CHAPTER 1
INTRODUCTION

1.1 GENERAL INTRODUCTION:
Transportation contributes to the all round development of a country and hence plays a vital role towards its progress. The present scenario in India demands maximum transit facilities to be developed at a low cost within shortest feasible time. India being predominantly rural in nature, road links are found to have distinct advantage over other modes of communication. However economy, time, environmental constraints and several other factors make a highway professional's job more challenging in delivering a safe and cost effective road network to its users.

One of the major problems faced by the engineers in highway construction in plains and coastal areas of India is the presence of soft/loose soil at ground level. This strata of being considerable depth cannot be removed by excavation, thus leaving no choice to build road over them. This condition may be further worsened if supplemented with poor drainage or lack of it. Assam being situated in a region of high rainfall area suffers from poor drainage as well as weak subgrade condition.

1.2 GEOSYNTHETICS:- HISTORICAL DEVELOPMENT:
Geosynthetics is the collective term applied to thin, flexible, sheets of material incorporated in or above soil to enhance its engineering performance. It comprises a variety of products largely grouped under geotextiles, geogrids, geomembranes and geo composites. Applications of Geosynthetics fall mainly within the discipline of civil engineering and the design of these applications, due to the use of geosynthetics with soils, is closely associated with geotechnical engineering.
The earliest of civilizations used natural materials to improve soil behaviour. For instance, in the ziggurats of Babylonia, woven mats of reeds were used and in the construction of the Great Wall of China, tree branches along with leaves were placed. In India, it is common to see dry branches and leaves of trees being used to reinforce soft soil (or softened shoulder on the roadside) on which heavy laden trucks get bogged down during monsoon. In the vast waterfront areas of Kerala, it has been an age old custom to spread coconut leaves on the ground before gravel/aggregate is laid over a road formation. Nature itself exercises control on erosion through vegetation (more specifically by the fine well spread roots which while supporting the plant upright, also hold the soil together). Walking on bundles of trees has enabled man to cover even marshy lands. Such examples are plenty. In British India, a certain Col. Powell, while constructing retaining walls found that the thickness of the wall could be reduced by incorporating construction waste like bamboos, canvas, etc. into the backfill. Textile material was perhaps first used in road construction in South Carolina in the early 1930's. One of the first mills to produce jute geotextile, popularly known as Soil Saver was established in Calcutta in the early forties. In the Ludlow Jute Mills a separate line was then established to manufacture this industrial by-product (as it was made from jute caddies, meaning waste jute). It was and even now is an export oriented product.

The first use of a woven synthetic fabric for erosion control was in 1950's in Florida by Barrett. In the 1960's geotextiles were extensively used for erosion control both in Europe as well as in the U.S.A. Later in 1960, Giroud used non-woven fabrics as a filter in the upstream face of an earthen dam. The real fillip to the use of woven fabrics came through their confident use in Netherlands to build storm resistant
structures over soft soils on the sea front. With such humble beginnings, geotextiles or related products or geosynthetics as they are now called, are now being increasingly used the world over for every conceivable application in civil engineering, be it in roads, foundations or earth and earth retaining structures.

1.3 FUNCTIONS AND APPLICATIONS OF GEOSYNTHETIC

Geosynthetics serve the following principal functions (Fig 1.1, Table 1.1):

Separation – in which a geosynthetic placed between two dissimilar geotechnical materials, prevents intermixing.

Filtration – in which a geotextile allows passage of fluids from a soil while simultaneously preventing the uncontrolled passage of soil particles.

Drainage – in which a geosynthetic may collect and transport fluids in its own plane.

Reinforcement – in which by virtue of the tensile characteristics, a geosynthetic resists stresses and contains deformations in geotechnical structures.

Barrier – in which a geosynthetic acts as a barrier to liquid/gas.

In addition, geotextiles serves the following functions:

Protection or cushioning – in which a geotextile serves as a localized stress reduction layer to prevent or reduce damage to a given surface or layer.

Surficial erosion control – in which a geotextile may prevent the surface erosion of soil particles due to surface water run-off and/or wind forces.
Tensar geogrids
Confinement effect
Reinforcement
Aggregate penetration
• Geotextiles (Woven & Nonwoven)
* Biaxial Geogrids
Separation
Barrier
Protection or Cushioning
Subsoil
Geotextile separating riprap from subsoil
Water level
Riprap revetment
Filtrating geotextile

Fig: 1.1 Various applications of Geosynthetics
## Table 1.1 Geosynthetic Application Summary

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1.4 TYPES OF USES OF GEOSYNTHETICS IN CIVIL ENGINEERING – INDIAN SCENARIO:

With the recent emphasis on infrastructure development, geosynthetic in India have received a tremendous boost. It has been extensively used in the pavement of the East-West and North-South corridors and Golden Quadrilateral of the NHDP project of National Highway Authority of India (NHAI). Apart from that reinforced soil walls in urban flyover approaches have become common due to their distinct advantage over conventional reinforced concrete walls. Further, the use of high strength geotextiles and geocell mattress for foundation of high embankment on soft soils has also proven to be feasible even in black cotton soil areas. Increasing emphasis is being given to the development and use of natural fiber (particularly jute and coir) geotextiles for engineering applications.

Geosynthetics were introduced to Indian engineers by the Central Board of Irrigation and Power in 1985 when they organized the first National Workshop on Geomembranes and Geotextiles. Ever since, the subject began to be commonly discussed at various Indian Geotechnical Conferences and local experiences began to be exchanged. Textile manufacturers began to diversify their product range to include geotextiles. The first 3-week short course on the subject “Geotextiles in Civil Engineering” was organized by the Indian Institute of Technology, Delhi in the year 1987.

The first State-of-the-art volume on “Use of Geosynthetics in India-Experiences and Potential” was brought out by the Central Board of Irrigation and Power in 1989 (Rao and Saxena, 1989). This was a compilation of the field trials in the
country, which helped other engineers to gain confidence in the use of geotextiles. It also emerged that out of the many and varied uses of geosynthetics the world over, some could be adopted in the country. This was the focus of discussion in the 3-day National Workshop on Engineering with Geosynthetics, organized in Delhi under the aegis of Delhi Chapter of the Indian Geotechnical Society in 1990 (Venkatappa Rao and Raju, 1990). Over the years, several academic and research institutions notably Indian Institute of Science, Bangalore, Indian Institute of Technology at Delhi, Kanpur, Bombay and Madras and University of Roorkee, Central Building Research Institute, Roorkee, Central Road Research Institute, New Delhi, Research and Designs Standards Organisation, Lucknow and Gujarat Engineering Research Institute, Vadodara, have started focussing attention on geosynthetic material. The field experiences have begun to mount, be it of the Indian Railways, Indian Navy (Nhawa Sewa Project, Bombay), Calcutta Port Trust, Calcutta, U.P. Public Works Department, Delhi Administration and the ministry of Surface Transport (Roads Wing) ADB projects on NH-1. Further, the Government of India sponsored various research schemes through the Central Board of Irrigation and Power, Department of Science and Technology and the Ministry of Surface Transport (Roads). Attempts were also being made by the Bureau of Indian Standards to standardize the testing procedures and to bring out design guidelines.

The application of geosynthetic in Indian context is explained in the following subtitles (Rao. 2007)
1.4.1: Pavement

The conventional way of constructing a road in an area having very soft subgrade is to spread a carpet of unbound aggregate over soft deposit to act as a load dispersing medium, when forming a roadway to keep distress within tolerable limits. When a wheel load traffics over such an unprotected formation soil it imposes dynamic stress. When shear strength of the subgrade is inadequate then this ongoing trafficking will initiate a bearing capacity failure by creating progressively deeper ruts. This causes subsequent losses on original fill thickness with a portion of the underlying soil being squeezed upwards into the voids of the granular fill and some of the aggregate penetrating into the subgrade. If this contamination remain unattended then ultimately a stage is reached when the fill diminishes in thickness to such a degree that unacceptable rutting occurs and the formation can no longer serve as a trafficable one.

On principle geosynthetic, when used as a separator, must prevent the intermixing of particle from two soil layers with different properties. This prevents contamination which may impair the intended behaviour of granular soil layers. The field application of geosynthetic as separator commonly adopted are: unpaved road, paved road, railways and protection of slopes. They also perform several other function like drainage and reinforcement. Fig 1.2 (Giroud and Noirway, 1981) explain the beneficial effect of use of geosynthetic in unpaved road.
Fig: 1.2 Schematic diagram showing beneficial effect of using geosynthetic

$h_0 =$ thickness of aggregate layer when there is no geotextile.

$h =$ thickness of aggregate layer when there is geotextile.

$\Delta h = h_0 - h =$ reduction of aggregate thickness resulting from the use of a geotextile.

Extensive studies are being carried out in laboratory and semi-infinite model pavement to study the role of geosynthetic in pavements and overlays and are continuing in several institutions around the world.

Ghosal and Som (1989) have reported the first major use of a non-woven fabric in a heavy duty construction yard in Haldia. It has been found to decrease the pavement thickness to the extent of 30%.

Placement of geotextiles/geogrids at the interface between the subgrade and the sub-base course has been shown to improve the behavior of pavements, under cyclic loading both in terms of permanent deformation (rutting) and resilient modulus. Also use of geogrids in a flexible overlay is found to improve the overall behavior. Non-woven geotextiles and bi-oriented geogrids have been successfully utilized in Maharashtra (1997) in the State Highways by the PWD for strengthening the road pavements in black cotton soil.
Subsequently, for most highways being constructed under the aegis of National Highway Authority of India (NHAI), a separation-drainage geotextile is being used. The specifications of these largely follow the AASHTO recommendations.

1.4.2 LANDSLIDE MITIGATION

Most hill regions in the fragile Himalayas be it in Utter Pradesh, Himachal Pradesh, Jammu and Kashmir, the North-eastern Hill States or the Nilgiri Hills in Tamil Nadu, land slides pose a recurring problem. They damage the highway structures as well as endanger the thickly populated hill towns. There are many classic examples of continuing problems, say, on the Jammu-Srinagar National Highway as well as the Konkan Railway, Sonapur area of Shillong-Silchar Highway.

It is possible to use this technique at many other problematic areas. For instance, in many of the water resources projects as well as new railway projects considerable (sometimes indiscriminate) blasting results in instability of the region, exposure of fresh rock face, appearing like as an eye sore. In such cases geosynthetics offer convenient economic and permanent solutions. More so, because they can be made green. A beginning has been made in this application in the Konkan Railways using wire rope gabions.

1.4.3 EMBANKMENTS ON SOFT SOILS

Many high embankments are coming up on soft soil regions. Experience has been gained in use of high strength geotextile as basal reinforcement in the Port Connectivity Project and Airport projects at Visakhapatnam. Also, geocells with high strength geotextiles or with geogrids in construction of bridge approaches
over Vasishta Godavary and Gautami Godavary at Rajahmundry and Palakol have been found to be successful.

1.4.4 GROUND IMPROVEMENT - PVD

More than a decade ago, prefabricated vertical drains were effectively deployed at Kakinada Port to consolidate soft submarine soils. They have been successfully used at Kandla Port. Currently they are being used at Visakhapatnam for the Port Connectivity project by NHAI, as part of NHDP and also for the development of a new runway by the Airport Authority of India at Visakhapatnam Airport.

A machine was developed at the Textile Technology Department, IIT Delhi (Banerjee, 1996; Banerjee and Rao, 1997; Rao, Sampath Kumar and Banerjee, 2000) to manufacture jute-coir strip drain, designated BRECODRAIN using the braiding technique.

1.4.5 GEOSYNTHETIC REINFORCED SOIL WALLS

The first geosynthetics reinforced soil structure was constructed on National Highway No. 1, near Ludhiana in the mid-eighties for a road over rail bridge approach, wherein geosynthetics strips have been used as a reinforcing element and precast concrete panels were used as facia. With a maximum height of 8m, the saving achieved was more than 15% depending on wall height. The speed of construction was also faster when compared with RC walls. Similar construction was later carried out at Phagwara in Punjab.

A few years later at the Visweswarayya Setu (Road over Rail Bridge) in Delhi, the Public Works Department, Delhi Administration, has successfully constructed a 59 m length of geogrid reinforced wall with 15 cm thick precast concrete
facia elements with average height of 6m using fly ash as the fill material. This wall was built on a geogrid reinforced mattress wherein Fly Ash was used. With all these novel features, this was the first construction of its type in India. A similar wall (59 m long) was constructed at the Hanuman Setu near Jamuna Bazar intersection in the proximity of Red Fort. In this case, however the maximum height was only 3.42 m, the wall facing was cast in-situ. In both the cases, mono-oriented geogrids were made use of, as reinforcement and the overall saving were over 20%.

Since then, particularly in the last 5 years, few hundred such structures have been built in the mega cities of our country, notably in Chennai, Delhi, Mumbai and in many National Highways in different parts of the country using a variety of geosynthetics, geogrids, geotextiles, geostrips, metallic rods and ribbed metallic strips with precast anchor blocks and facia elements of precast concrete panels of different shapes, segmental concrete blocks and also gabion facia.

1.4.6 GEOMEMBRANE LINING SYSTEMS

Use of thin LDPE liners has been recommended in canal lining and guidelines have been drawn by the Central Board of Irrigation and Power and the Central Water Commission, but with limited success. Particularly Indira Gandhi Canal in Rajasthan, because of puncturing and bursting, they did not take off in a big way. With well engineered geomembranes, now being available, a beginning has been made in using them for pond lining, as well as in landfill lining systems.

The need for developing guidelines for landfills for Indian conditions has been adequately highlighted, as early as 1996. A single composite liner comprising of a
HDPE geomembrane of thickness 1.5 mm or more (see Specification below), and the cover system with a 1.5 mm HDPE liner has been recommended by CPCB. Experience has been gained in the country in construction of landfills for industrial waste notably at Hindustan Zinc Ltd. at Udaipur, Visakhapatnam and for Binani Zinc Ltd. at Kochi. Construction of an engineered landfill is in active progress at Ankleswar and Vapi. At megacities like Mumbai, Bangalore, Hyderabad hazardous waste fill landfills have been constructed and maintained under a kind of BOT/Co-operative system under the aegis of the respective State Pollution Control Boards.

1.4.7 EROSION CONTROL

India has about 25% of its geographical area under mountainous terrain. Over 80% of the annual rainfall occurs from June to October. This leads to flooding every year causing environmental degradation which in itself is caused by excessive grazing, road construction, mining and unscientific farming practices. This results in an estimated soil loss of the order 6 billion tones per annum. Thus the importance of erosion control need hardly be emphasized in the Indian context.

Not only the many rivers that crisscross the country, but the longest sea coastline and the storms and hurricane add to major concerns of degradation and particularly severe erosion around port and harbour works.

The various causes of erosion, the different geosynthetics solutions available are detailed in “Erosion Control with Geosynthetics” published by the CBIP (Venkatappa Rao, 1995). Experiences have been gained in the country in using polymeric geomeshes (at Ghaziabad byepass by UPPWD), gabion mattress underlain by...
needle punched geotextile (on Gandhar River Gujarat by GERI), grouted mattress (Kakarpar Canal, Gujarat) and in many other water ways and locations.

Denuded forest cover in hilly regions due to indiscriminate lime stone quarrying around Dehradun are controlled environmentally by use of jute geotextiles and other measures by CSCRI, Dehradun.

The 1993 Market survey on erosion control materials reveals that 50% to 65% of them comprise natural material. As India produces around 66 and 44 percent of the world share of coir and jute fibres respectively, India should occupy a pre-eminent position in production, use and international marketing of natural geotextiles.

The ability of natural fibres to absorb water and to degrade with time is its prime properties which give it an edge over synthetic geotextiles for erosion control purposes.

The “drapability” factor of natural geotextiles (due their flexibility) allows them to conform closely to the terrain, i.e., the ability to follow the contours of the slope and staying in intimate contact with the soil.

Natural geotextiles can be used where vegetation is considered to be the long term answer to slope protection and erosion control. They have a number of inherent advantages.

i. They have protection against rain splash erosion.

ii. They have the capacity to adsorb even up to 5 times their own weight

iii. They reduce the velocity and thus the erosive effect of runoff by functioning as a series of mini check dams.

iv. They help retain the seeds, even in steep terrain.

v. They maintain humidity in the soil and atmosphere.
vi. They probably mitigate the extremes of temperature and
vii. They biodegrade, adding useful mulch to the soil

From literature one also notes that erosion control measures with jute
based geotextiles had given a good response but the textile degraded after about one
year. In the more severe situations, either because of climate or steepness of slope, a
longer period of function by the geotextile is required. This is also the case where one
prefers to select species compatible with surrounding native vegetation, such species,
being inevitably slower growing than the commonly sown productive species used in
lowland situations. The combination of slow growth and short growing season may
means that species barely becomes functional within a season in terms of surface
erosion control. Coir based geotextiles provide both the advantages of biodegradable
geotextiles and the longevity and the longevity required where plant establishment
might be slow (upto 3 years).

Jute and Coir Geotextiles are being manufactured as Rolled Erosion
Control Products in various weights and in various configurations such as woven
nettings meshes and blankets for different applications requiring varying degrees of
protection. More varieties were developed at Indian Institute of Technology, Delhi for
the industry.

Several successful case studies have been reported by Central Road
Research Institute, New Delhi and others in use of jute and coir matting for erosion
control in different hill regions of the country. A study was conducted in Western Ghats
wherein coir mattings have been used for erosion control in a rubber plantation. The
coir matting could prevent successfully the surficial erosion of particles along the
surface of the slope and helped in sedimentation of soil even on previously exposed rock surface, presumably through the action of a series of check dams as mentioned in literature (Rao, 1995)

1.5 TYPES OF GEOSYNTHETICS AND ITS MANUFACTURING METHODS

Information on different varieties of geosynthetics that are in use and its manufacturing methods as compiled by Rao, 2007 are explained below.

*Geosynthetic* is defined by the International Geosynthetic Society as a planner, polymeric (synthetic or natural) material that are synthesized for use in contact with soil/rock and/or any other geotechnical material in civil engineering applications.

It is a generic term which includes:

- Geotextiles
- Geogrids
- *Glasstex*
- Geonets
- Geomembranes
- Geocomposites
- Prefabricated vertical drain (PVD)
- *Geosynthetic clay liner* (GCL)
- *Geomat*

1.5.1 Geotextiles are permeable textile materials and may be woven, non-woven or knitted. Depending on the weaving technology and the fibres used (polymer used, and the technology of drawing) the strength of woven fabrics can be as high as 1100 KN/m at 5% elongation. On the other hand the non-woven geotextiles are better known for
their filtration and drainage in view of their high porosity. Even when thin and of low strength they can act as separators.

A woven geotextile is made by interlacing two or more sets of yarns, fibres, filaments, tapes or other elements. Non-woven geotextile is obtained in the form of a manufactured sheet, web or batt of directionally or randomly oriented fibres, filaments or other elements, with either mechanical, and/or thermal and/or chemical bonding. It could be also be knitted, obtained by interloping one or more yarns, fibres or filaments shown in Fig.1.3.

Generally, woven geotextiles exhibit high-tensile strength, high modulus and low elongation. Non-woven geotextiles have high permeability and conformability because of their high elongation characteristics. The properties of knitted geotextiles are different from the others two.

There are many types of non-woven geotextiles now available in the market. For example,

- Continuous filament, needle punched, polypropylene
- Staple fibre, needle punched polypropylene
- Continuous filament thermally bonded polypropylene
- Staple fibre needle punched, calendared on one side, polypropylene
- Continuous filament, thermally bonded, polypropylene and polyethylene
- Continuous filament, needle punched polyester

The woven geotextiles available in the market are generally:

- slit film tape woven,
- mono-filament, and multi-filament woven.
(a) Woven monofilament geotextile
(b) Woven multifilament geotextile
(c) Warp knitted geotextile
(d) Needle punched nonwoven geotextile

**Fig 1.3:** Scanning electron micrograph view
Manufacturing method:

*Woven geotextiles* are made by traditional weaving methods in which two parallel sets of elements interlaced orthogonally to form a coherent textile structure. A manufacturing loom shown in Fig. 1.4. The properties of the resulting geotextiles will be a function of the nature of the elements used in weaving, the material from which these elements are made, and the weaving pattern. Although modern weaving looms are extremely versatile and sophisticated items of plant, they operate on the basic principles embodied in the flat loom.

![Fig.1.4 Manufacturing Process of woven geotextile](image)

*Nonwoven geotextiles* are produced from continuous filaments, which are effectively of infinite length, or filaments which have been cut to a length of 50 mm to 300 mm, to form staple fibre. The continuous filaments, or staple fibres, are laid down on a special conveyor belt, called a brattice, in the form of loose web shown in Fig 1.5. In the
processing of continuous filaments, the filaments proceed from the spinnerets, through a drawing process, onto the moving brattice to form a randomly oriented loose web. Under the microscope the web looks rather like a plate of spaghetti, however, despite this seeming disarray the web is laid down with a view to achieving uniform coverage of the brattice transports thereby a sensibly constant mass per unit area throughout. The brattice transports the loose web to a needle loom which is essentially a bank of reciprocating barbed needles which penetrate the full depth of the web.

Fig 1.5 The needle punching process of nonwoven geotextile and typical barbed needle

1.5.2 Geogrid is a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be liked by extrusion, bonding or interlacing, whose openings are larger than constitutes. Geogrids manufactured by extruding polymers and drawing in a sheet form are called Extruded Geogrids. These are generally rigid in nature compared to the more flexible types of bonded geogrids or
woven geogrids of knitted geogrids. Extruded grids are of two varieties, viz., uniaxially oriented and biaxially oriented shown in Fig. 1.6.

1.5.3 *Glasstex* is used in asphaltic pavements and this is non-corrodible so it will not be affected by slippage of oils and fuel or be attacked by de-icing salts. It is also thermally stable and can be safely installed within asphalt to at least $165^\circ C$ without significant change in geometry and physical properties.
Manufacturing method:

A method of production which produces an integral, in plane, junction between machine and cross machine directions, involves the drawing of an extruded plain sheet which has been punched, or pierced, at regular intervals. The action of drawing the sheet in the machine direction, (Fig. 1.7), simultaneously extends the holes in the sheet, to become grid apertures, and induces molecular orientation in the solid material in the direction of draw. The end result is a uniaxially oriented geogrid with geometry typified that shown in Fig. Having drawn the grid in the machine direction, there is then the option of drawing the grid in the cross machine direction. This action widens the initially elongate apertures, until they become approximately square, and at same time induces molecular orientation in the cross machine direction so producing a biaxially oriental grid.

Fig 1.7 Manufacturing Process of Tensar oriented Geogrids
1.5.4 *Geonet* is a planar, polymeric structure consisting of a regular dense network, whose constituents’ elements are linked by knots of extrusions and whose openings are much larger than the constituents shown in Fig 1.8(a).

1.5.5 *Geomembrane* is planer relatively impermeable, polymeric (synthetic or natural) sheet used in contact with soil/rock. It could be bituminous, elastomeric or plastomeric materials and the various types of geomembranes are shown in Fig 1.8(b).

**Fig 1.8(a) Geonet**  **Fig 1.8(b) Different types of geomembranes**

![Calendering Process](image)

**Fig 1.9 Calendering Process**

**Manufacturing Method:** The process involves rolling the doubly plastic between hot steel rollers which nip the dough and reduce its thickness to the required sheet.
thickness. This process is called Calendering process, this process commonly used in the production of geomembranes and the manufacturing process of geomembranes by calendering process shown in Fig 1.9.

1.5.6 Geocomposite Drain is a prefabricated subsurface drainage product consisting of a geotextile filter skin supported by a geonet.

1.5.7 Prefabricated vertical drain (PVD) useful in the consolidation of soft soil, has a geotextile filter sleeve with a central drainage core and Fig 1.10 showing the sample of geocomposite and prefabricated vertical drain.

Fig 1.10 Showing the Geocomposites and Prefabricated Vertical Drains
1.5.8 Geosynthetic clay liner (GCL) is a manufactured sheet, having a central core of bentonite clay, between two geotextiles and needle punched or otherwise bonded together.

1.5.9 Geomat is used to control the soil erosion. It consists of a flexible three-dimensional polymer mat which initially stabilizes the surface whilst assisting vegetation to establish. It then goes on to provide long-term, tenacious reinforcement of the root system. Fig 1.11 showing the sample of geosynthetic clay liner and geomat.

![Diagram of Geosynthetic clay liner and Geomat](image)
1.6 Use of Natural geotextile in civil Engineering applications

With the growing awareness of using environment friendly products wherever possible natural geotextile made of jute and coir is now becoming very prospective for road construction in our country.

1.6.1 Jute Geotextile : (JGT)

Jute Geotextile is a fabric manufactured out of natural jute fibre, which is ground in abundance in India. Further, it displays some advantageous intrinsic properties like high tenacity, high thermal insulation value, high hygroscopicity and drapability, non-toxicity, biodegradability etc. among several others and has also been found to be ecofriendly (Chattopadhyay et al, 2003). Experience gained from sporadic applications of these in roadways (Talukdar et al, 1994, Mandal et al, 1994), indeed portray sufficient scope for it to be regarded as an essential highway commodity.

The addition of JGT in a roadway is anticipated to aid in the following manner:-

a) To permit heavier traffic over soft sugrades and hence increase the service life of the pavement systems involving wet subgrade management in a cost-effective manner with the utilization of jute geotextiles.

b) Confine the aggregate layer and thus enable the aggregate layer to maintain its original shear strength.

c) Separate the aggregate from the subgrade and help to maintain its integrity.

d) Distribute the stresses due to wheel load more evenly over the subgrade etc.

However, there exist two different schools of thought as to the basic structural mechanism by which a geotextile might improve the performance of the road. According to one school, the capacity of a soil to sustain a purely vertical loading is reduced if the
ground surface is simultaneously subjected to horizontal shear. In the case of a static vertical load such as wheel load, placed at the surface of a granular pavement layer, it is argued that this introduces, outwards horizontal shear stress at the surface of the subgrade soil. A geotextile installed at the surface of the subgrade is assumed to absorb the horizontal shear stresses imposed by the granular pavement thus preventing these from being transmitted to the subgrade. This consequently implies an improvement in the effective bearing capacity factor according to this theory.

The second school prescribes to the notion that ruts do develop in the running surface and that these are echoed by ruts developed at the surface of the subgrade. If a geotextile is secured at the pavement subgrade interface then this will deform in sympathy with the rutting and act as a tensioned membrane. Since the membrane is deformed, there is a vertically upward component of the membrane tension which acts to reduce the vertical stress transmitted from the wheel load, through the granular layer to the underlying subgrade soil. Thus argument is consistent with the fact that a geotextile cannot reinforce the roadway unless it carries a significant tensile force that can only be generated in it as a result of significant straining during rutting. However, the rut depth in case of application involving JGT in roadways is limited to a practical minimum value of 3cm (Chattopadhyay et al 2003). Since this is insignificant to develop any reinforcing effect, the JGT in roadways is assumed to provide a low cost alternative performing essentially a separating function thereby restraining contamination of a good quality aggregate base material providing no reinforcement effect as per this school of thought.
However, it is important to realize here that, the geotextile must have its tensile strength mobilized via the subgrade’s deformation i.e. the yielding of the subsoil allows for deformation and mobilization of its tensile properties. How much deformation is necessary with regard to the vehicular loading, the particular geotextile, the time it takes for adequate strength mobilization etc. are all pressing questions, but the quality of the subgrade takes precedence. In other words, a soft yielding soil subgrade is needed to mobilize the geotextile’s strength i.e. soil CBR values should be low.

If underlying soil is of high plasticity clay, then this will have a low CBR value, reflecting in low bearing capacity, thus requiring the use of a thicker and stronger construction. Mandal et al, 1988, studied the effect of JGT on CBR values of soft marine clay and the experimental results clearly indicated the beneficial effect of JGT on CBR values of the soil. Similar findings were reported by Aziz et al, 1994, who also reported substantial increase in the CBR values of a clayey subgrade, when compacted with two layers of JGT interposed within the soil at varying moisture contents. Observations made by the authors while conducting CBR tests on locally compacted soil with one layer of JGT (both in treated and untreated forms) showed considerable increment in the CBR value both in soaked and unsoaked conditions (Chakravarty et al, 2003).

The probable explanation for the observed enhancement in CBR value of the soil in presence of JGT may be attributed to the relatively quicker gain in strength of the weak formation soil due to JGT deployment which act here as a filter fabric, as the soft soil is inevitably compressed and consequently displaced. Further, assuming proper drainage provisions within the pavement systems, the subsoil would not be expected to deteriorate once it gains strength but rather would stabilize with the passage of time.
This consideration also makes it imperative that in such specific applications, biodegradability of JGT should be of secondary concern. The point that is emphatically harped here is that while durability criterion should be defined in a realistic manner so that it may not be over conservative, quantification of the rate of decrease of the need for dependence on JGT by the founding material which progressively improves with time should also be given due consideration. Hence the laboratory findings exhibiting a considerable improvement of the soil-JGT system against deformation may be suitably employed to obtain economy in thickness of the pavement by application of JGT for site remediation of soft soils for purposes of pavement construction over them.

**DURABILITY OF JGT** (Courtesy: Jute Manufactures Development Council, Manual on use of jute geotextiles in civil engineering application, 2008)

It has been established after several laboratory tests on samples of JGT with varying linear density that its biodegradation depends on environmental factors. It has been observed that jute degrades faster in an acidic ambience having pH value less than 5.2. The rate of degradation of JGT is generally fast in the initial stages, but slows down subsequently. On the other hand, when pH is in a higher range (above 7) i.e., in an alkaline environment, the laboratory tests conducted by IIT, Delhi have initially revealed that higher is the linear density of yarns in a JGT, quicker is its degradation, though more elaborate studies are needed for this purpose to come to a definite conclusion. Bacteria and fungi are two main groups of micro-organisms responsible for the microbial decomposition of any natural geotextile. Moisture plays a key role in this respect. It has been reported that the minimum moisture requirements for the growth of bacteria and fungi in JGT are 20% and 17% respectively. Jute attains the aforesaid moisture contents when the relative humidity in the atmosphere is 90% and 80%
respectively. Temperature is also instrumental for bacterial and fungal attacks on jute. A temperature of 37°C is the most favourable temperature for bacterial growth and 30°C for growth of fungi in JGT. Both sunlight and rain causes quick degradation of JGT. The organic content of soil accelerates the decay of jute fibre. The degradation studies on jute so far conducted indicate that the mechanism of its biodegradation is complex, being dependent on interaction of a number of influencing factors. To prolong the durability of JGT, rot-resistant chemicals are presently used. The chemicals are essentially copper based compounds – usually Copper Napthalate and Cupramonium. The former is a non-leachable compound and costlier. The latter gets leached on continuous exposure to water. A branded product (COMPSOL) is also being used. It is a copper ammonium carbonate solution that meets the US and Canadian WHMIS (Workplace Hazardous Materials Identification system) standards. It is a stable additive completely soluble in water and does not cause hazardous polymerization. Bitumen (90/15 grade) is also in current use as a coating on JGT for the same purpose in addition usually for its application in bank-protective work in rivers and waterways. As a result of the application of rot resistant chemicals/bitumen, the life of a JGT can be prolonged to about 4 to 5 years, subject to the specific subsoil ambience. Indian Institute of Technology, Kharagpur has recently been entrusted with a research project to develop an eco-friendly additive that will further enhance the durability of all types of JGT.

1.6.2 COIR GEOTEXTILE:

Coir is a product derived from coconut husk. The fibrous material forming part of the soft mass surrounding coconut, the fruit of the tree “Cocos Nucifera” or the coconut palm is world over known as coir. The word ‘Coir’ has been
derived from Kayar which in Malayalam means a rope. The word seems to have been introduced into the European literature by Marco Polo, the Italian traveler, in the thirteenth century. Coir is used for the production of products like mats, matting, carpet, handicrafts etc.

Coir usage has become very common among professionals in various industries due to its versatility. In the horticultural industry, agricultural industry, or erosion control industry, coir has established a remarkable reputation for its superiority to other available natural materials. Compared to the horticultural and agricultural industries, coir is relatively new to the civil engineering application and it may take some time for this industry to learn and understand about coir. Recognition of coir in the erosion control industry has come from the fact that it is an abundant, renewable natural resource with an extremely low decomposition rate and a high strength compared to other natural fibers. In traditional erosion control blanket applications, coir blankets are well known for superior performance compared to other organic blankets. In most of these applications, long-term tensile strength in the blankets is not a critical design criterion. The rapid growth of environmentally concerned designers with their innovative bioengineering designs has increased coir use in many civil engineering applications.

A review of literature on the subject reveals that coir geotextiles can be adopted economically in unpaved roads on weak subgrades and low to medium height embankments on weak foundations. Coir is a strong cellulose fibre with high lignin content. It is naturally long lasting in soil environment compared to other natural fibers such as jute. No chemical treatment is required when it is used for soil erosion
applications. Coir fibre is hard and strong, with good properties for being spun and woven into matting (CSIR, 1960). Coir geotextiles have unique properties and just the right strength and lifetime to protect slopes against erosion and help the natural vegetation to take root. Coir geotextiles have the mechanical strength necessary to support the soft subgrade and stay intact for 1 to 3 years at varying strengths to support the loads by itself. Coir geotextile resembles natural soil in its capacity to absorb solar radiation. Coir geotextiles are good soil reinforcing material as they offer good interface friction with soil. A range of different mesh mattings is available.

With the improvement of technology in the processing of coir fibre starting from their extraction, spinning, weaving and finishing, various forms of coir geotextiles can be assembled to cater for a number of applications such as erosion control, slope stabilization, bearing capacity improvement, and soft soil consolidation applications etc. Most applications involving coir geotextiles depend upon the initial membrane action which is easily provided due to its high tensile strength. In most cases the gradual decrease in strength due to decay is compensated by the gain in strength requirement becomes unimportant. The separation, filtration and drainage function of coir geotextiles will also be unhindered by loss of strength or decay of fibres which is a very slow process. Therefore, it is important that for filtration and drainage applications, long term strength and durability are not the criterions to look for. By the time decay sets in within six months of installation the soil gets strengthened. Later on the decayed structure will also act as a filter cake to perform separation, filtration and drainage.

The potential uses of coir geotextiles in the Indian context can be summarized as follows (Rao and Balan 1994):
i) for separation and reinforcement in temporary roads, forest roads and village roads,

ii) for small height embankments in compressible soft soils

iii) in sports fields as a blanket drain,

iv) in breakwater and jetties on soft sea bed,

v) in land reclamation with hydraulic fill,

vi) for French drains with or without pipe,

vii) for slope stability,

viii) Noise control banks,

ix) Defence installations.

Coir geotextiles simulate the salient proportion of vegetation which controls the erosion, like vegetation cover, coir geotextiles intercept and store rainfall. The composition of the products imparts a roughness to run down in much the same way as vegetation stems. Buried coir geotextiles simulates the root effect and due to their biodegradability they act as mulch also. Their effectiveness is immediate, unlike vegetation which may take year to more to reach the stage of growth where it becomes effective in reducing soil erosion rates.

Coir fabrics swell when they get wet. This causes them to fill the open areas and produce a fine mesh fabric which will filter the soil from water passing through them. In side-by-side testing the stabilization fencing compares from favourably with conventionally manufactured close weave fabrics.

As the coir geotextiles biodegrade over time it is highly probable that their effectiveness diminishes. But by that time the establishing vegetation becomes
more protective. As they biodegrade, there are no harmful substances left in the environment, indeed the addition of organic matter is beneficial for soil fertility. Finally and probably to most interest to the end uses, the coir geo textiles are considered more cost effective than their synthetic competitors, if a solution to soil erosion control and vegetation establishment is required.

The heavier construction of coir geotextiles when well seeded on the soil surface provides physical protection for the young seedlings against desiccation and wind-rock as well as moisture retention. This is of great value where climatic conditions may result in slow plant establishment.

Natural, pleasing to the appearance, coir fabric can thus be used successfully in most applications where more expensive chemically treated synthetic fabrics are now used.

**History of coconut and Coir (courtesy: Coconut Board, India)**

The history explains different stories on the birth of the coir the golden fibre. The first recorded history of coconut in the country dates back to Ramayana period. In the Valmiki Ramayana there are references of coconut in the Kishkindha Kanda and Aranya Kanda. It is reported that Ramayana was written by Valmiki sometimes in 3rd Century BC. Generally it is believed that coconut was introduced in India during the post-Vedic period.

References have been made on coconut in Raghuvamsa of Kalidasa and Sangam literatures, which proves the antiquity of the coconut in India. But its origin in India remains disputed. But Marco Polo, the famous Arab traveler who visited India in the 13th Century called coconut "Indian Nut" and the logic for such a reference needs
investigation by historians. Shri. P. K. Balakrishnan, a Kerala historian argues that organised coconut cultivation started in Kerala only after the arrival of the Portugese.

Ropes and cordage, made out of coconut fibre have been in use from ancient times. Indian navigators, who sailed the seas to Malayasya, Java, China and to the Gulf of Arabia centuries ago, had been using coir as their ship's cables. Arab writers of the 11 th Century AD referred to the extensive use of coir as ship's cables, fenders and for rigging. Facts record that there was coir industry in UK before the 2nd half of the 19 th Century. During the year 1840, Captain Widely, in co-operation with Captain Logan and Mr. Thomas Treloar, founded the well-known carpet firms of Treloar and Sons in Ludgate Hill, England for the manufacture of coir into various fabrics suitable for floor coverings.

The coir manufacturing industry producing coir mats, matting and other floor coverings, was started in India on a factory basis, over a hundred years ago when the first factory was set up in Alleppey in 1859 by the Late Mr. James Darragh, an adventurous Irish born American national. Enterprising Indians followed the trail blazed by this foreigner.

Kerala and the Coir Industry

Kerala is the highest coconut producing state in our country. The history of Coir and its association with the state of Kerala dates back to the 19 th Century. Sandwiched between the Western Ghats on the east and the Arabian Sea on the west, Kerala is one of the most beautiful States in India. A tropical paradise of waving
coconut palms and wide sandy beaches, this thin strip of coastal territory slopes down from the mountain ghats in a cascade of lush green vegetation and varied fauna. One of the most commonly seen tropical trees in Kerala is the Coconut tree. In fact, even the name Kerala (Kerlam in Malayalam) is derived from this tree ("Kera" in Malayalam language means Coconut and "Alam" means Land, thus Keralam = Land of Coconut). Everything from Kerala's culture to its dishes is evolved around the Coconut tree.

Alleppey (Alappuzha in Malayalam) is the nerve centre of Kerala's famous Coir industry. Here, one can see coconut husks being beaten into fibre for making beautiful mats and other coir products. Both men and women are actively involved in the production of Coir. Coir Industry enjoys the status as the largest Cottage Industry in the State of Kerala, giving employment to over a million people

1.6.2.1 Manufacturing method of coir geotextile: (Lanka et al 1999)

Coir is typically processed from ripe coconut husks which are dark brown in color and have been retted in freshwater for three to six months. The retting process of coconut husks acts as a curing process for fiber in coconut husks. Curing in freshwater increases resistance to UV (ultraviolet) degradation and also increases the flexibility of processed fiber without causing deterioration. During traditional processing, coconut fiber from cured husks is separated by skilled labor into grades depending on the length of fiber. The longer and stronger fibers are called bristle coir and the shorter and thinner fibers are called mattress coir. Coir processed from ripe husks cured in freshwater is dark brown in color.
When the ripe coconut husk is dry, it is an excellent firewood. As a result in countries with a high population density, most of the ripe brown coconut husks are used for firewood and the coconut husks available for processing coir are unripe green husks. Unripe green coconut husks are usually soaked in brine to make the coir processing easier. An economical way to soak coconut husks in brine is to use lagoons. Coir processed from lagoon-cured green husks is light brown or white in color. This coir is referred to as white coir. Salt in lagoon water makes it easier to process unripe green coconut husks. Needless to say, fibers in coir processed from unripe green coconut husks are not fully mature compared to fibers coming from ripe brown coconut husks. Lagoon-cured brown coconut husks also produce white coir. Salt in lagoon water acts as a bleaching agent that can weaken coir used in field applications. White coir is, therefore, much weaker than brown bristle coir processed from ripe brown husks.

High demand for coir has led to new coir processing methods which may produce a weaker product than the traditional freshwater-curing process. Mass-scale coir manufacturers recently implemented coconut husk defibering machines. These machines can separate fiber from uncured or partially-cured husks or unripe green husks or ripe brown husks. Advantages of these defibering machines to the coir producer include reduced expense and faster production rates since skilled labor is not required and the six-month curing time is reduced or eliminated. Some of these mass-scale coir manufacturers go further and soak unripe green husks in a bacterial solution and process for white coir within 72 hours of curing. These machines do not separate fiber into bristle coir and mattress coir but yield a mixture of long and short (strong and weak) fibers. A quick way to produce white colored coir for decorative coir products is
chemical bleaching of the coir. In chemical bleaching, brown or light-brown colored coir is treated with chemicals to remove the brown color. Chemical bleaching may have some negative effects on the strength and durability of coir. On the other hand, coir from the ripe husk is well known as a natural fiber and the rich brown color is more attractive than a white color for erosion control applications. Most importantly, addition of chemicals to natural coir may create a potentially hazardous situation in many environmentally sensitive applications.

Experience with coir in the agricultural industry has shown that only the traditional brown bristle coir which is processed from ripe brown coconut husks cured for at least six months in freshwater has performed well in applications where durability and strength retention are critical for satisfactory field performances. Manufacturing methods of coir is discussed in the following subtitles.

**Retting**: For extracting the fibre, the first step is the removal of husk from the nut. It is usually achieved by ramming the coconut against a wooden or iron spike fixed to the ground and splitting the husk into three or four pieces. The separation of fibre from the husk is effected by retting, which consists essentially of soaking the husk in water for several weeks. The process varies from place to place according to the local conditions. In the common method of retting, known as pit retting, the husk are buried in basin shaped pits dug on the banks of backwaters and the ebb and flow of water at the top and free percolation of subsoil water from below provide the necessary water movement. Alternatively, the pits are provided with channels to allow water to flow in and out with the rise and fall of the tide. The bottoms of pit are covered with sand and
the sides are lined with coconut leaves. After charging, the top of the pits are covered with coconut leaves and weighted down with mud to prevent the husk from floating when water is admitted. As many as 20000 to 30000 husks are placed in each pit. The pits are opened after the completion of retting and the mass is treated for separating the fibre.

In Anjengo and Ponnani areas of Kerela State, where the best quality of coir is produced, retting is carried out by placing the husks in coir nets called vallies and transferring them to brackish backwaters subjected to tidal action. The husks are kept floating for a few days and then immersed by weighting with mud and stones. The retting period ranges from 6 to 9 months after which the mass is taken out for further husking, accompanied by frequent liberation of pungent smelling bubbles of hydrogen sulphide. After the sixth month, the water becomes clear and the liberation of gas bubbles and the foul odour diminishes. A major part of the husk gets softened at this stage and the separation of fibre is possible with the exception of the hard tips and the inner layers of the exocarp, which require ten months or even more for a satisfactory ret (CSIR 1960).

A third method is to prepare the enclosures in shallow backwaters with stakes and coconut leaves, and put the husks inside the enclosures. The husks are covered with coconut leaves and weighed down with mud. In localities with no backwaters nearby, retting is effected by either burying the husks in sandy soils or by immersing them in pools of water for short periods (a few days to a few weeks). The husks so treated are known as soaked husks. This method is in vogue in some parts of Kerala and West Bengal.
SPINNING

Spinning of coir yarn is mainly a cottage industry and it is done in three different ways:-i) by wheel spinning, ii) by mechanical spinning and iii) by hand spinning.

i) Wheel spinning: Two wheels, one stationary and the other movable, are employed in wheel spinning. The stationary wheel, which is generally fixed to the ground, contains two spindles which are set in motion by rotating a central wheel by means of a handle inserted through its centre. The movable wheel contains one spindle and is mounted on three smaller wheels so that it can be moved forward and backward. A group of three workers is required for spinning, one to handle the stationary wheel and two to make the strands which make up the two-ply yarn. Silvers are taken by two persons, who, keeping them in their arm pits, make a loop with a small quantity of fibre. Each worker in turn puts the loop into the notch of one of the spindles of the stationary wheel and gives the silver a uniform thickness. The third worker rotates the wheel to give the necessary twist. As the wheel is rotated the two spinners deliver the fibre in the required thickness, walking backward till the required length of strands is reached. The fixed wheel is then stopped and the two strands are passed through grooves on the sides of a triangular block of wood and tied together to the notch of the single spindle of the movable wheel, which is then gently rotated to give a twist in the opposite direction to the two-strands yarn, while one of the spinners moves with the grooved wooden block towards the stationary wheel. The grooved wooden block regulates the counter – twist, prevents entanglement of strands at the time of twisting and binds the strands close.
ii) Hand spinning: In hand-spinning, the fibre is rolled between the palms with a clockwise twist into short length threads (150-230 mm). When of sufficient length, the threads are taken in two's and twisted together in the opposite direction to form a strand of yarn. The spun yarn is held in position by toes while further pieces of short length are added one after the other and counter twisting by hand is continued till the required length of yarn for a knot is reached (6-8m) is reached. The yarn is then reeled in the form of a hunk and a knot made at the end. One worker produces 1.8 to 2.2 Kg of yarn per day. Combed fibre is not used for hand spinning.

iii) Mechanised spinning: The Coir Board has introduced a treadle operated mechanized spinning machine in India. This machine produces a yarn which is less hairy, more regular in twist and of longer continuous length than yarn spun on spinning wheels used at present. The machine can be operated indoors and requires less space.

Hand-spun yarn is soft and the twist and thickness are even. Wheel- spun yarn has a hard twist; it is stronger and more uniform in size and twist than hand-spun yarn. The quality of yarn is judged by the thickness, colour, appearance, uniformity in twist, strength, fineness, texture, and freedom from impurities, etc. Yarns are accordingly named after the places of production, for example, Anjengo yarn, Vycome yarn, etc. The place names have come to the associated with definite characteristics, so much so, that a yarn conforming to the characteristics of Anjengo yarn, no matter where it is made, is called Anjengo yarn.

WEAVING

By virtue of its lower cost and its wear and damp-resistance qualities, coir is suitable for floor covering. The manufacture of coir mats and mattings was
started in 1859 on a small scale by James Darragh, who founded and developed the well-known firm of Darragh, Small & Co. Ltd., Alleppey Coir yarn as received from spinners is not suitable for weaving for various reasons, such as uneven distribution of thickness, shades, twists, etc. The first process in a weaving factory, therefore, involves the treatment of yarn with a dilute solution of sulphuric acid which improves cloud and gives it a certain amount of brightness. This treatment is particularly necessary for yarns used for the better types of mats. Mats and mattings are woven on wooden handlooms similar to those used in cotton weaving, but of stronger build. Wheel-spun yarn is generally used for warp and hand-spun for weft. Holland, Germany and also in UK the manufacture of coir mats and matting is an established industry.

Depending on the quality of yarn employed and the method of weaving, mats are divided into four main types: i) Coir, ii) Fibre mats, iii) Speciality mats and vi) Mattings (coir geotextiles). Each type is further divided into varieties depending on the construction of the mat.

i) Coir mats: Beach-Rod (good quality coir mat) is an inexpensive mat made from Beach yarn. It is produced in a large range of attractive designs. Beach-Creel is also made of Beach yarn, but differs from rod mats in weaving. Creel weaving is designed to produce an article with low pile. The loose and tight warfare employed, the loose warp is carried over a slotted rod to form loops while the texture is woven with the taut warp and weft. Beach-Bit is an inexpensive medium weight mat which, however, does not possess the same uniformity of colour as Beach-Rod. The mats are bound with braid manufactured from five or seven ends of hard-twist yarn. Vycome-Rod is a superior variety of mat made out of Vycome yarn. The construction of
Vycome-creel mats is the same as Beach-Creel mats, but the material used is much superior and the articles produced have clean and light appearance. A stronger variety is manufactured with jute twine for chain.

ii) Fibre mats: Fibre mats are made direct from the fibre without being spun into yarn. They are produced in plain natural colour, or in a variety of woven designs and patterns. The fibre employed is machine cleaned. The process of weaving is more or less the same as that used for woolen carpets. After weaving, the mats are stitched and braided, sheared by machine, and finally trimmed with scissors to give a relief to the pattern.

iii) Speciality mats: Mats bearing initials, names, monograms, trade marks, etc. and sinnet and corridor mats are classed as speciality mats. They are hard-wearing utility articles produced without brush.

iv) Mattings (coir geotextiles): Coir mattings are manufactured from four types of coir yarn, viz superior Anjengo, superior Aratory, Vycome and Beach. The yarn is wound on bobbins and transferred to a creel. Warping is done between sticks or by means of a peg board, the yarn from the bobbins being passed on to the warping drum and the requisite width prepared by warping the sections on a weavers beam. Weaving is similar to pit-loom weaving without the fly-shuttle arrangement. For close weave, a stick is inserted through the shed and used as a beater before the weft is passed through the shed. The stick is removed and the sley beaten up; the shed is then changed. The process is repeated till the required length of 45 m is woven. The matting is removed from the loom and mended to eliminate knots and uneven coloured yarn and projecting warp or weft ends are cut. Matting is made in widths of 0.914m to 3m and in
lengths of 46m to 60m. Two-treadle (ordinary and basket weave) matting, the strands of coir yarn are interlaced individually in alternate order. Both sides of matting present the same appearance. This matting is woven by extending the two-treadle weave both vertically and horizontally so that two or more strands of yarn are present in both directions. Three-treadle (twill weave and Herringbone), the weave causes diagonal lines to be found in the matting which, when spread out gives the twill effect. Points of intersection move outward and upward on succeeding picks. The directions of lines are alternatively right and left in the Herringbone weave. In the present investigation three-treadle matting is used as geotextiles in the experiments. Four-treadle weave, twill lines are found either diagonally or in opposite directions on both sides of the fabric. Multi-treadle weaving done on hand-operated multi-needle looms enables the production of intricate patterns.

**DYEING**

Colour and design are very important in the case of coir products used for floor mattings and other such purposes. These chemical dyes can increase the life of the coir and hence are advantageous for geotechnical applications. Acid, acid-mordant, basic substantive and sulphur dyes, and also natural colouring matters like logwood, are employed for dyeing the coir fibre. Some of the dyes commonly used in coir dyeing are listed in the following: Auramine OS, Chrysoidine YS, Bismarck Brown RLS, Magenta PS, Methylene Blue 2BS, Methyl Violet 2BS, Malachite Green AS Crystals, Jute Black 75512, Naphthalene Orange GS, Naphthalene (courtesy: Coir board, India).
1.6.2.2 Physical and chemical properties of coir relevant to the projects in hand:

Individual fibres of coir are from 150mm to 200 mm in length and from 12 to 25 micron in diameter i.e., the ratio of length to the thickness if only 35. Coir gives the following micro chemical reactions.

i. With iodine and sulphuric acid- golden colour

ii. with Aniline sulphate – intense yellow colour

iii. Scheveitzer’s Reagent does not attack the fibre.

These reactions indicate that coir is a heavily lignified fibre. Accordingly to Schlesinger coir contains 20.6% of hydroscopic moisture. The physical and chemical properties of coir are given in the following Tables1.2,1.3. (Satyanarayana, et al 1981).

Table 1.2: Physical properties of coir fibre

<table>
<thead>
<tr>
<th>1. Single Fibres</th>
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</tr>
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<tbody>
<tr>
<td>a) Length in mm</td>
<td>150-200</td>
</tr>
<tr>
<td>b) Diameter in micron</td>
<td>16</td>
</tr>
<tr>
<td>c) Density (g/cc)</td>
<td>1.40</td>
</tr>
<tr>
<td>d) Breaking elongation(%)</td>
<td>30</td>
</tr>
<tr>
<td>e) Moisture regain at 65% R.H. (%)</td>
<td>10.5</td>
</tr>
<tr>
<td>f) Swelling in water (diameter)</td>
<td>5%</td>
</tr>
</tbody>
</table>
Table 1.3: Chemical composition of coir

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<table>
<thead>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water soluble</td>
<td>5.25%</td>
</tr>
<tr>
<td>Pectin and related compounds</td>
<td>3.0%</td>
</tr>
<tr>
<td>Hemi-cellulose</td>
<td>0.25%</td>
</tr>
<tr>
<td>Lignin</td>
<td>45.84%</td>
</tr>
<tr>
<td>Cellulose</td>
<td>43.44%</td>
</tr>
<tr>
<td>Ash</td>
<td>2.22%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

1.6.2.3 Biodegradability of coir

Santha et al, 2001 has reported the study on biodegradability of coir. The higher the resistance to degradation, the longer the strength retention. Lagoon-cured coir contains salts and when it comes in contact with moisture, degradation is greatly accelerated. As a result, degradation of lagoon-cured coir is much faster than freshwater-cured coir. Furthermore, degradation of smaller diameter fibers occurs much faster than degradation of larger diameter fibers. Increased degradation speed occurs because coir twine made of smaller diameter fibers has a significantly higher surface area compared to the same sized coir twine made of larger diameter fibers. In addition, fibers in white coir processed from unripe green husk are weaker compared to fibers from ripe brown husks. Also, resistance to UV degradation in brown coir processed from ripe husk is much higher than white coir processed from unripe green husk. Therefore, coir twine made of freshwater-cured mixed brown coir, lagoon-cured mixed white coir, or lagoon-cured bristle coir has a faster degradation rate than coir twine.
made of freshwater-cured brown bristle coir. The same arguments are true for coir twines made of chemically bleached white coir. This explains why freshwater-cured brown bristle coir twines are the most durable and retain the highest strength in field applications compared to coir twines made of any other coir. The hop industry provides convincing proof for this explanation showing that freshwater-cured brown bristle coir has superior resistance to degradation and the highest strength retention compared to any other coir type in field applications. In addition, freshwater-cured brown coir contains no excess salt or chemicals which may be present in lagoon-cured or chemically-bleached white coir. Considering horticultural industry's experience with coir dust, designers may find it valuable to look closely at the use of coir that has excess salt or chemicals for soil erosion control and bioengineering applications. **Fresh water is plenty in Assam so coir to be manufactured in this region would have obviously more durability.**

Plant cell wall material is composed of three important constituents: cellulose, lignin, and hemicellulose. Lignin is particularly difficult to biodegrade, and reduces the bioavailability of the other cell wall constituents. Because lignin is the most recalcitrant component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate. The effect of lignin on the bioavailability of other cell wall components is thought to be largely a physical restriction, with lignin molecules reducing the surface area available to enzymatic penetration and activity. Coir having highest percentage of lignin (45.84%) among other compositions of it enjoy less bio degradation compared to its counterpart jute having 13-18% lignin content.
Prevention of Bio-Deterioration

Bio-deterioration of coir can be minimized by treating the soil with antiseptics such as copper sulphate, zinc chloride, mercuric chloride etc. Bio-deterioration is also prevented by coating the coir with bio-stabilisers are Biomet, Fungitrol, Preventol etc. and polymers are polyester, epoxy, polypropylene, etc. Coating of Coir fibre with thermosetting polymers improves the strength and stiffness (Datye 1988, Satyanarayana, et al 1981)

1.6.2.4 Production, utilization and ecological importance of Coir product:

Coconut production in world wide perspective:

Coconut husk is the raw material for the coir industry, which is available in enormous quantities wherever there is large-scale coconut cultivation. The palm is essentially a plant of tropics and it thrives within 200 of the equator. Philippines, Indonesia, Thailand and neighboring islands, India, Sri Lanka, pacific territories, east and West Africa and the West Indies are the important coconut producing countries in the world. India and Sri Lanka account the major contributions out of the above. Table 1.4 shows the list of major coconut growing countries all over the globe. Coconuts are usually harvested at the end of every 45 days all throughout the year.

Production of coir product: (Courtsey: Coir Board, India)

Fifteen countries of the Asia-Pacific region produce 86% of the coconut in the world. But only a handful of them are known to be coir producers. India is the largest producers and exporter of coir and coir products. Sri Lanka, Indonesia, Malaysia, Philippines, Thailand and now Vietnam are the other primary producers of coir with varying levels of production capabilities. Value addition in coir is at its best in India.
where the fibre is converted into exquisite floor coverings, Geotextiles, etc. which have earned a name in the International market. The coir industry, which was confined to Kerala, has now spread to other states like Tamil Nadu, Karnataka, Andhra Pradesh, Orissa, etc. over the years largely on account of various developmental and promotional programmes. Apart from its traditional use as rope, yarn, and floor coverings, coir fibre is finding new applications as an eco-friendly substitute for wood and synthetics. A long-term biodegradable geo-fabric for soil bioengineering and garden articles. The byproduct of coir industry, coir pith, is increasingly being used as a soil conditioner. The future of coir industry depends on the non-traditional areas and non-conventional products.

Table 1.4 List of major coconut producing countries (Total coconuts in 1000 metric tons) Courtesy: Coconut Board, Govt of India

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Philippines</td>
<td>9.14</td>
<td>26.11</td>
<td>8.91</td>
<td>22.30</td>
<td>9.08</td>
<td>21.00</td>
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<td>12.32</td>
<td>30.80</td>
<td>14.38</td>
<td>33.20</td>
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<td>4.19</td>
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<td>6.19</td>
<td>15.50</td>
<td>7.59</td>
<td>17.50</td>
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<td>1.69</td>
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<td>1.83</td>
<td>4.50</td>
<td>1.69</td>
<td>3.90</td>
</tr>
<tr>
<td>Malaysia</td>
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<td>3.46</td>
<td>1.06</td>
<td>2.60</td>
<td>1.03</td>
<td>2.40</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.78</td>
<td>2.23</td>
<td>1.43</td>
<td>3.60</td>
<td>1.38</td>
<td>3.20</td>
</tr>
<tr>
<td>Other Asia</td>
<td>5.61</td>
<td>16.02</td>
<td>1.31</td>
<td>3.30</td>
<td>1.55</td>
<td>3.60</td>
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<tr>
<td>Total Asia</td>
<td>28.78</td>
<td>82.19</td>
<td>33.05</td>
<td>82.60</td>
<td>36.70</td>
<td>84.80</td>
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<td>Mozambique</td>
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<td>0.42</td>
<td>1.10</td>
<td>0.43</td>
<td>1.00</td>
</tr>
<tr>
<td>Tanzania</td>
<td>0.31</td>
<td>0.89</td>
<td>0.36</td>
<td>0.90</td>
<td>0.36</td>
<td>0.80</td>
</tr>
<tr>
<td>Other Africa</td>
<td>0.89</td>
<td>2.54</td>
<td>1.16</td>
<td>2.90</td>
<td>0.95</td>
<td>2.20</td>
</tr>
<tr>
<td>Oceania</td>
<td>2.31</td>
<td>6.60</td>
<td>2.21</td>
<td>5.50</td>
<td>1.89</td>
<td>4.40</td>
</tr>
<tr>
<td>Latin America</td>
<td>2.27</td>
<td>6.47</td>
<td>2.81</td>
<td>7.00</td>
<td>2.95</td>
<td>6.80</td>
</tr>
<tr>
<td>Total World</td>
<td>35.02</td>
<td>100.00</td>
<td>40.01</td>
<td>100.00</td>
<td>43.27</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Ecological importance of the product:
Ecological importance of the product:

Synthetic material like polyester, polyamide, polypropylene and polyethylene took their place as geo-textiles for engineering applications due to their long life. It has been established beyond any doubt that these plastic materials are one of the major toxic pollutants of our time. They pollute environment both during their production and disposal. Their production caused air and water pollution while their non-biodegradability was responsible for increasing soil pollution. Some of constituents like ethylene oxide, benzene, vinyl chloride are known to cause cancer, birth defects, damage to the nervous and immunity systems to adversely affect the blood and the kidneys. Further, they are inflammable to vitiate the air & earth.

Once a plastic is produced, the harm is done once and for all. Plastics defy any kind of attempts at disposal, be it through recycling, burying or land filling. When one recycles a hazard, one creates a hazard. Since plastics do not undergo bacterial decomposition, landfilling will mean preserving it for ever. When burnt, plastics release many poisonous chemicals including dioxin, the most toxic substance known to science. Recycling if not done under extreme care, it results from exposure to the fumes, the skin disease and respiratory problems. Plastics slowly degrade in the presence of U.V. light and acid rains and if they are used as geotextiles, slow release of toxic seepage will mix with rain water and will contaminate the water source. Further the waste mass will impede the flow of ground water as well as obstruct the free movement of roots of plants hereby affecting the soil’s biological balance and organic processes.
In an age of growing environmental awareness, the use of eco-friendly biodegradable material as geo-textile started gaining momentum. Natural geo-textiles like cotton and jute are successfully used. Coir fibre with very high lignin content comparable to that present in soft wood became the ideal choice as a geo-textile material. The lignin content in a fibre determines the resistance to microbial attack. Coir geo-textile with a lignin content of about 46 per cent scores heavily above jute (12 per cent) and leaf fibre (1% per cent). Coir suits very well for geotextiles and insulating materials and being environment friendly has an edge over synthetics for application in environmental operations. (Ramakrishna, 1996)

Experimental studies (Natrajan et al 1988) on use of coir for slope protection work has proved that its greatest advantage is its ecological niche for a rapid re-establishment of the vegetation cover by absorbing water and preventing the topsoil from drying. Once the natural vegetation takes over the fibre decomposes gradually and eventually disintegrates, leaving nothing but humus. Similarly, like natural soil coir has the capacity to absorb solar radiation. That is why there is no hazard of excessive heating that occurs sometimes while using synthetics.

Coir fibre is 100% organic, biodegradable, ethnic and hygienic. It is hard and strong, resistant to rot, moulds and moisture. Coir is a natural product of mother earth derived from a “renewable resource,” i.e. the coconut tree a horticulture product. It is sufficiently eco-friendly product and so its application will never sustain any damages to environment and so is free from resentments.
Case study: A case study was carried out at Kerala by Central Coir research institute, Kalavoor, Kerala to study the effectiveness of coir geotextile to reduce soil erosion. (Sharma 1997)

One experimental section of 23 kilometer at left bank main canal of Muvattupuzha Valley Irrigation Project near M.C. Road crossing between Muvattupuzha and Kuthattukulam, Kerala was selected. The area was highly eroded due to the high stream velocity at this point of the canal due to two major rainy seasons in a year. The treatment with the vegetation turfing grass failed in this area because the seeds and the sprigging were getting washed away during the following monsoon since it takes a lot of time for the vegetation to take root. It was therefore felt necessary to protect the slope adequately till such time that the seeds broadcast over the slopes or the roots slips of grass dubbled into the slope take time to germinate, grow and take root. The coir geotextile helped to dampen the kinetic energy of the flowing water and kept both the soil and the root slips in their place. The technique is also cost effective in comparison to the vegetative turfing method. The fabric chosen for this purpose was having sufficient space for the proper dabling of the grass. The strength of the coir nettings was monitored at regular intervals so as to understand the longevity of the material under natural conditions in the region. It has been found that the strength of the yarn was reduced to its half after a period of 6 months which indicates that the netting will last for about 5 years under the normal conditions in that region. The method of such estimation was followed as per the half life method usually adopted. It was assumed that after 10 half lives the fabric will be completely degraded and will be the part of soil. Based on these, it has been derived, that the fabric will be totally degraded after 5 years.
under the normal conditions in the region. In the process the degradation products of the
coir helped the good growth of the plantation for permanent consolidation of the soil on
the slope.

The Ph of soil at the time of laying the geotextile in the region was 4.3
and the organic carbon percentage was 0.18. After the laying of coir geotextile on the
slope the organic carbon percentage is increased to 0.46. The growth of lemon grass
was abundant in the area where the geofabric was laid. the length of the roots was found
to be more than 1.5 ft. and the leaves of the grass grew between 3ft to 4 ft.
It was also found that the lemon grass did not grow so abundantly in the nearby area
where it was planted without the aid of coirgeotextile. It was estimated that the growth
in this area was 1/3 rd of the growth in the geotextile treated area. Even that the growth
was in patches, not homogenous.

There was a marginal increase in the nitrogen and potassium content of
the area where geotextile were applied. However there was a substantial increase in the
phosphorous content of the area which increased from 0.140 to 0.195%.
The above study indicate that coir geotextile has been successful in controlling erosion
by establishing the vegetation in erosion control area by protecting root slips of lemon
grass as well as providing essential nutrients to soil.

1.7 PRESENT WORK

1.7.1 Statement of the problem: One of the major problems faced by the engineers in
highway construction in plains and coastal areas of India is the presence of soft/loose
soil at ground level. This strata of being considerable depth cannot be removed by
excavation, thus leaving no choice to build road over them. Roads constructed over
this loose soil demands higher thickness of granular materials resulting high cost of construction. Alternately attempts of reducing the thickness of pavement layer to make an economic construction will lead to early damage of pavement which in turn will make the road unserviceable within a short period after construction. This condition may be further worsened if supplemented with poor drainage or lack of it. Assam being situated in a region of high rainfall area suffers from poor drainage as well as weak subgrade condition. This is one of the major causes of deplorable road condition in Assam. Attempt has been made in this study to develop a methodology of road construction to improve the road serviceability by using locally available material.

1.7.2 Motivation and justification of the study: Looking at the poor road condition of the state of Assam use of geosynthetic is thought for road construction to improve the performance of roads. Coir mat a natural geotextile is selected for this purpose. River sand being abundantly available in all the rivers and tributaries of Assam is an easily available material. So use of river sand in combination of coir mat is studied in the present work.

1.7.3 Justification for using coir mat in the project:

Most of the geosynthetics used now a days are synthetic in nature which are non biodegradable leaving the possibility of ground and water contamination. Coir mat a natural product is being selected for this purpose to overcome the menace of land contamination.

The initial strength and stiffness properties of coir reinforcements are almost comparable to those of synthetic reinforcement, and hence are good alternatives
to the costly geosynthetics in soil structures. In particular when the requirement of reinforcement is for shorter durations, coir products can be the first choice for reinforcement applications. In such cases, the soil structures can be designed with reinforced concepts utilizing the principles of soil reinforcement. During the early periods of the structure, the coir reinforcements will help the soil in sharing the loads. With the passage of time, the foundation soil will attain higher shear strengths at which stage the additional support from reinforcement may not be required. For such cases, the coir reinforcement is ideally suited as the degradation of the reinforcement with time will not adversely influence the performance of the reinforced structures. If required, the life of coir products can be improved by using chemical treatment, polymer coatings etc

**Production and utilization of coconut in Assam**

Coconut tree is an integral part of the Assam scenario, especially in rural part of Assam it is almost omnipresent. From roots to trunk to its fruit to leaf nothing is wasted. The most important of all is its fruit, the coconut.

If we look at the coconut production and utilization scenario in Assam, it shows a dismal picture. In Assam farmers are growing coconut palm in their homestead garden commonly called as 'Bari system of cropping' under rainfed condition. In such a system, different crop combinations like coconut, arecanut, banana, fruit trees, timber trees, tuber crops and spices are being grown in an unscientific way without proper spatial arrangement and nutrient management. In most of the areas of this region, it is observed
that almost every household is having two to five coconut palms in their homesteads. It is also observed that coconut palms are being planted around fish ponds. Commercialization of coconut plantation is yet to take place in Assam. Coconut plays a very important role in the socio-cultural and economic life of Assam. In Assam, coconut harvesting is coincided with two big festivals i.e. Magh bihu (January) and Durga Puja (October). Generally people prepare or make many dishes/table items like laddu, pitha, chira etc. made of coconut. Coconut milk is a popular additive used for tea preparation in villages. The oil from copra is used for cooking and manufacturing soaps and other toiletries on a limited scale. The tender coconut and cut pieces of copra are being sold in railway stations and other places.

Assam being one of coconut growing states produces 153 million nuts per year having productivity of 8053 nuts per hectare per year. Its productivity in fact is higher than the highest coconut producing state Kerala which has a productivity of 6951 nuts per hectre per year. Table 1.5 shows the state wise production of coconut in India. (source: Directorate of Economics and Statistics 2006-2007, Govt of India). Thus there is a huge potential of availability of coconut husk in the state, which might be used for soil improvement works. Further more it will brighten the prospect of setting up coir based ancillary industry in the state

1.7.4 Justification for using Brahmaputra sand in the project:

River sand is abundantly available in all the places of Assam. Regular floods in Assam has made thousands of acres of agricultural land completely infertile by the gradual expansion of large scale deposit of silt and sand carried by flood water into the fields.
Table 1.5: All India Final Estimates of area and production of Coconut
(Source: Directorate of Economics & Statistics, Ministry of Agriculture, Govt. of India)

<table>
<thead>
<tr>
<th>States /Union Territories</th>
<th>2005-2006 (Revised)</th>
<th>2006-2007 (Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AREA ('000 Hectares)</td>
<td>Production (Million nuts)</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>104.0</td>
<td>892.0</td>
</tr>
<tr>
<td>Assam</td>
<td>19.1</td>
<td>204.9</td>
</tr>
<tr>
<td>Goa</td>
<td>25.3</td>
<td>125.3</td>
</tr>
<tr>
<td>Gujarat</td>
<td>16.4</td>
<td>138.3</td>
</tr>
<tr>
<td>Karnataka</td>
<td>385.4</td>
<td>1209.8</td>
</tr>
<tr>
<td>Kerala</td>
<td>897.8</td>
<td>6326.0</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>18.0</td>
<td>273.4</td>
</tr>
<tr>
<td>Nagaland</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Orissa</td>
<td>50.8</td>
<td>274.6</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>370.6</td>
<td>4867.1</td>
</tr>
<tr>
<td>Tripura</td>
<td>3.3</td>
<td>7.0</td>
</tr>
<tr>
<td>West Bengal</td>
<td>24.9</td>
<td>323.5</td>
</tr>
<tr>
<td>A &amp; N Islands</td>
<td>25.5</td>
<td>87.1</td>
</tr>
<tr>
<td>Lakshadweep</td>
<td>2.7</td>
<td>53.0</td>
</tr>
<tr>
<td>Pondicherry</td>
<td>2.1</td>
<td>27.9</td>
</tr>
<tr>
<td>All India</td>
<td><strong>1946.8</strong></td>
<td><strong>14811.1</strong></td>
</tr>
</tbody>
</table>
Restoration of these agricultural land is becoming a big challenge. The increased use of sand and silt for road construction work may to some extent serve the purpose of expansion of large scale deposit of silt and sand carried by flood water into the fields. Restoration of these agricultural land is becoming a big challenge. The increased use of sand and silt for road construction work may to some extent serve the purpose of restoration of such land. Brahmaputra sand is considered in the present study because of its easy availability in and around Guwahati. The source is near Chandrapur.

To check the representative ness of Brahmaputra sand over the entire state of Assam river sediment deposited by flood in twenty three districts excepting the hill districts out of twenty seven districts of Assam are analysed. The uniformity coefficient (Cu) of samples are computed. Table 1.6 shows the uniformity coefficient results of samples. The mean value of cu found as 2.58 which is nearer to the cu value of Brahmaputra sand. Furthermore mean deviation of the results is 0.55 < 1 which shows the homogeneity of samples. Thus the Brahmaputra sand used in the present study may be considered to be representative of the river sediment of the entire state.

1.8 Approach to be adopted in the project: A series of laboratory and model tests are conducted in this study to explore the behaviour of coir mat reinforced soil for using in road construction.

Laboratory CBR tests are conducted on soil samples with and without inclusion of Coirmat and also by varying the position of coir mat in the CBR mould. CBR tests are also conducted at different types of mould by varying the diameter of mould to study the effect of mould to plunger diameter ratio on CBR value. Results show significant increase in CBR values after inclusion of Coir mat. Field CBR test
were also conducted to compare the laboratory and field test results. A pavement section is designed as per IRC2001 based on CBR values for both the conditions of with and without inclusion of coir mat.

Static plate load test are conducted on a model two layered flexible pavement over soft subgrade soil with and without coir mat at the interface to study the bearing capacity variation and determination of modulus of subgrade reaction at different combinations. Repetitive load test were conducted on WBM layers for different thickness combinations. Tests are used to predict settlement for higher repetitions. Settlements so predicted for specified load repetitions is used for determining the thickness of pavement layers for with and without inclusions of coir mat.

Both the pavement design method with geosynthetic viz "U.S. Department of Transportation, Federal Highway Administration's Method" and "Giroud and Noiray (1981) Method" is developed on clay subgrade. Since the subgrade material used in the study is of coarse grained the above mentioned method cannot be applied directly. Burmister's two layer theory is used as design method in the present study.

Economic evaluation of pavement construction with and without inclusion of coir mat is carried out which shows coir mat reinforced pavement is an economically viable option.
Table 1.6: Cu value of river sand collected from different districts

<table>
<thead>
<tr>
<th>SI No</th>
<th>Name of districts</th>
<th>Uniformity coefficient, Cu Xi</th>
<th>Absolute (Xi-A )</th>
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<tbody>
<tr>
<td>1</td>
<td>Kamrup Metropolitan</td>
<td>2.2</td>
<td>0.38</td>
</tr>
<tr>
<td>2</td>
<td>Kamrup Rural</td>
<td>3.3</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>Tinsukia</td>
<td>4</td>
<td>1.42</td>
</tr>
<tr>
<td>4</td>
<td>Dibrugarh</td>
<td>2.1</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>Sibsagar.</td>
<td>1.4</td>
<td>1.18</td>
</tr>
<tr>
<td>11</td>
<td>Dhemaji</td>
<td>1.8</td>
<td>0.78</td>
</tr>
<tr>
<td>12</td>
<td>Jorhat</td>
<td>3.1</td>
<td>0.52</td>
</tr>
<tr>
<td>8</td>
<td>Lakhimpur</td>
<td>3.3</td>
<td>0.72</td>
</tr>
<tr>
<td>9</td>
<td>Golaghat</td>
<td>2</td>
<td>0.58</td>
</tr>
<tr>
<td>10</td>
<td>Sonitpur</td>
<td>2.4</td>
<td>0.18</td>
</tr>
<tr>
<td>11</td>
<td>Nagaon</td>
<td>1.7</td>
<td>0.88</td>
</tr>
<tr>
<td>12</td>
<td>Marigaon</td>
<td>1.9</td>
<td>0.68</td>
</tr>
<tr>
<td>13</td>
<td>Darrang</td>
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<td>14</td>
<td>Nalbari</td>
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<td>Barpeta</td>
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<td>17</td>
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<td>0.48</td>
</tr>
<tr>
<td>18</td>
<td>Kokrajhar</td>
<td>3.1</td>
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</tr>
<tr>
<td>19</td>
<td>Dhubri</td>
<td>2.1</td>
<td>0.48</td>
</tr>
<tr>
<td>20</td>
<td>Cachar</td>
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<td>0.42</td>
</tr>
<tr>
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<td>Baksa</td>
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</tr>
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<td>22</td>
<td>Udalguri</td>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>23</td>
<td>Chirang</td>
<td>2.7</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Summation</td>
<td>59.3</td>
<td>12.68</td>
</tr>
</tbody>
</table>

\[ \text{Mean }, \mu = \frac{59.3}{23} = 2.58 \]

\[ \text{Mean Deviation } = \frac{12.68}{23} = 0.55 \]