are placed at sub-base layer III and evaluated the performance. Incorporation of the coir geotextile mats with reduction of the soil sub-base layer material shows more impact due to transfer of the load and reduction of stresses over the top of the subgrade. The reinforced and unreinforced model layer shows a higher difference in the form of rut depth at this position. The maximum of 24mm rut depth was noticed in case of unreinforced section. However, the placement of coir mats at this position is reduced to 5mm with the GG+NWCM. The provision of the coir mats at a position of Sub-base layer III showed better reinforcement performance while reducing the sub-base material under the repeated loading condition. The higher, the rut depth obtained in unreinforced pavement model layer at the Sub-base layer I. The provision of the composite mats shows better performance in the form of increased passes over the subgrade. This material is more significant with morrum material than the gravel. It is due to the presence of a fine particle in the morrum soil. It is evident that the coir geotextile is more effective to reduce the stress over the subgrade, and it also helps in proper separation and reinforcement. The position of coir mats at the Sub-base layer III positions with several wheel passes are shown in Fig 4.26. Figure 27 shows the Images of laboratory study with and without the reinforcement of the coir geotextile at Sub-base layer I, Sub-base layer II and Sub-base layer III positions with a thickness of 300mm assembles of mould.

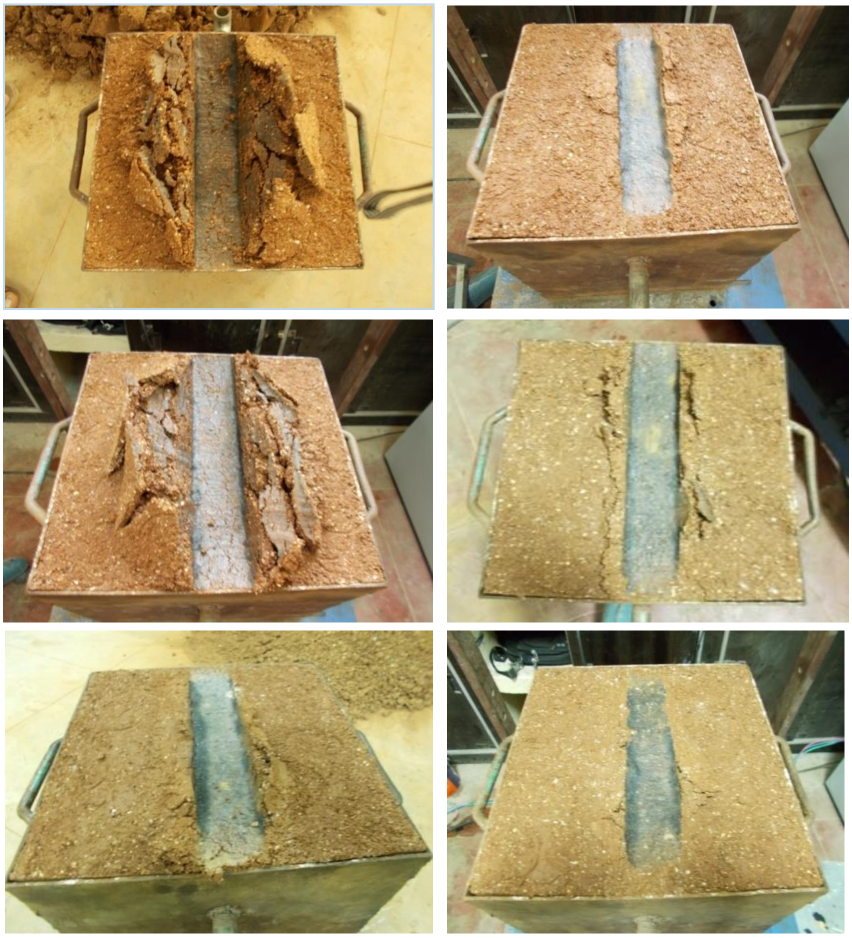


Figure 27 Snapshots of without and with reinforcement of coir geotextile

Fig 4.28 shows the comparison of coir geotextile mats along with different sub-base layer. The composite material has more significance to reduce the deformation than the woven and non-woven coir geotextile material. In unreinforced model case, the maximum rut depth was noticed at Sub-base layer III positions is 37mm and minimum rut depth is found as 13mm at

Sub-base layer I position with the 200mm assembles of the mould with morrum as sub-base soil. In the case of a reinforced model, the maximum rut depth was greatly reduced at Sub-base layer III positions (8mm) with GG+NWCM mats. The coir composite material is a flexible material that shows better separation than the GG+NWCM, possess the proper function of separation and reinforcement function to the pavement. It was found that the composite materials have shown better performance of the pavement than the WCM and NWCM. The reinforcement model layer is more significant in the reduction of the unreinforced section.

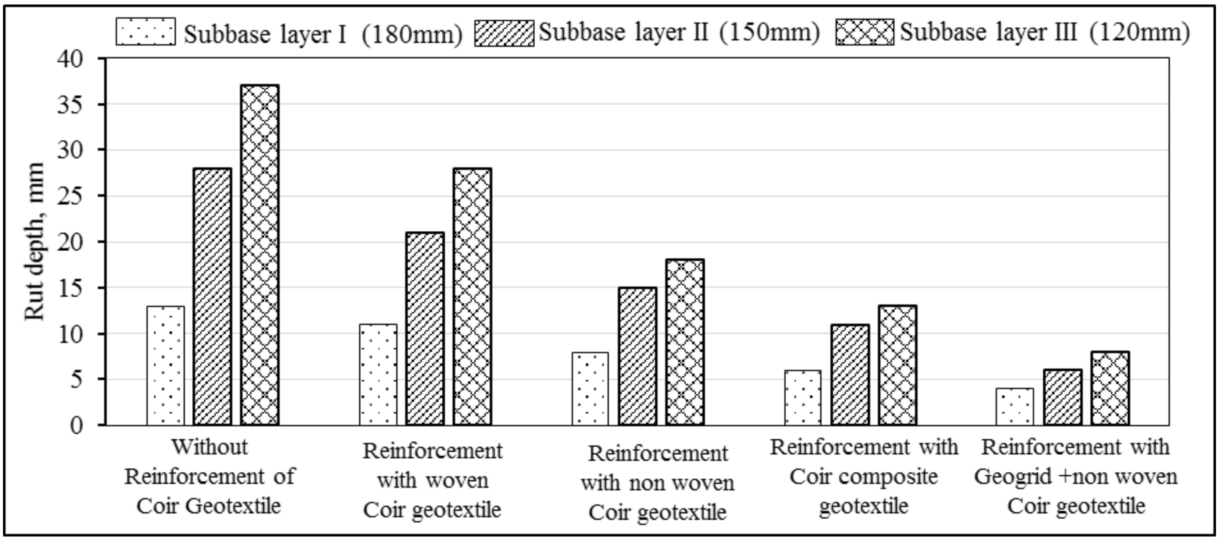


Figure 4.28 Rut depth of coir geotextile with a 200mm thickness of mould (morrum)

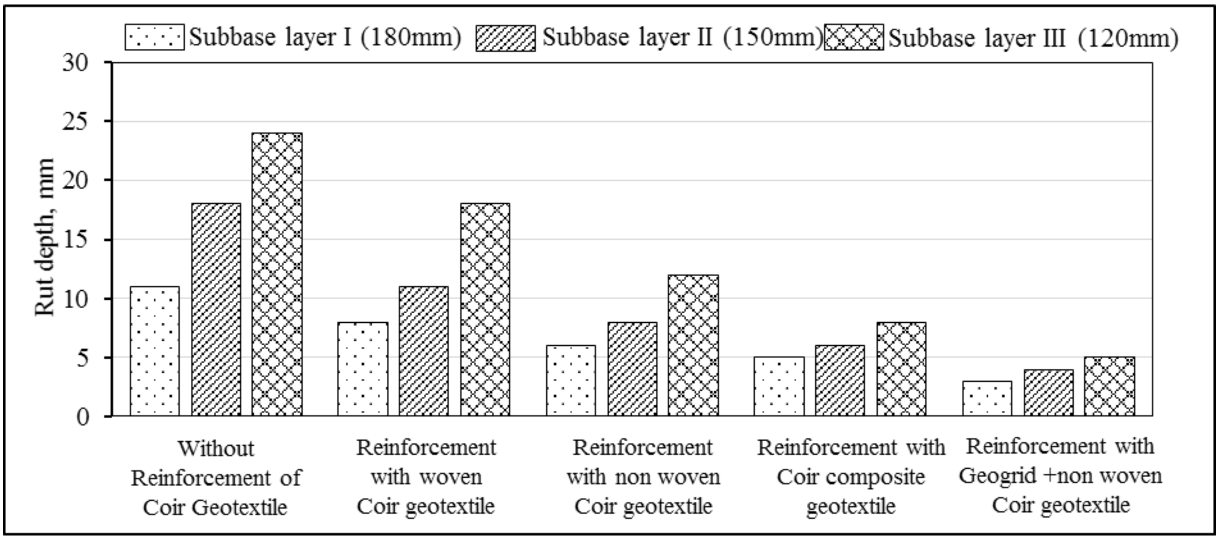


Figure 4.29 Rut depth of coir geotextile with a 300mm thickness of mould (morrum)

The above Fig 4.29 indicates the rut depth for different types of coir geotextiles with different sub-base layer thickness such as Sub-base layer I, Sub-base layer II and Sub-base layer III with 300mm of assembles of mould. The provision of the coir geotextile mats such as CC and GG+NWCM showed effective performance than WCM and NWCM. The obtained rut depth of 24mm is reduced up to 8mm and 5mm with CC and GG+NWCM at Sub-base layer III respectively. From the Figures, it was noticed that the composite material are more significant with morrum as sub-base material than the gravel as the sub-base layer material.

From the study, the maximum rut depth was noticed at sub-base layer III without the reinforcement of coir geotextile. It was observed that the 24mm and 11mm rut depth of sub-base layer III and sub-base layer I respectively.

4.5 Summary

This chapter contains the details description of the material used in the study. It describes the experimental study set up along with the fabricated mould and also experimental results and description. This chapter gives a detailed description of coir mats rutting behavior in various positions. The study noticed that the maximum rut depth 37mm and 24mm was found for the un-reinforcement section of 200 mm and 300 mm thickness. Further, it was reduced up to the 8mm and 5mm with reinforcement of GG and NWCM at sub-base layer III in both the cases respectively.

CHAPTER 5
ACCELERTAED PAVEMENT TEST RESULTS AND DISCUSSION

5.1 General

This chapter deals with the in-situ evaluation of coir geotextile using the Accelerated Pavement Testing (APT). The test track is constructed to quantify the in-situ benefits and effectiveness of coir geotextile materials over the poor subgrade. The response of the Accelerated Pavement Testing was obtained in the form of stress, strain, and rut depth characteristics and analyzed.

5.2 Accelerated Pavement Test (APT)

The accelerated pavement testing apparatus is loaded to produce a contact pressure of 5.6kg/cm^2. The weight of 55kg was arranged to produce the required contact pressure of 5.6kg/cm^2. A frequency of 12 repetitions per minute with the motor speed of (720) rpm was used to vary the frequency of load applications. The test was performed at a rut depth of 40mm, and the potential benefits of coir geotextile along with sub-base materials were evaluated.

5.3 Details of Accelerated Pavement Test Track

Flexible pavement structure consists of different layers with different types of materials. The primary function of this layer is to reduce the stress over the subgrade and improve the performance. The applied traffic loads over the subgrade should not exceed the safe bearing capacity and should be provided with safer riding quality to the road user. In order to reduce the stress over the weak subgrade, APT was performed to evaluate the potential benefits and its ability to resist the trafficking load under the repeated loading condition in a short period.

5.4 In-Situ Evaluation

The laboratory wheel tracking test device suffers from several drawbacks that the specimen subjected to testing is always surrounded by mould used for resting on a metal base which is never given with the testing of real pavement. Specimen size also plays an important role with respect to laboratory and field performance. In the laboratory, a wheel tracking device is used to quantify the rut depth under the constant load over the granular surface layer course. Whereas, in-situ real-time pavement test track is constructed with a moving load and determined the rut depth. Also, this equipment can be used to evaluate the performance of materials response in terms of stresses and rut depth of material, and also evaluate the potential benefits of the material.

The prepared APT test track was divided into five sections. Among them, one section is without reinforcement, and the remaining four are reinforced with coir geotextiles. The adopted subgrade thickness is of300mm. Over the prepared subgrade, the coir geotextile mats are anchored with mild steel wire at four corners over that the morrum soil is placed as a sub-base layer (I, II, and III) material. Each layer of sub-baselayer material is tested for OMC and density at field conditions. The undrained value of subgrade soil Cu is 30. Table 5.1 shows the OMC and density results, along with the thickness of the subbase layer. In order to evaluate the field condition to simulate the laboratory test and performance of the coir mats in the field, the APT is tested at the same rut depth (40mm) as adopted in the laboratory.

Table 5.1 Material properties and layers thickness used in APT Study

Subgrade thickness (mm)	Sub-Base thickness (mm)	Optimum moisture Content (%)	Dry density kN/m^3	IS Soil classification
300	120	7.5	17.5	Well Graded (GW)
300	150	7.3	16.7	Well-Graded (GW)
300	180	7.6	17.8	Well Graded (GW)

Table 5.1 shows the adopted thickness of the layer at the OMC and the density of the materials. The deformation characteristics of each layer with 60,000(IRC: SP: 72 - 2015) repetitions for (T2) traffic category were measured, maintaining the OMC and density of the sub-base soil. The Degree of Compaction (DOC) was determined at each sub-base layer of the APT. the DOC of sub-base layer Isub-base layer II, sub-base layer III are 79.5%, 75%, 80 % respectively. The placed sub-base layer material (GW and SP) was compacted using roller compaction to maintain the OMC and the density of the field sub-base soil. The sub-base soil is placed as three layers at 120mm, 150mm, and 180mm. Each layer is subjected to 60,000 repetitions. The rut depth of each layer, stress transfer efficiency and strain on the subgrade are measured with the help of a data acquisition system.OMC and MDD of the APT layer were tested on different days so that the variation has occurred. The resilient modulus of each layer at in-situ were determined using the equation of $M_R = 0.2 \times (h)^{0.45} \times M_R$ (supported) (IRC: 37-2015). The M_R value of sub-base I, sub-base II and sub-base III are found has 35 Mpa, 38 Mpa, and 39 Mpa respectively.

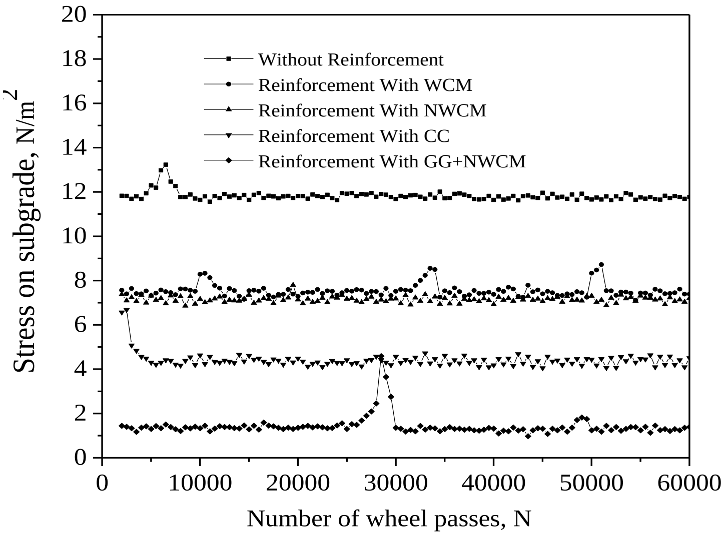


Figure 5.1 Stress and number of wheel passes for morrum sub-base layer (120mm)

Fig 5.1 shows that the stress on top of the subgrade is 12N/m^2 in case of without the reinforcement section. On the other hand, it is obtained as 1.7N/m^{2}withthe inclusion of GG and NWCM.In this case, higher stress is noticed with WCM and NWCM than the CC and GG+NWCM. The pictures are also obtained with WCM due to the lower thickness of mats (3mm) and also the opening size. However, the WCM and the NWCM have exhibited the reduction of stress than the unreinforced section. The obtained stress for WCM and NWCM coir mats are 7N/m^2 and 8N/m^{2,} respectively. The stress at the top of the subgrade along with the number of passes with different types of coir geotextile mats are shown in Fig. 5.1.

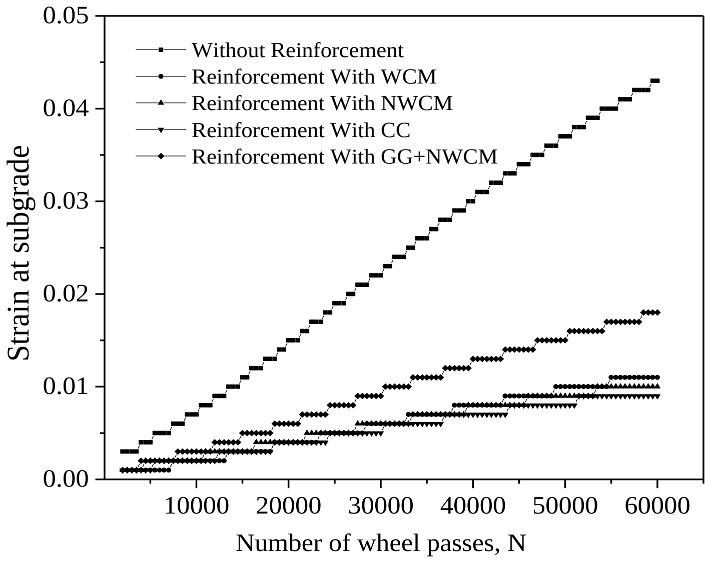


Figure 5.2 Strain and number of wheel passes for morrum sub-base layer (120mm)

Fig 5.2 shows the strain of the material at 120mm thickness of the sub-base layer from the top of the sub-base layer. The strain of 0.05 was noticed unreinforced section. In the reinforced section, strain with GG+NWCM is 0.005. The obtained strain with composite mats indicated that the provision of the coir geotextile mats over the weak subgrade evidenced in the reduction of strains. This may be due to its excellent tensile strength property as well as the thickness of the composite mats compared to the WCM. The GG and NWCM with the higher thickness of the sub-base material greatly influence the strain over the weak subgrade. It is observed that the obtained maximum strain is 0.052 in an unreinforced section than the reinforced section. The minimum 0.0125 strain is obtained in reinforced sections with coir composite mats. It is evident that the coir geotextile reduces the stress over the subgrade. Fig.5.2 shows strain over the subgrade with a respective number of passes. In this case, the horizontal dashed lines represent the same strain up to certain repetition; it is obtained without an increase in deformation. On the other hand, increasing deformation strain will increase over the coir mats and subgrade.

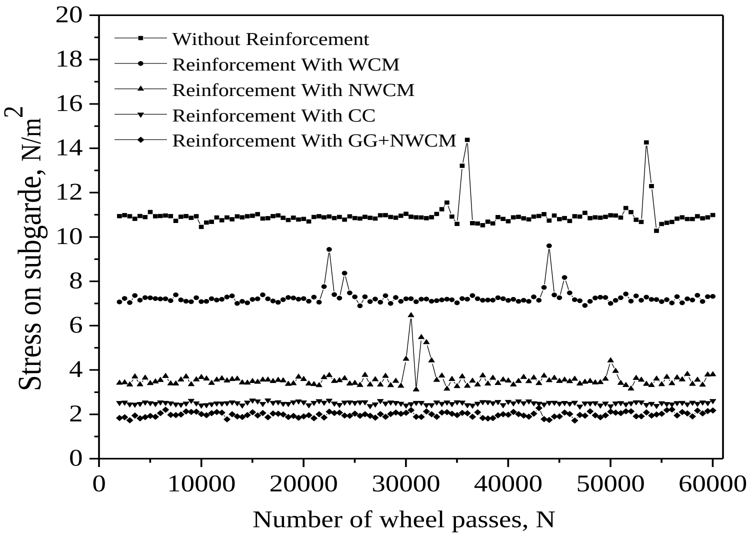


Figure 5.3 Stress and number of wheel passes for morrum sub-base layer (150 mm)

From Fig 5.3, it is evident that the unreinforced section shows higher stress over the subgrade with coir geotextile at 150mm thickness from the top sub-base layer. It is noticed that the unreinforced section has transferred more stress over the subgrade than the reinforced section. The obtained maximum stress is 11N/m^2, and it reduced up to 2.2N/m^2. The obtained stress over the unreinforced section was transferred towards the edge of the pavement. It is revealed that the composite material possesses better separation and reinforcement functions. It is evident that the coir geotextile plays a key role to reduce the stress over the subgrade and improves the number of passes. This phenomenon helps in extending the service life of the pavement.

The response of the strain with and without incorporation of coir geotextile mats was observed with morrum as sub-base layer at 150mm thickness from the top of the sub-base. It was observed that the strain in the unreinforced section is 0.04maximum, and it reduced up to

0.005 with reinforcement of the coir geotextile mats. The significant reduction of the strain was noticed with the incorporation of the coir geotextiles such as GG+NWCM, and CC. The obtained strain, along with the number of wheel passes, is shown in Fig 5.4. In this case, the provision of the coir mats such as CC, GG, and NWCM and NWCM are more effective than the WCM. This is obtained due to the woven coir mats thickness than the non-woven coir mats. It is revealed that composite mats showed better reinforcement performance in terms of the stress distribution over the weak subgrade than the non-woven and woven coir mats.

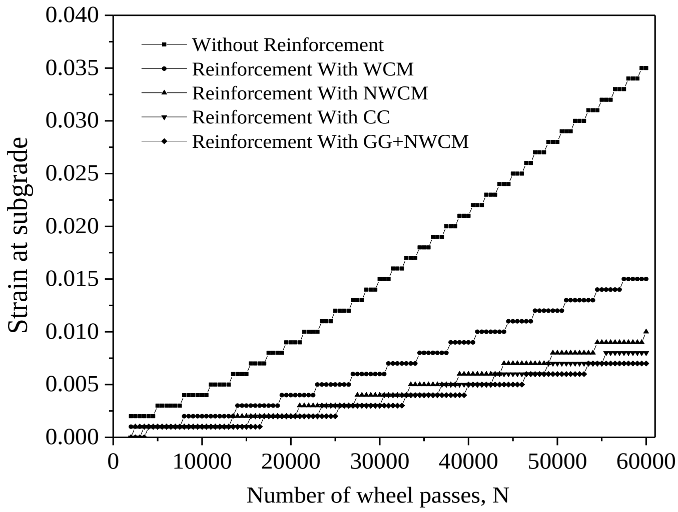


Figure 5.4 Strain and number of wheel passes for morrum sub-base layer (150mm)

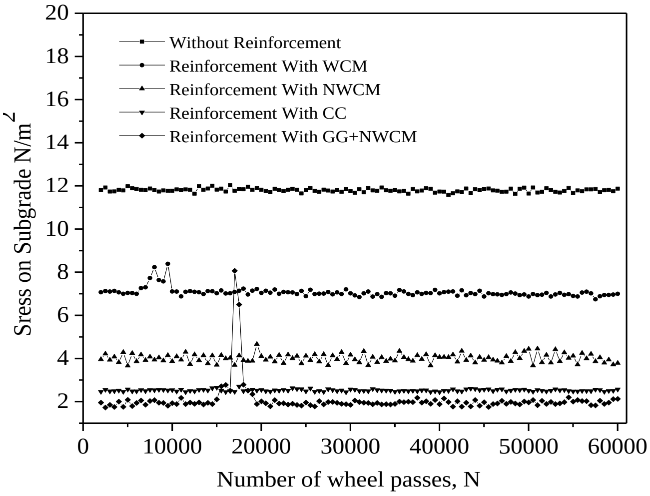


Figure 5.5 Stress and number of wheel passes for morrum sub-base layer (180mm)

From the test, it is obtained that the maximum stress was noticed as 12N/m^2 in case of the unreinforced section, while the provision of coir mats, reduced the stress to 1.5N/m^2. Among the coir geotextile, the composite mats showed more reduction of stress (CC and GG+NWCM) due to the effects of the attached geogrid. The attached geogrid gives additional tensile strength to the weak subgrade. It is noticed that the provision of coir geotextile mats helps in slow settlement and reduction of rut depth over the weak subgrade soil. Fig 5.5 shows the observed stress over the top of the subgrade with and without the inclusion of coir geotextile at 180mm thickness of sub-base.

Among the three placement positions of coir geotextile mats, the placement of coir mats with a sub-base layer thickness of 120mm is more significant with morrum soil. The morrum sub-base soil is more effective to reduce the stress over the sub-grade due to the presence of its fine cohesion particles. It improves the confinement of the coir geotextile mats and helps in extending the service life of the pavement. The inclusion of the coir mats at this position significantly reduces the thickness of the sub-base (120mm) when compared with the 180mm thickness of the sub-base.

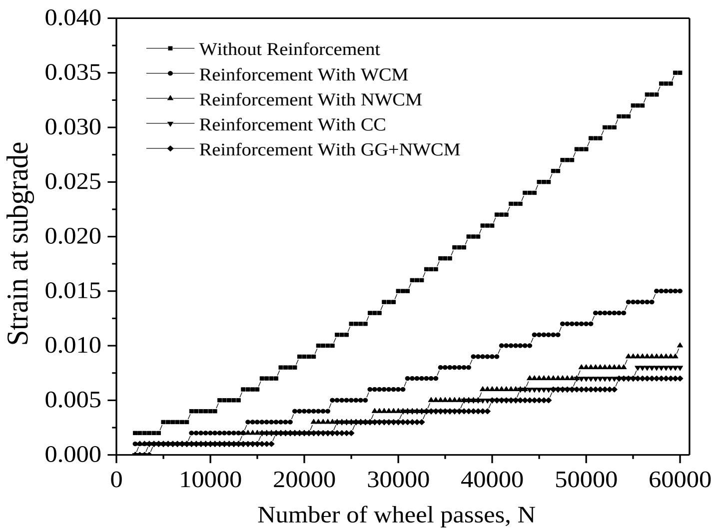


Figure 5.6. Strain and number of wheel passes for morrum sub-base layer(180mm)

Fig 5.6 shows the strain of the pavement with and without the reinforcement of coir geotextile mats at 180mm thickness of the sub-base layer from the top of the sub-base layer. At this position, reduction of strain over the subgrade was noticed in reinforcement sections (0.0057) due to composites mats (CC and GG+NWCM). In the case of unreinforced sections, without coir composites mats, the observed strain is0.012. The obtained strain, along with the number of passes, is given in Fig 5.6.

From the field study, it was evident that the obtained strain over the subgrade is higher in the case of the unreinforced section. Due to this stress, the pavement structure is subjected to several problems. However, in the same position, while reduction of the sub-base layer with the reinforcement of coir geotextile gives the additional strength to pavement structure and increases the wheel passes. The study evidence that the incorporation of the coir geotextile helps in the reduction of the stress and rut depth and also extending the service life of the pavement. Among the coir geotextile, the coir composite mats such as GG+NWCM mats show the consistent resistant to prevent the stress over the subgrade soil.

Table 5.2 Thickness of pavement layers, OMC and density of the gravel material

Layer	Subgrade layer thickness (mm)	Sub-base layer thickness (mm)	Optimum moisture Content (%)	Density (kN/m^3)	Soil classification
1	300	120	6.2	17.6	Gravel (SP)
2	300	150	5.7	16.7	Gravel (SP)
3	300	180	5.8	17.2	Gravel (SP)

Table 5.2 shows the variable thickness of the sub-base layer along with their OMC and density of gravel soil. The sub-base layer I is taken as 120mm, the sub-base layer II is taken as 150mm, and the sub-base layer III is taken as 180mm. Each of the APT layers is prepared and compacted to attain maximum density and at OMC of the soil. The evaluated OMC and density of the soil along with sub-base layer material are presented in Table 5.2. The DOC of sub-base layer II, and sub-base layer III are 88%, 83%, 86% respectively.

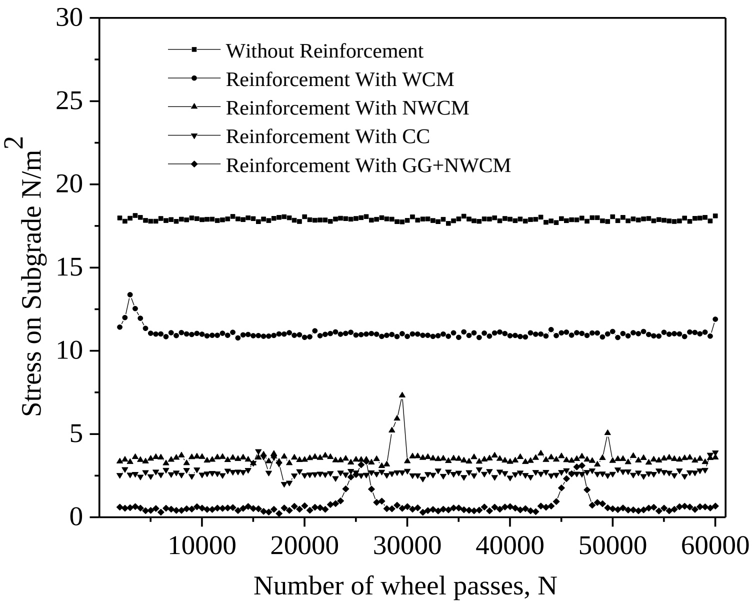


Figure 5.7. Stress and number of wheel passes for gravel sub-base layer I

The coir geotextile mats are provided at 120mm thickness of sub-base layer material from the top of the sub-base soil. Observed stress was noticed as 12N/m^{2}inthe unreinforced section of the APT. On the other hand, the reinforced section of the test track greatly reduces the stress on subgrade with the inclusion of GG+NWCM, CCand NWCM. The WCM reduced the stress to 7N/m^2. The CC and GG+NWCMobtained a significant reduction of stress to 2.7N/m^{2}and 3N/m^{2,} respectively. This obtained reduction of stress occurs due to the thickness of the coir geotextile mats and the attached geogrid. The attached geogrid added additional strength to the pavement section and improved the wheel passes. The obtained stress along with the number of passes of the reinforced and un-reinforced section is given in Fig 5.7.

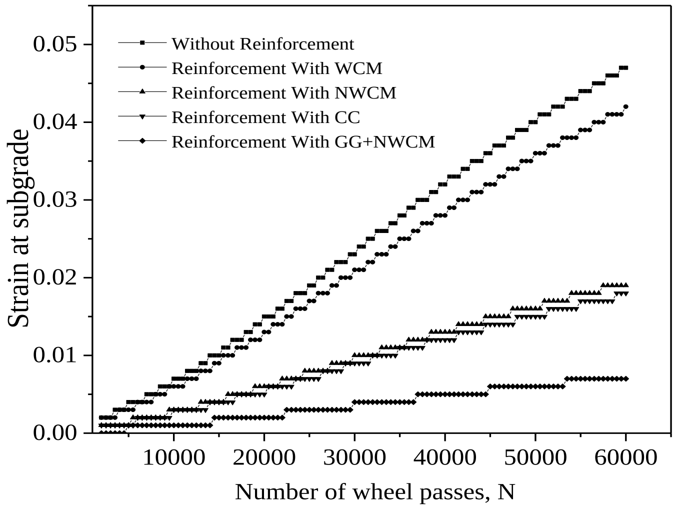


Figure 5.8. Strain and number of wheel passes for gravel sub-base layer I

Similarly, the strain of the coir geotextile mats is evaluated at 120mm thickness of the sub-base layer from the top of the sub-base. It was noticed that the strain in material is higher such as 0.047 without the provision of coir mats. It is reduced when the coir geotextile mats are provided to the pavement section. The obtained strain of the material from the APT is 0.0044 and 0.014 by the incorporation of GG+NWCM and CC, respectively. The provision of coir mat with gravel as sub-base layer initially has shown higher settlement in case of the without reinforcement section. The settlement of the layer slowly reduced with the provision of coir geotextile mats. The obtained strain on the subgrade and the number of wheels passes with the gravel as a sub-base layer (120mm) is shown in Fig 5.8. Similarly, in this case, the stress of the coir mats are evaluated with gravel as a sub-base material. The reinforced sections of the test track with gravel as sub-base layer material have shown more significant performance than 120mm and 180mm thickness of the sub-base layer material.

It was observed that without the geotextile section of APT having the stress of 15N/m^2. Further, it is reduced up to 1.5N/m^{2}with GG+NWCM. The reduction of stress is obtained with the reinforcement of coir geotextile to 1.5N/m^2 with the help of GG+NWCM. The WCM and CC mats have shown lower differences than with GG+NWCM mats. The stress on the subgrade with CC and NWCM is 2.5N/m^2 and 3N/m^{2,} respectively. The number of wheel passes and the stress at the top of the subgrade soil is shown in Fig 5.9. The gravel sub-base soil with the non-cohesive particle content sub-base can be replaced in the case of natural aggregate over the reinforcement of the coir mats. Further, it also helps in improving the confinement of the coir mats at the subgrade and sub-base interface.

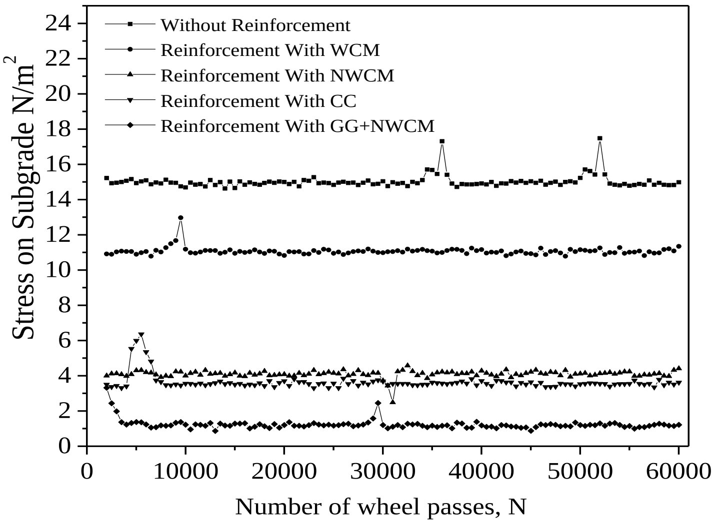


Figure 5.9 Stress and number of wheel passes for gravel sub-base layer II

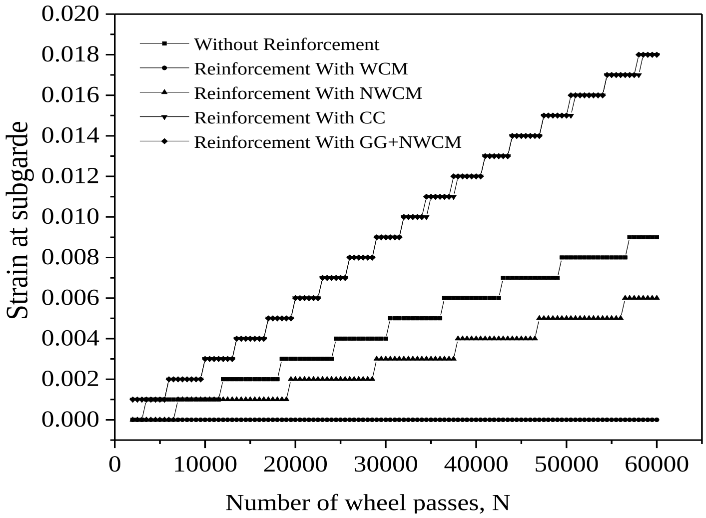


Figure 5.10 Strain and number of wheel passes for gravel sub-base layer II

Fig 5.10 shows the observed strain of the APT test at 150mm thickness of the sub-base layer. The incorporation of composite (GG+NWCM) mats has shown more significance than the CC and other types of coir geotextile mats. In this case, the minimum reinforcement was obtained as 0.001 with composite material. The reduction of strain at 150mm thickness of sub-base soil was more significant when compared with morrum as sub-base layer material than the gravel soil. The strain values and the number of passes at 150mm thickness of gravel as sub-base layer with and without Coir geotextile mats are shown in Fig 5.10.

In both cases, the provision of the coir composite mats at every position shows more significant results to reduce the stress and strain over the subgrade. It is noticed that the coir composite mats poses as multi-function to the reinforcement of the APT section and extend service life. It was concluded that the stress and strain distribution over the subgrade is greatly reduced in the case of gravel sub-base soil reinforcement with coir mats than the unreinforced pavement cross-section. The reduction of the applied load over the top of the subgrade was more significant than the morrum as the sub-base layer material.

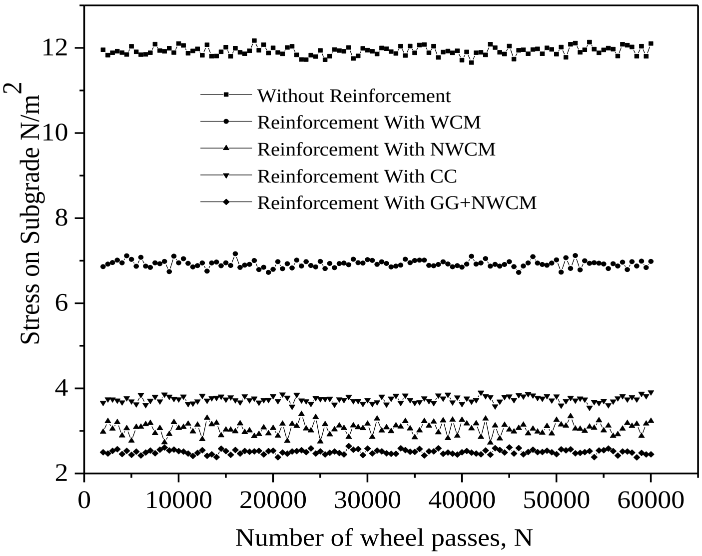


Figure 5.11 Stress and number of wheel passes for gravel sub-base layer III

Fig 5.11 shows the reinforced and unreinforced section of APT at 180mm thickness of the sub-base layer from the top of the sub-base. In this case, the stress in the unreinforced section of APT was found as 18N/m^2, and it tends to reduce up to 2N/m^2 with coir composite mats. The incorporation of coir mats with a 180mm thickness of the sub-base layer has shown a more significant reduction of the stress than with gravel of 120mm and 150mm later. The study indicates that the un-reinforced section of the test track transferred higher stresses over poor subgrade soil in all the cases. The reinforced section of the test track reduced the stresses on the poor subgrade by the provision of coir geotextile mats. The higher stress reduction was found with composite material, and among them, GG+NWCM was found more effective than the other type of coir geotextiles. The stress, along with the number of wheels passes with 180mm sub-base material, was shown in Fig 5.11.

Similarly, the strain of the coir geotextile mats is measured at 180mm thickness of the sub-base layer with gravel as sub-base soil. The reinforcement section of the APT test track showed a significant effect on the pavement section.

On the other hand, in the unreinforced section of the APT test track, the strain was measured as 0.018. The strain in the reinforced section was measured as 0.007. The inclusion of coir geotextile mats over the poor subgrade soils shows the higher reduction of strain due to the fine particles of gravel as the sub-base material. The obtained strain, along with the number of passes at 180mm thickness of sub-base layer material, is shown in Fig.5.12.

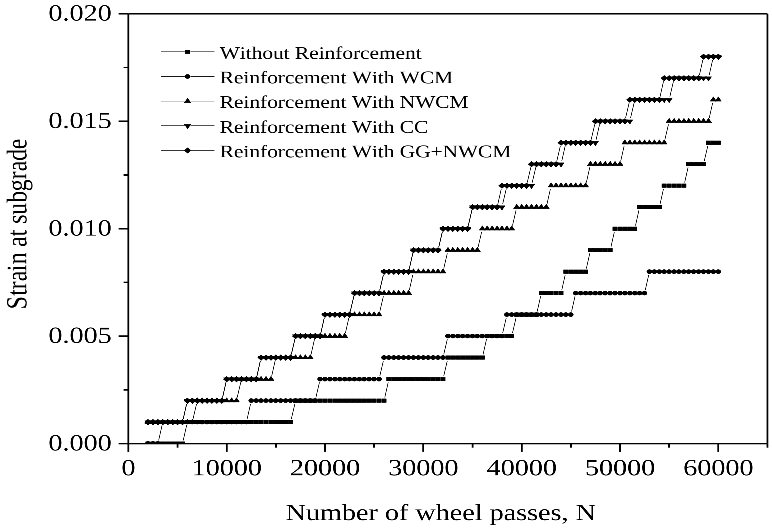


Figure 5.12 Strain and number of wheel passes for gravel sub-base layer III

Among the coir mats, it was noticed that the lower effects are obtained between the coir mats (NWCM, CC, and GG+NWCM) at the thickness of 180mm of the sub-base soil. The GG+NWCM is more effective in the reduction of the stress over the subgrade. In the other case, at the same position, the obtained load over the subgrade was lower in the case of coir composite mats and NWCM. Design of pavement based on the laboratory study, reveals that the coir geotextile is more significant with morrum as sub-base layer II thickness as compared to gravel soil. Due to the confinement and constraint of mould, it provides better results too.

Table: 5.3 Rut depth of coir geotextile mats at sub-baselayer I (120mm)

Description of the materials	Sub-Base Layer Thickness (mm)	Rut depth (mm)	IS Soil classification
Without Reinforcement	120	37	Morrum (GW)
Reinforcement With WCM	120	34	Morrum (GW)
Reinforcement With NWCM	120	35	Morrum (GW)
Reinforcement With CC	120	30	Morrum (GW)
Reinforcement :GG+NWCM	120	30	Morrum (GW)

The rut depth of the APT section was noticed at sub-base layer I. The maximum rut depth of APT section was observed as 37mm with GG+NWCM. From the APT test, the rut depth and the settlement of the pavement were measured with and without the reinforcement of coir geotextile. The rut depth and thickness of the sub-base layer material along with the type of coir geotextile mats are presented in Table 5.3. The composite (CC, Combination of GG and NWCM) material posses resistance with morrum as sub-base material, both the material show good reinforcement.

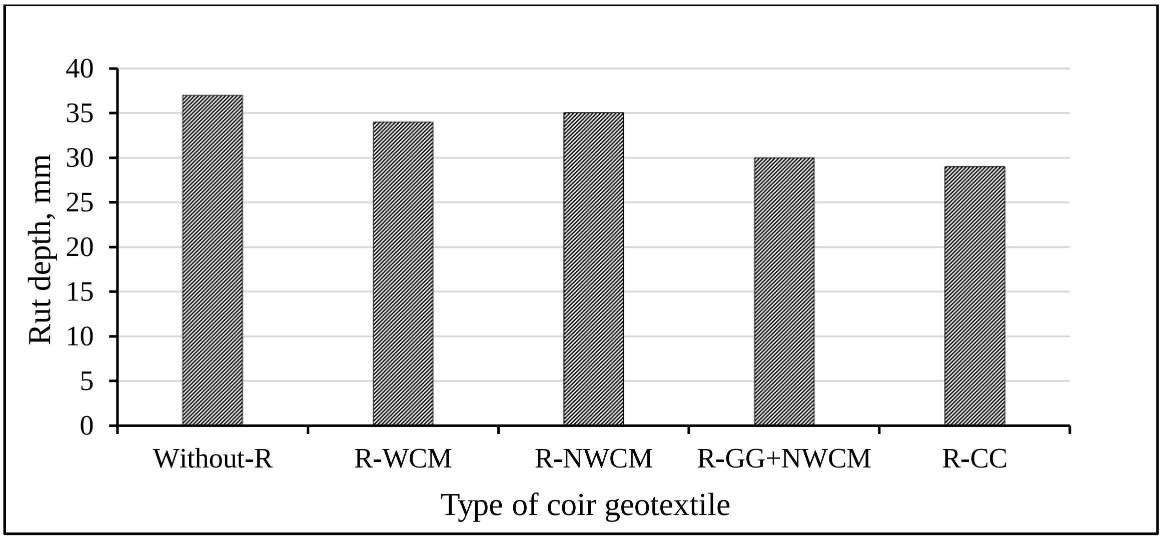


Figure 5.13. Results of Rut depth for various coir geotextile mats at sub-base layer I

The observation is made on the reinforced and unreinforced section of the field test in terms of the rut depth of the APT test section. The unreinforced section of the test track had higher rut depth with a 120mm thickness of subbase material. The provision of GG+NWCM with morrum as sub-base layer soil shows the lower rut depth than the other types of geotextile mats. The higher rut depth was noticed as 35mm in case of the unreinforced section of the APT test track, which reduced to 28mm with the placement of coir composite material. The rut depth, along with the type of coir geotextiles at 120mm thickness sub-base material, is shown in Fig 5.13.

Table: 5.4 Rut depth of coir geotextile mats at sub-base layer II (150mm)

Description of the materials	Sub-Base layer thickness (mm)	Rut depth (mm)	IS Soil classification
Without Reinforcement	150	34	Morrum (GW)
Reinforcement With WCM	150	32	Morrum (GW)
Reinforcement With NWCM	150	33	Morrum (GW)
Reinforcement With CC	150	29	Morrum(GW)
Reinforcement :GG+NWCM	150	30	Morrum (GW)

The reinforced section with CC shows 29mm of rut depth and the unreinforced section shows 34mm. At this position, the CC mats have performed better to reduce the rut depth while decreasing the stress over the subgrade, which is due to the tensile strength as well as the flexibility of the composite material. Table 5.4 shows the thickness of the sub-base layer, types of the coir geotextile mats and rut depth of each section.

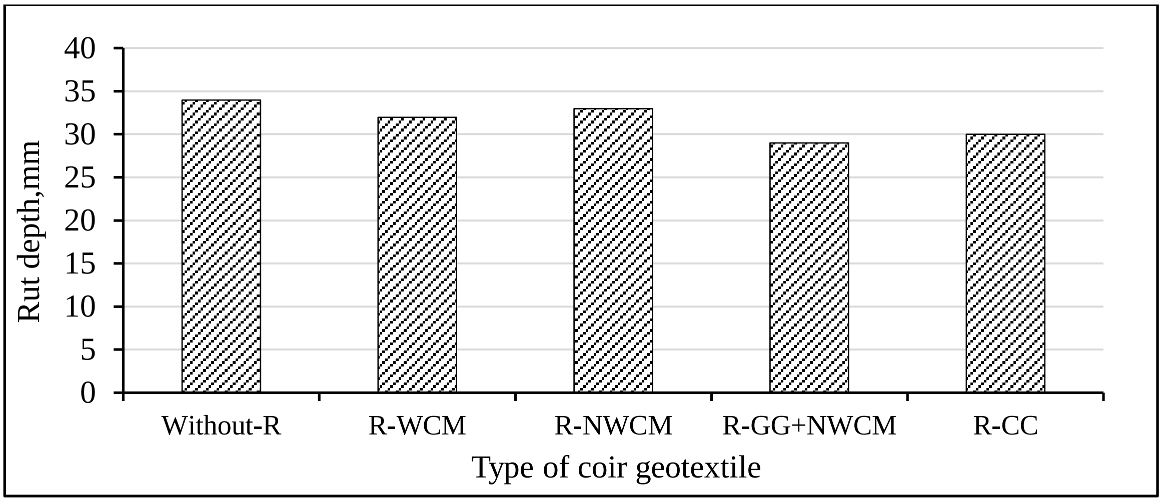


Figure 5.14 Results of rut depth for various coir geotextile mats at sub-base layer II

The rut depth of the coir geotextile in the field was estimated at each section of APT with the provisions of the 150mm thickness of the sub-base layer material. The maximum of 32mm rut depth was noticed in the unreinforced section of APT. On the other hand, the reduction of the rut depth was found as 28mm with GG+NWCM. The deformation and the types of coir geotextile are shown in Fig 5.14.

Table: 5.5 Rut depth of coir geotextile mats at sub-base layer III (180mm)

Section	Description of the materials	Sub-base layer thickness (mm)	Rut depth (mm)	IS Soil classification
1	Without Reinforcement	180	32	Morrum (GW)
2	Reinforcement With WCM	180	31	Morrum (GW)
3	Reinforcement With NWCM	180	30	Morrum (GW)
4	Reinforcement With CC	180	30	Morrum (GW)
5	Reinforcement :GG+NWCM	180	29	Morrum (GW)

The field study was performed to evaluate the rut depth of each segment of the test track. The placement position of the coir geotextile and theirrutdepth along withmorrum soil sub-base thickness are presented in Table 5.5. It shows the greater reduction of the rut depth than the gravel sub-base soil. The reduction of rut depth was obtained while reducing the similar thickness of the sub-base layer material.

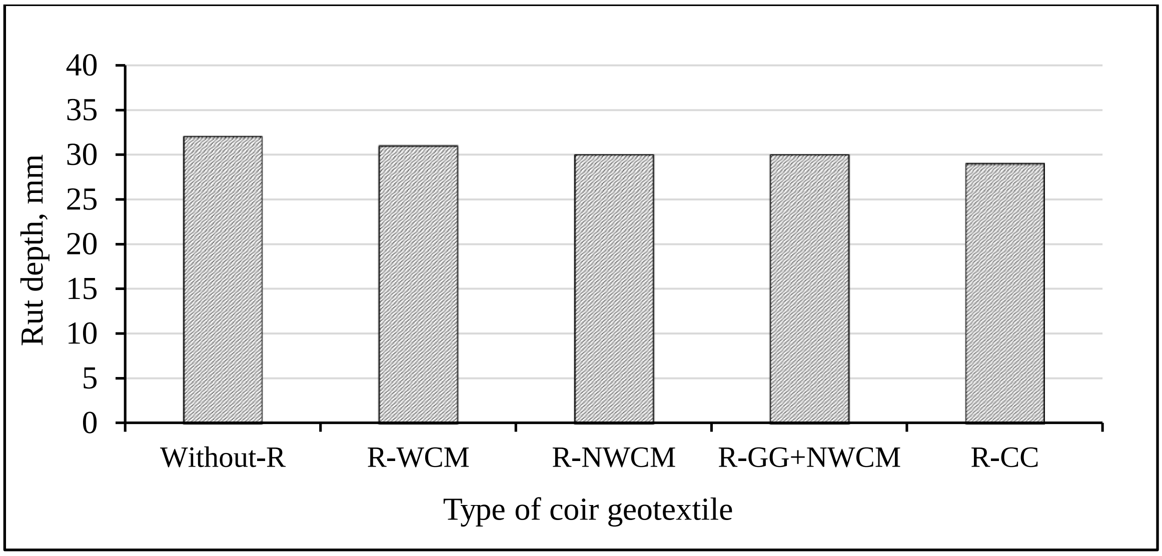


Figure 5.15 Rut depth and types coir geotextile mats at sub-base layer III

Fig 5.15 shows the rut depth of each section, rut depth of the APT with morrum as sub-base layer material from the bottom of the APT wheel (120mm). The higher rut depth was measured in the unreinforced section, such as 34mm. The reinforcement section of the APT test track with morrum as sub-base soil has shown more significant results than the gravel soil. The reduction of the rut depth was noticed in the case of the reinforced section of APT with coir mats. Due to the dual function of the composite material, the obtained stress was transferred towards the edge of the pavement and improved the performance. The rut depth of coir geotextile is shown in Fig 5.15

Table: 5.6 Rut depth of coir geotextile mats at sub-base layer I (120mm)

Section	Description of the materials	Sub-Base layer Thickness (mm)	Rut depth (mm)	IS Soil classification
1	Without Reinforcement	120	37	Gravel (SP)
2	Reinforcement With WCM	120	34	Gravel (SP)
3	Reinforcement With NWCM	120	35	Gravel (SP)
4	Reinforcement With CC	120	32	Gravel (SP)
5	Reinforcement With GG+NWCM	120	28	Gravel (SP)

The current study evaluated the rutting potential of coir geotextile mats with variable thickness of the sub-base layer, as shown in Table 5.6.At this position, coir geotextile mats are shown with higher rut depth as compared with the thickness of 150mm and 180mm. The rut depth of the test track was measured after the test of each layer. In the unreinforced section, rut depth is 37mm at 60,000 passes, which is the higher rut depth in all the cases. The reduction of rut depth up to 28mm has taken place with GG+NWCM. It is due to the composite mat, which gives the proper separation as well as reinforcement function to the pavement section.

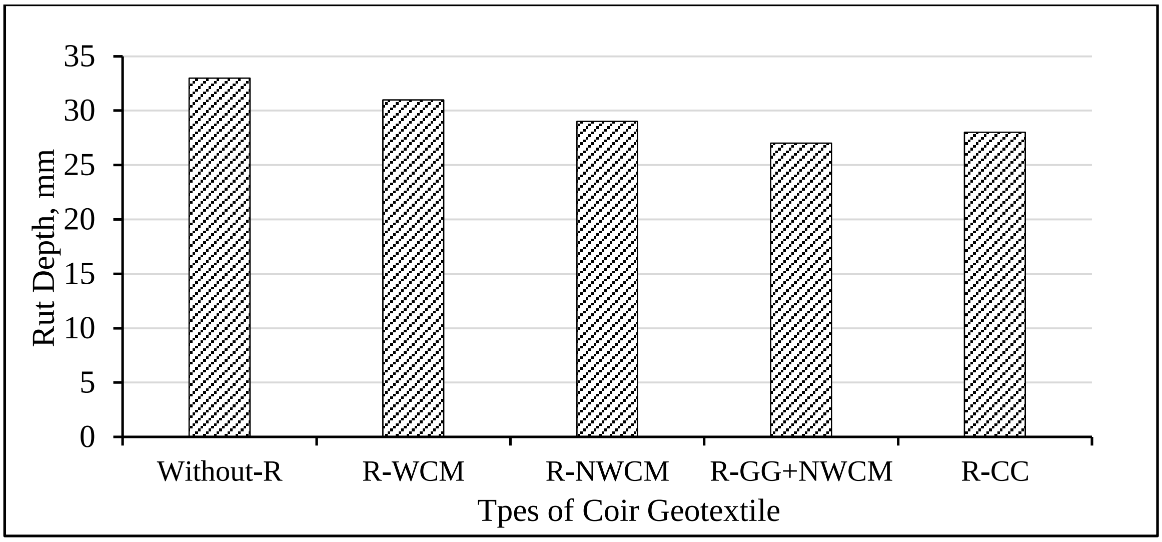


Figure 5.16 Rut depth and types of coir geotextile mats with gravel as sub-base layer I

The rut depth of the coir geotextile is observed at 120mm thickness of the sub-base layer. The obtained rut depth after the test was measured as 38mm in case of the unreinforced section of the test track. The placement of the GG+NWCM along with 180mm thickness (higher thickness of the sub-base layer) of the sub-base material has shown lower deformation as 25mm. It clearly reveals that it posses insufficient separation functions to the pavement due to its larger opening sizes. The rut depth of the coir geotextile with gravel as a sub-base material as the layer is shown in Fig 5.16.

Table: 5.7 Rut depth of coir geotextile mats at sub-base layer II (150mm)

Section	Description of the materials	Sub-Base layer thickness (mm)	Rut depth (mm)	IS Soil classification
1	Without Reinforcement	150	35	Gravel (SP)
2	Reinforcement With WCM	150	31	Gravel (SP)
3	Reinforcement With NWCM	150	33	Gravel (SP)
4	Reinforcement With CC	150	26	Gravel (SP)
5	Reinforcement With GG+NWCM	150	27	Gravel (SP)

The APT test was revolved at 150mm thickness of the sub-base layer material from the top. The unreinforced section of the APT test track has shown higher rut depth as 35mm, and the reinforced section of the APT has shown lower rut depth as 27mm, which is due to the thickness of the coir mats and attached geogrid. The thickness of the sub-base, type of the geotextiles, along with their rut depth, is shown in Table 5.7. The significant reduction of rut depth was obtained with composite material; among them, the CC has shown lower rut depth than the GG+NWCM.

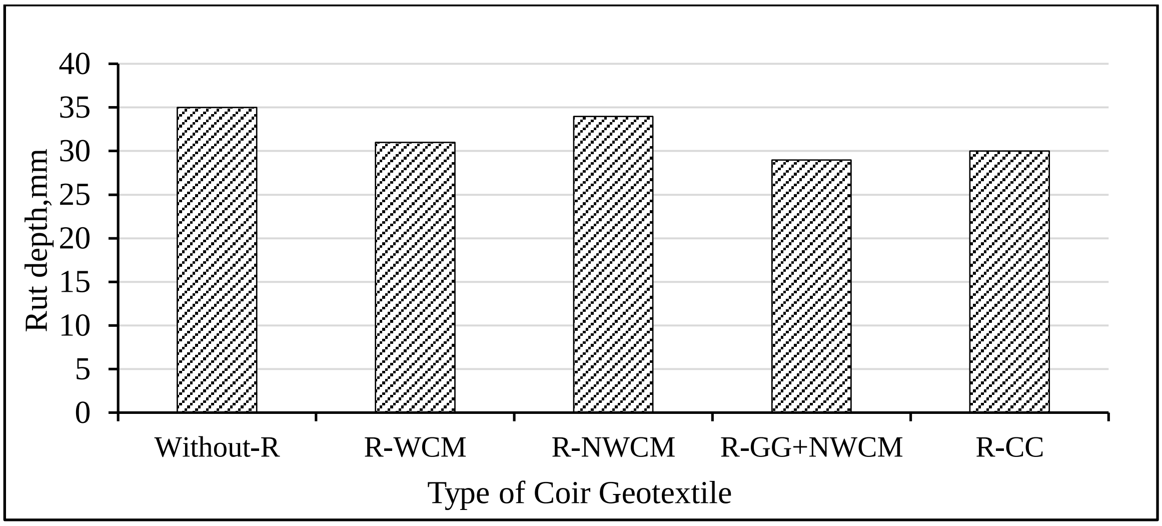


Figure 5.17 Results of rut depth for various coir geotextile mats gravel sub-base layer II

In this case, the unreinforced and the reinforced section of the APT test track with WCM were showing similar rut depth (behavior). The WCM was poor in action as a tension member and also posed insufficient separation function to the pavement section. The reduction of rut depth was found in the case of the provision of CC because of its better separation and reinforcement functions to the APT test track. The obtained rut depth along with coir geotextile as sub-base layer II is shown in Fig 5.17. The study observed that the composite material possess dual functions to the pavement functions such as reinforcement as well as separation. It helps in the reduction of rut depth and also helps in extending the service life of the pavement.

Table: 5.8 Rut depth of coir geotextile mats at sub-base layer III (180mm)

Section	Description of the materials	Sub-base layer thickness (mm)	Rut depth (mm)	IS Soil classification
1	Without Reinforcement	180	33	Gravel (SP)
2	Reinforcement With WCM	180	31	Gravel (SP)
3	Reinforcement With NWCM	180	28	Gravel (SP)
4	Reinforcement With CC	180	26	Gravel (SP)
5	Reinforcement With G+NWCM	180	27	Gravel (SP)

The cross-section of the APT test track was planned with the sub-base thickness of 120mm with gravel material, and the rut depth of each section was measured after the revolution of

APT (test). The maximum and minimum deformation of each section was measured with and without the reinforcement of coir geotextile mats. The thickness of the layer and the type of the geotextiles along with their deformation are presented in Table 5.8.

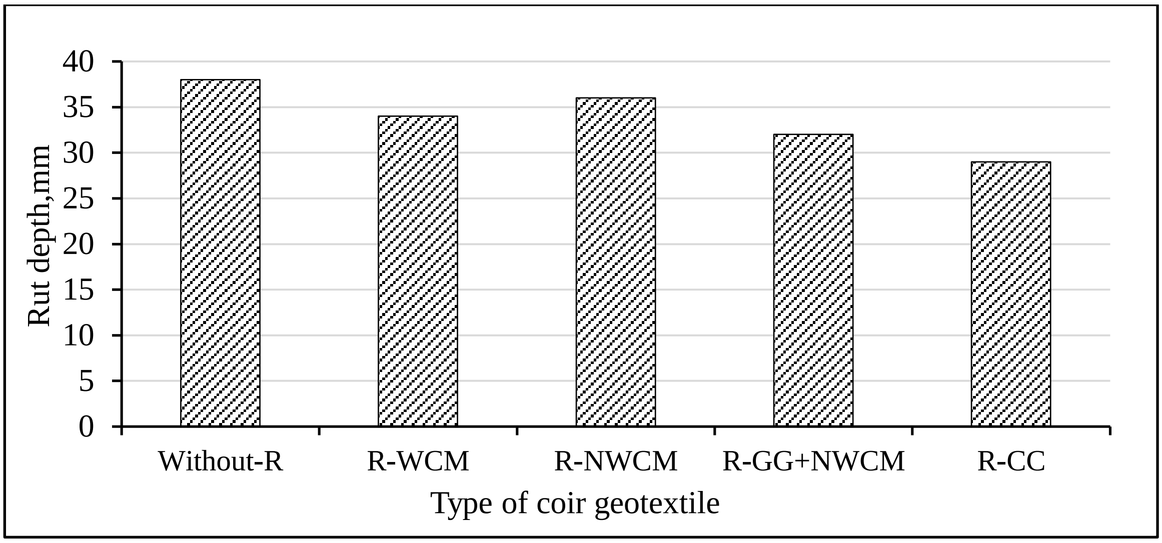


Figure 5.18. Results of rut depth and types of coir geotextile mats with gravel as sub-base layer III

The field study determines the rut depth of the test track at each section with gravel as a sub-baselayer material (120mm thickness). The unreinforced section of the test track showed higher rut depth (38mm) than the sub-base layer thickness of 150mm and 180mm. The higher Rut depth occurred with, the lower thickness of the sub-base layer without the reinforcement of coir geotextiles. The reinforcement of CC mat shows a better reduction of rut depth than the other types of coir geotextile. The incorporation of CC to the APT test track will perform better over a longer period and possess dual functions. The types of the coir geotextile and their rut depth at layer III are shown in Fig 5.18.

Design of pavement based on the laboratory study using coir geotextile shows the poor performance with morrum soil as a sub-base material. This may be due to the constraint of the mould size. However, in the in-situ method, the morrum soil showed dust when the tyre was moving over the track, due to the presence of the cohesive fine particles. Coir geotextile with gravel as sub-base material showed more effectiveness. While providing the sub-base thickness in descending order, it showed that there is a significant performance of coir geotextile. It is noticed that the reduction in sub-base material thickness is more for gravel soil (55mm) as compared with 40 mm thickness of morrum soil. This settlement phenomenon helps in the slow settlement of pavement while improving the passes and extending the service life of LVRs.

5.5 Summary

This chapter has addressed the evaluation of coir geotextile mats in in-situ conditions using the APT. From the APT study; it was observed that the coir composite materials are better in reinforcement and separation functions. The CC and GG with NWCM with Gravel (GW) as sub-base material shown more significant results than the morrum sub-base material. Among the woven and non-woven coir mats, non-woven coir mats are helped for the protection of intermixing of layer material.

Chapter 6
FLEXIBLE PAVEMENT DESIGN USING COIR GEOTEXTILE

6.1 General

The design of flexible pavement is mainly dealt with determining the thickness of the pavement layer and the performance of the underlying soil. The life of the structure mainly depends upon the underlying material properties. This present chapter insight into various flexible pavement design methods and demonstrate the pavement design using coir geotextile for LVRs.

6.2 Methods of Flexible Pavement Design

Several methods of flexible pavement design are available with their limitations and boundary conditions. The following are the design methods of flexible pavement such as

- Indian Road Congress (IRC) method,
- Giroud and Noiray method,
- Empirical Method (with and without soil strength),
- Limiting shear failure methods,
- Mechanistic-Empirical (ME) methods,
- AASHTOand US army method

In the current study, the IRC method of pavement flexible pavement design was adopted to design the flexible pavement using the coir geotextile. The flexible design pavement for LVRs is carried based laboratory and in-situ test track studies using coir geotextiles.

6.2.1 IRC Method

First design guideline of flexible pavement was given by the Indian Roads Congress (IRC) in 1970, in which the thickness of the pavement was considered by CBR value of the subgrade soil from the charts. Further, the design guideline was revised in 1984 while considering traffic load in terms of the cumulative standard axle loads. The design chart is given to arriving pavement thickness as per IRC: SP: 20-2002. After that, the existing design guidelines were modified and new guidelines entitled "Guidelines for the design of flexible pavements for Low Volume Rural Roads (IRC: SP: 72 2007) came into practice. There are several important points considered while evolving the suitable and economical design for LVRRs in India. The first and foremost aspect is practicable construction of LVRs is to recommend the locally available resources of the material. Moreover, the level of expertise in the rural areas, availability of the equipment for construction and maintenance as well as the level of quality control that can be effectively exercised. To the extent possible, the use of locally available materials as such or after suitable processing has to be maximized in the larger interest of the economy. The design life to be taken for purposes of pavement design should be neither be too short require expensive up-gradation at close intervals not should it be so long as to require prohibitively high cost of initial construction. Lastly, the design approach should aim at providing the level of serviceability which should not fall below the minimum acceptable level during the design life, essentially amounting to evolving performance-based designs. All these essential considerations and international experience have to be kept in view while working out suitable and economical pavement designs for LVRRs.

6.2.2 IRC: SP: 20-2002 Design Approach

In the first edition of IRC: SP: 20-2002 the traffic is considered in terms of the commercial vehicle per day, grouping the heavy commercial vehicle. The percentage of laden and overloaded commercial vehicles have not been considered in the traffic parameter. The subgrade strength parameter is evaluated in terms of 4 days soaked CBR. A set of pavement design charts were provided for traffic levels ranging from 15 to 150CVPD classify A to D category.

6.2.3 IRC: SP: 72-2007 Design Approach

Recognizing the above issues in IRC: SP: 20-2002 and international expertise for the past several decades on LVRRs and Gravel roads, the first revision of low volume road pavement design is recommended. Namely "Guidelines for the design of flexible pavements for low volume rural roads (IRC: SP: 72-2007), the salient features of the design are

- Pavement design for new roads as well as for the up gradation and rehabilitation have been included.
- The recommenced design procedure recommended using the locally available materials, including waste materials.
- The traffic is considered in terms of MSA and traffic defined T1to T7 curves.
- The subgrade is categorized intofive classes.

6.2.4 IRC: SP: 72-2015 Design Approach

Considering the growth of traffic in rural areas and the modifications in IRC: 37-2012, design guideline for high volume roads with minimum traffic for 2msa, it has become necessary to include design charts for the traffic more than 1msa and up to 2msa. Accordingly, two more traffic categories of T8 and T9 have been included in the code practice.

The existing IRC: SP: 72-2007 recommends a minimum thickness of 150mm soil-cement base and 100mm soil-cement sub-base for all the LVRRs. However, the design charts considering the strength of the subgrade and the design traffic was not available in these guidelines. The revised guidelines provide design monographs of cement stabilized base and sub-base course based on traffic and subgrade strength.

6.3 Giroud and Noiray approach for the design of pavement using Geotextiles

The design of pavement using geotextile was proposed by Giroud and Noiray in 1981. This method was proposed and used extensively by various engineering communities responsible for the construction and maintenance of LVRs. This method is suitable for light to medium traffic over a lifetime road. The subgrade thickness was sufficient for the development of the plastic zone. The subgrade is homogeneous, and the provision of geotextile increases the bearing capacity, which is met from elastic to ultimate bearing capacity or local to general shear failure (Terzaghi's).

The Giroud and Noiray approach

Normal highway vehicles including lorries

$$B = \sqrt{p/pt} \tag{6.3}$$

$$L = 0.707B \tag{6.4}$$

Heavy construction plant with wide or double tyres

$$B = \sqrt{1.414p/pt} \tag{6.5}$$

$$L = 0.5B \tag{6.6}$$

For the construction plant, a typical value of pt is 620 kN/m^2. The stress p applied to the cohesive formation by the axle is

$$p = P/2(B+2h * \tan\alpha)(L+2h * \tan\alpha) \tag{6.7}$$

As the analysis is not very sensitive to the exact value of tanα and experiments indicate that tan lies between 0.5 and 0.7, tanα may be taken as 0.6

$$p = P/2(B+1.2h)(L+1.2h) \qquad (6.8)$$

Making use of the net elastic bearing capacity (qc) and the ultimate or plastic bearing capacity (qp),

Defined as:

$$q_e = \pi Cu \qquad (6.9)$$

$$q_p = (\pi + 2)Cu \qquad (6.10)$$

Where,

Cu is the undrained cohesion of the underlying soil

To control any contamination of the aggregate, it is suggested that in the absence of a geotextile, the applied load from the axle be limited to qe for $p = q_e$

$$\pi\, Cu = P/2(B+1.2h)(L+1.2h) \qquad (6.11)$$

The value of ho remains valid for very light traffic, up to about 20 axle passes. However, the aggregate depth must be increased to ho for heavier traffic.

$$h_o = \frac{[(125 \log N - 294(r - 0.075)]}{C_u^{0.63}} \qquad (6.12)$$

Where,

N is the number of passes of a standard axle (80 kN)

r is the rut depth in m

Cu is undrained soil cohesion in N/m^2 (not in kN/m^2)

h_o is the aggregate depth in m

The loading is represented in terms of wheel passes $N^!$, other than the standard axle load can be converted into the equivalent standard axle load using the following equation.

$$N/N' = (P'/P)^{3.93} \qquad (6.13)$$

If the equation is not suitable (the suitability of this question is doubtful), an appropriate theoretical equation is given to convert the axle load using the equation below: (P' is an applied aload, and P is standered load)

$$N/N' = (P'/P)^{6.2} \qquad (6.14)$$

6.4 Flexible Pavement Design Based on Laboratory Study

The performance study has been conducted in the laboratory as well as in the field. The in-situ test track study was performed for the T2 traffic category (30,000-60, 0000, ESALs). Each of the axle loads was 55kg; the tyre pressure was 5.6 kN/m^2. The underlying soil has an undrained cohesion of 30 kN/m^2, the unit weight of the soil is 18 kN/m^3. Then determining the thickness of pavement material with and without reinforced section using Giroud and Noirayapproachfor 10 year life. There are two main approaches to the design of flexible pavement, as presented below.

- Without reinforcement of Geotextiles and,
- With Reinforcement of Geotextiles

6.4.1 Conventional Design Steps

Step 1: N=60000 =two tyre = (2 * 60000) = 120000

$N= 60000 * (55/80)^{6.2} *2$

$N= 60000 * (0.6875)^{6.2} *2 =60000 * 0.0979 * 2=11,756$ ESAL

Step 2: Loading to 11,756 pass of standard load (80 kN).

$$h_o = \frac{[(125x4.0-294(0.37-0.075)]}{30^{0.63}} \quad (6.15)$$

$$h_o = \frac{[500-294*0.295]}{8.5} \quad (6.16)$$

ho= 413.27/8.55=48.33=480mm (without geotextile)

6.4.2 Giroud and Noiray approach

Normal highway vehicles including lorries

$$B = \sqrt{p/pt} \quad (6.17)$$

$$L = 0.707B \quad (6.18)$$

Heavy construction plant with wide or double tyres

$$B = \sqrt{1.414p/pt} \tag{6.19}$$

$$L = 0.5B \tag{6.20}$$

The value of ho remains valid for very light traffic, up to about 20 axle passes. However, the aggregate depth must be increased to ho for heavier traffic.

$$h_o = \frac{[(125logN - 294(r - 0.075)]}{C_u^{0.63}} \tag{6.21}$$

Where,

N is the number of passes of a standard axle (80 kN)

r is the rut depth in m

Cu is undrained soil cohesion in N/m^2 (not in kN/m^2)

h_o is the aggregate depth in m

Step 1

$N/N' = (P'/P)^{3.93} =$

$N/N' = (P'/P)^{6.2} = 60000 * (55/80)^{6.2} * 2 = 60000 * 0.0979 * 2 = 11{,}756$ ESAL

$$h_o = \frac{[(125logN - 294(r - 0.075)]}{C_u^{0.63}} \tag{6.22}$$

h_o= (500-294 * 0.295)/(8.5)=413.27/8.55=48.33=480mm

The un-reinforcement section thickness was 480mm. The reduction of the layer thickness using the coir geotextile mats are as follows. With the help of a modified CBR value equation, the reduction of thickness was determined.

$$CBRm = 0.916 + 1.249\,(CBR) - 0.363\,D + 0.0255\,Es \tag{6.23}$$

Where,

CBR=California Bearing Ratio

D=depth of the coir mats placed

Es= young's modulus of the coir geotextile

6.5 Design of Pavement using Coir Geotextiles

6.5.1 Design of Pavement Thickness with Woven coir mats

(CBR=2, Es=5.559, D=220mm,250mm,280mm)

$(CBRm)_{wcm}at = 0.916 + 1.249 (CBR)-0.363 D + 0.0255 Es$ (6.24)

=3.414-0.363 * D+0.1417 =3.557-0.0798 =347 mm

Sub-base layer I = 480 - 347 =133mm;

Sub-base layer II = 480 – 346 =134mm;Sub-base layer III = 480 - 345 =135mm

6.5.2 Design of Pavement Thickness with CC

(CBR=2, Es=13.35, D=220mm, 250mm, 280mm)

$(CBRm)_{CC}at = 0.916 + 1.249 (CBR)-0.363 D + 0.0255 Es$ (6.25)

=3.414-0.363 *D+0.1417 =3.754-0.0798 =367mm

Sub-base layer I =480 – 367=113mm

Sub-base layer II =480 – 366 =114mm

Sub-base layer III =480 – 365 =115mm

6.5.3 Design of Pavement Thickness with GG+NWCM

(CBR=2, Es=14.560, D=220mm, 250mm, 280mm)

$(CBRm)_{GG+NWCM}at = 0.916 + 1.249 (CBR)-0.363 D + 0.0255 Es$ (6.26)

=3.414-0.363 * D+0.371 =378-0.0798 =377.9mm

Sub-base layer I = 480 -377.9 = 102 m

Sub-base layer II = 480 - 377.92 = 102 mm

Sub-base layer III = 480 - 377.89 =102.1mm

6.6 Flexible Pavement Design Based on the Field Study

6.6.1 Design of Pavement Thickness with Woven coir mats

(CBR=2, Es=5.559, D=120mm, 150mm, 180mm)

$(CBRm)_{wcm}$ at= 0.916 + 1.249 (CBR)-0.363 D + 0.0255 Es (6.27)

=3.414- 0.363 * D+0.1417 =3.557- 0.043 = 351 mm

Sub-base layer I =480 – 351 =129mm

Sub-base layer II =480 – 350 =130mm

Sub-base layer III =480 – 345 =131mm

6.6.2 Design of Pavement Thickness with CC

(CBR=2, Es=13.35, D=120mm, 150mm, 180mm)

$(CBRm)_{CC}at = 0.916 + 1.249\ (CBR)-0.363\ D + 0.0255\ Es$ (6.28)

= 3.414 - 0.363 * D+0.1417 =3.754-0.0798 = 371mm

Sub-base layer I = 480 -371 =109mm

Sub-base layer II = 480 – 369 =111mm

Sub-base layer III = 480 - 368 =112mm

6.6.3 Design of Pavement Thickness with GG+NWCM

(CBR=2, Es=14.560, D=120mm, 150mm, 180mm)

$(CBRm)_{GG+NWCM}at = 0.916 + 1.249\ (CBR)-0.363\ D + 0.0255\ Es$ (6.29)

= 3.414-0.363 * D+ 0.371 =3.785 -0.0798 = 374.1 mm

Sub-base layer I = 480 – 374.1 = 105.9 mm

Sub-base layer II = 480 - 373 = 107 mm

Sub-base layer III = 480 – 371.9 = 108.1mm

It is observed from the analysis that, design of pavement based on the laboratory study using coir geotextile required higher pavement thickness. The reduction of stress and obtained deformation are affected by the pavement design due to the constraint of sample mould size. It was observed that the coir geotextile reinforced pavement section is more significant with morrum as a sub-base material.

Design of pavement based on the laboratory study consists of the higher thickness of sub-base material then the field. On the other hand, the design of pavement based on the filed condition shows the more effective in the reduction of stress and deformation. The reduction of sub-base layer thickness depends on the properties of the coir geotextile (opening size, thickness, woven and non-woven and composite mats) and also depends on the strength properties (CBR) of sub-base layer material. The reduction of sub-base material is more in the case of gravel soil as compared with morrum material.

The design of pavement based on field condition shows that the field studies are more realistic and suitable for pavement design with coir geotextile. As per the field study, the design with gravel and morrum as sub-base material reduces the thickness of pavement 75mm and 45mm, respectively, with the inclusion of coir geotextile mats (CC, GG+NWCM). The inclusion of geotextile is evidencedin the reduction ofstress and strain over the subgrade and also rut depth. It was concluded that providing coir geotextile improves the confinement of the pavement structure and extending the service life of the pavement.

6.7 Economic evaluation of coir geotextile mats for LVRs

The long-term benefits of coir geotextile obtained by saving of overlay thickness and the loss of aggregate to subgrade in the form of separation and reinforcement to the pavement over the BC soil subgrade. It is evident that the pavement without coir geotextile requires overlay within the five years, but in this case, the use of coir geotextile extends ten years.

Cost comparison of the contaminated base layer without using coir geotextile, in such case the 25mm of base layer material gets contaminated to fine soil of the subgrade. In this case, the cost of geotextile compared to the cost of the 25mm base course layer. Sometime the whole base course may contaminate due to fine soil of subgrade. In this case, the cost comparison may extend to the whole depth of the base course.

6.7.1 Fringe Benefits Coir Geotextiles

The conventional system of pavement design required pavement structure as subgrade, sub-base, base and the wearing course (IRC: SP: 72-2015). The GSB is acting as a drainage layer. However, the uses of coir geotextile mats with gravel and morrum as sub-base material gives the benefits of saving the GSB layer. The role of the GSB layer is taken care of by coir geotextile, which is highly permeable. The absence of the GSB layer by providing the coir geotextile, there will be a considerable saving of natural material required for the construction of the GSB layer, and it is more economical.

Whenever the problematic soft ground is encountered, the pavement is constructed on a high embankment, and the flowing of rainwater over the embankment may result in soil erosion, which leads to a reduction of life of embankment. In that situation, the coir geotextile can be used to prevent soil erosion. For this purpose, different densities of coir yarn are spread over the embankment slopes, resulting in the deposition of eroding soil on the ropes of coir geotextiles. Coir geotextile can absorb water naturally, and it helps in the growth of new vegetation for up to five years. This is enough time to protect soil erosion. Which support to new vegetation to strive root and improve soil properties.

6.8 Cost Benefits Analysis

It is observed that the inclusion of coir geotextile mats reduces the thickness of the sub-base layer material up to 45 and 75 mm with different types of sub-base material (Morrum and Gravel). The cost-benefits analysis carried out in this research study shown that a saving of GSB course materials against the cost of coir geotextile mats. The following is the typical example of a cost analysis of road constructed with and without coir geotextiles inn Thotapalli village of NagramMandal in Guntur district of Andhra Pradesh. In this case study, the coir geotextile mats are installed over BC soil subgrade and then the 25mmof GSB layer laid over the coir geotextile mats. The study provided composite mats. The cost of the composite mats is 170/- per meter as per the Standard Schedule of rates (SSR) Coir board Kerala. The length of the roads is 1 km, and the width is 3.75 m. The conventional pavement thickness over the BC soil is 480mm without the inclusion of coir geotextile. It can be reduced with coir geotextile with the replacement of morrum and gravel as sub-base material in the case of the GSB layer.

Table 6.1 The thickness reduction of Sub-base materials.

S.No	Description	Type of Coir Geotextile	Total thickness (mm)	Saving of sub-base material (mm)
1	Conventional Pavement thickness	Without geotextile	480	-
2	Adopted thickness	With Woven coir mats	350	130
3	Adopted thickness	Coir composite	369	111
4	Adopted thickness	Combination of GG and NWCM	373	107

Reduction of cost is obtained with the inclusion of the coir geotextile mats, and along with the sub-base (morrum and gravel), the material is Rs 234.37 per/m. From the study, it is found that the more saving is shown in case of woven mats which are relatively functioning poor separation and reinforcement functions. The coir composites are showed more economical and efficient material than the combination of geogrid and non-woven coir mats. It is noticed that the coir composite mats showed a better reduction of rut depth and proper separation function over such poor subgrade soil.

Table 6.2 Cost analysis of various geotextiles

S.No	Description of Materials	Quantity	Price per single Unit materials	Total (Rs)
1	Geogrid and Non-Woven Coir mats Width of the mat is 1m Length of the mat is 10m	For 01km of road length and 3.75 m width, the required mats are 500 No of mats	Cost of GG+NWCM is Rs.190/ m	9,50,000
		For 01km of road length and 3.75 m width, the required mats are 500 No of mats	Cost of coir composite is Rs.170/m	8,50,000
		For 01km of road length and 3.75 m width, the required mats are 500 No of mats	Cost of woven coir mats is Rs.110/m	5,50,000
2	Granular subbase materials	The thickness of the GSB layer for unit length is (250*1000*3.75) 937.5 m^3	Rs.450/m^3	4,21,875
3	Morrum (or) Gravel	937.5 m^3	Rs.200/m^3	1,87,500
Saving in terms of sub-base layer (GSB - Morrum (or) Gravel)				**Rs. 2,34,375/km**

6.9 Summary

This chapter consists of the design of flexible pavement using the empirical equation. The design methodology was adopted based on the thickness of reinforcement and without the reinforcement section of the pavement in the laboratory as well as field study and also the economic evaluation of coir geotextiles.

CHAPTER 7
SUMMARY AND CONCLUSIONS

7.1 General

In the present chapter, the summary of the study and the conclusions drawn are presented. Further, the limitations of the work and the scope of future work are also presented.

7.2 Summary

The key to the effective performance of flexible pavement is to understand the cause of failure and certain method to extend the performance of the pavement. In general, Low-Volume roads consist of a combination of natural soil subgrade, granular layer and thin asphalt surface course of 20mm. This 20mm of asphalt surface course does not add any strength to the pavement layer. It only acts as a dust palliative layer and sound riding surface layer.

Weak subgrade soil causes various kinds of problems in the form of distress such as rutting, cracking, fatigue, etc. Conceptually, whenever the poor subgrade soil is encountered, it has been a practice to increase strength and replace it with alternative soil. However, this process is laborious and time-consuming. Given the recent past, the geosynthetic materials gained much importance as an alternative material in the form of various types of geotextiles, geogrid, composites, woven and non-woven materials as an alternative solution. In this study, an attempt is made to introduce coir geotextile materials in between the subgrade and granular layer to act as reinforcement, a medium of separation and provide drainage to improve the service life of the pavement. To achieve this target, a laboratory study using wheel tracking test has been used to check the performance of various types of coir geotextiles.

The different geotextiles used in this study are NWCM, WCM, CC, and GG. To understand the performance of this material as separation and reinforcement functions between the various layers, and to evaluate the performance in lab as well as in –site, wheel track test and medium scale accelerated pavement testing facility was used. The field study was undertaken by constructing a test track with the inclusion of geotextiles.

Due to practical limitations and difficulties in the lab, wheel tracking equipment is used as a testing pavement performance study against the rutting potential of various geotextile materials. Geotextile successfully functions as a reinforcement weak, poor subgrade, as geotextile held in position reduces the rut depth over the subgrade and granular layer. The reduction in rut depth over the poor subgrade/granular layer is due to the separation/ reinforcement of geotextile as an interface between the layers. Based on the results obtained from the laboratoryand, the field investigation and analysis carried out in the present study; the following conclusions are drawn.

7.3 Conclusions

7.3.1 Experimental Study (WTT)

Based on the laboratory work, the following significant conclusion is drawn and presented below.

1. It is observed that the maximum and minimum rut depth was 37mm and 13mm at sub-base-I and sub-base-III position with 200mm thickness of the fabricated mould. The placement of the coir geotextile mats with morrum soil showed more significant performance in terms of rut depth.
2. It is concluded that the inclusion of coir-geotextile mats improved the number of repetitions (1200passes) in sub-base-IIwith100mm layer thickness with 300mm assemble of mould while reduction thickness of the sub-base material. The rut depth at sub-base-I and sub-base-III position are noticed with reinforcement and without reinforcement as 11, 24, 3 and 4 respectively.
3. The maximum stress at the top of the subgrade without reinforcement is found to be 12kN/m^{2}and 18kN/m^2 with gravel and morrum sub-base soil. The un-reinforced section of the pavement was noticed with 18kN/m^2 stress at sub-base layer-III position, and it decreased up to 1.5 kN/m^2 with GG+NWCM.
4. The inclusion of coir-geotextile mats improved the number of repetitions (1200 passes) in sub-base-II with 100mm layer thickness with 300mm assemble of mould due to the higher thickness of the sub-base soil. Coir geotextile mats at sub-base-II (66.6mm) and sub-base-III (50mm) position are showed with the 490 and 840 repetitions respectively. The repetitions with 200mm and 300mm assembled mould are shown with the different types of repetition at the same position with this type of coir geotextile.
5. The unreinforced pavement model layer samples are shown with the maximum rut depth such as 15mm, 25mmand 35mm at a position of sub-base-I, sub-base-II and sub-base-III position respectively. The reinforced model layer samples showed that the minimum rut depth are reduced from 3mm to 5mm.
6. The placement position of coir mats depends on the types of geotextile, the position of mats and the thickness of the sub-base soil. The GG+NWCM coir mats are useful to provide the reinforcement function only. However, in the case of CC mat, it is very active over the weak subgrade to give the reinforcement and separation function to the pavement.

Table 7.1 Ranking of geotextile based their performance with various combinations

S. No	Types of geotextile	Rank	Functions		Combination
			Reinforcement	Separation	
1	Geogrid with Non-Woven Coir mat	1	Appropriate in reinforcement,	in Appropriate as separation	Good with gravel sub-base layer II and III
2	Coir Composite	2	Appropriate reinforcement	Appropriate Separation	suitable with morrum and gravel sub-base layer II and III
3	Woven coir mat	3	in Appropriate Reinforcement	In Appropriate Separation	Suitable for separation/partial reinforcement sub-base layer III
4	Non Woven Coir mat	4	in Appropriate Reinforcement	Appropriate Separation,	Suitable for separation in all the combination

The work can be recommended for pavements not meeting the specification and availability of limited funds. The composite (CC and GG with NWCM) mats better in a reduction of stress in the pavement in both types of sub-base material.

7.3.2 In-Situ Test Track Study

1. The un-reinforced section of the pavement was noticed with 18kN/m^2 stress at the sub-base layer-III position, and it decreased up to 1.5kN/m^2 with GG+ NWCM. The GG+NWCM mats showed better reinforcement function in terms of reduction of stress over the subgrade than the other types of the coir geotextile mats.
2. The inclusion of the coir geotextile mats in a gravel sub-base soil layer evidenced the reduction of stress from 12kN/m^2 to 2kN/m^2 at all positions. The provision of the coir composite mats at all positions is more significant to reduce the stress over the subgrade. It is also noticed that the coir composite mats poses as a multi-functional layer to the reinforcement section and extends the service life.
3. The stress in the un-reinforced section of the pavement was 17kN/m^2 at sub-base layer III position, which decreased upto1.5kN/m^{2}with GG+NWCM. The GG+NWCM mats have shown better reinforcement to reduce the load over the subgrade than the other types of the coir geotextile mats.
4. The maximum strain was noticed as 0.13 (micros) at sub-base layer I with morrum soil. The obtained strain was reduced to 0.041 due to the incorporation of the coir mats at the same sub-base. It is indicated that the inclusion of mats reduced the stress over the weak subgrade and enhanced the performance.

5. The observed deformation was 29mm and 30mm at sub-base layer I with the provision of GG+NWCM and CC respectively. It was revealed that the thickness of the sub-base soil could be reduced from 75 mm to 45 mm while providing coir mats with gravel and morrum as sub-base material respectively.

7.3.3 Design of Pavement with Coir Geotextiles

1. The gravel sub-base soil is more effective when providing the decremented thickness of the sub-base as per the design standard charts (22.5cm or 225mm). From the test track study, it was noticed that the reduction of the sub-base soil thickness is more in the case of gravel soil from 55mm to 40mm. The deformation in the gravel sub-base soil is more significant than the morrum sub-base soil.
2. The higher reinforcement occurs at sub-base II for all types of CC, GG+NWCM, WCMand NWCM coir mats in sandy, gravel and morrum soils. In the unreinforced model, maximum layer deformation of 22mm is obtained with morrum at the sub-base-II position. It can also reduce up to 5mm with a reduction of suitable sub-base soil over the coir mats.
3. The GG+NWCM coir mat has shown better reinforcement at the sub-base layer III positions in both the cases. The CC mats showed better reinforcement along with the proper separation of function. Cohesion and non-cohesion properties of the sub-base soil dramatically influences the deformation and load at the top of the subgrade in both the conditions in reinforcement and a un-reinforcement section of the test track.
4. The study recommends the composite (CC and GG with NWCM) mats can be utilized for reinforcement in the pavement because of their better reduction of stress over the subgrade (T2 traffic category). The NWCM can be used for the separation function in pavement applications.

7.4 Limitations of the Study

- The present work was carried out with one type of subgrade and two types of sub-base soil such as gravel and morrum.
- Only four types of coir geotextile were used to conduct the study such as NWCN, WCM, CC and GG+NWCM.
- The present study was limited to the rutting potential of the sub-base and subgrade.

7.5 Scope of Future Work

- The present work can be extended using other different types of coir mats over the different subgrade and sub-base with treated coir geotextiles.

- Further, the investigation can be carried out with different loading conditions in the laboratory as well as in the field. Ruttig performance cab be carried different types of coir geotextile mats.
- The test track studies can be carried out to evaluate the long term performance with factors affecting pavement condition based on seasonal changes.
- The durability effects of coir geotextiles seasonal changes of pavement performance can be evaluate along with detailed benefit-cost ratio and life cycle cost analysis of the pavement.

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2. **Harinder, D.,** and Shankar, S. (2018). “Performance evaluation of coir mats over the weak subgrade soil for low-volume roads by wheel tracking test”, International Journal of Geoscience, Engineering Environmental and Technology, Vol 03, No 01.
3. **Harinder, D**., and Shankar, S .”Evaluation of Coir Geotextile Mats to Enhance the Poor Subgrade under Repeated Load for Low-Volume Roads”. International Conference on Emerging Trends in Engineering (ICETE).
4. **Harinder, D.,** and Shankar, S. “Experimental Investigation of Coir Geotextile to Reinforce the Weak Subgrade Soil for Low-Volume Roads under static and dynamic loading condition”. International Journal of Engineering and Technology Innovation. (Under review)
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1. **Harinder, D**., and Shankar, S. 2017. “Experimental Evaluation of Coir Geotextile over Weak Subgrade Soil under Repeated Loading for unpaved LVR”. Two-day National conference on roads and transport-2017 at IITR.
2. **Harinder, D**., and Shankar, S. 2017. “Studies on Coir Geotextile over Weak Subgrade for Betterment of Service Life of Low Volume Roads”. 11^{th} International conference on recent trends in science and management, IETE, OU. Published in international journal of advance research and technology.
3. **Harinder, D**., and Shankar, S. 2017. “Reinforcement of Weak Subgrade Using Coir Geotextile Mats for Low Volume Roads”. 2^{nd} international conference on recent innovation in structural engineering, IC-ISE-2017 on Dec 29-31, 2017.
4. **Harinder, D**., and Shankar, S. 2018. “The Experimental Study of Coir Composite Mats and Woven Coir Mats Reinforcement for Unpaved roads”. 1^{st} International Conference on New Frontiers in Engineering, Science & Technology, NFEST-2018. On January 8-12, 2018.