Developments in Geotechnical Engineering

Tapobrata Sanyal

Jute Geotextiles and their Applications in Civil Engineering

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DEDICATED TO MY LATE REVERED PARENTS

PROF. BINAYAK SANYAL & SM ANNAPURNA DEVI

Preface

Synthetic (man-made) geotextiles were first used in India way back in 1987 for riverbed protection when Calcutta Port Trust was building a massive guide wall in the estuarine reach of the mighty river Hugli opposite the Haldia Docks to extend the northern tip of Nayachar island for diversion of flow. Dutch assistance was sought for using geosynthetic (man-made) materials for bed protection for the founding of the guide wall. At the same time, the western bank of the island was threatened by severe erosion. The Indian Jute Industries' Research Association (IJIRA) of Kolkata developed at my suggestion bitumen-treated woven jute fabric and supplied it for an experimental study to control the threat of bank erosion. The experiment was a big success. The treated bank is still in excellent shape and that too without any expenditure having been reportedly incurred by the port to maintain it even after 25 years! This was an eye-opener focusing the suitability of jute as an alternative to man-made geotextiles notwithstanding its quick degradability when in persistent contact with water.

Jute has been in use traditionally as a flexible packaging material. Its use for geotechnical purposes was not conceived before the mid-1980s. Over the years, there have been extensive studies and trials as to how best the material could be put to use for various geotechnical applications. Till date more than 260 applications of Jute Geotextiles (JGT) in three major areas, viz., low-volume roads, eroded riverbanks, and slopes, have been recorded in India with hardly any case of failure. A lot of applications of JGT, mostly for protection against soil erosion, have been done overseas as well. Unlike countries in the West where makers of man-made polymeric geotextiles invested large amounts for research and development, investment on Jute Geotextiles for research and development has so far been far less than what JGT deserves. Research and development related to JGT have remained principally dependent on government initiatives so far.

Successful field applications of JGT and my personal association with the majority of such applications in India in the advisory capacity have prompted me to write this book. The innovative technology is not taught in any of the technical institutes in India or abroad. The book, the first reference book on the innovative technology of Jute Geotextiles, will at least partially fulfill the requirements of the interested engineering students and practicing engineers and may prompt them to delve deeper into the subject to explore new avenues for its study and use.

My endeavor would have been incomplete had I not gotten support and encouragement from my colleagues in the project management unit of the National Jute Board, Ministry of Textiles, government of India. I would especially thank the young lady civil engineer, Ms. Rumki Saha, who helped me in giving shape to the design methodology for three specific applications of JGT. My thanks also go to Prof. S. K. Ghosh, head of the Department of Jute and Fiber Technology, the University of Calcutta, for being always on my side in this endeavor. And above all, I have received unstinted encouragement from my elder brother Er. R. B. Sanyal who has inspired me to write this book.

I would feel amply rewarded if the book generates interest in civil engineers and jute technologists.

Kolkata, West Bengal, India Tapobrata Sanyal

Acknowledgements

National Jute Board/Indian Jute Industries' Research Association/Department of Jute & Fiber Technology, University of Calcutta/CSIR-Central Road Research Institute/Kolkata Port Trust/CSIR-Indian Institute of Soil & Water Conservation, Dehradun/Eastern Railways/University of Wollongong, Australia.

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Tapobrata Sanyal Retd. Chief Hydraulic Engineer, Calcutta Port Trust, India. Ex-Chief Consultant, National Jute Board, India. Tapobrata Sanyal is an internationally known geotechnical and river expert, an acclaimed writer, a speaker, and a social thinker. He graduated in civil engineering from Calcutta University (BE College, now IIEST) in 1961. He had his postgraduate stint in Holland as a government nominee in river engineering in the specialized field of geosynthetic applications. He was the Chief Hydraulic Engineer of Calcutta Port Trust and acted as the Chief Consultant to National Jute Board, India after his retirement. He is a fellow of the Institution of Engineers (India) and member of several academic bodies in India and abroad. He has contributed more than 60 technical and research papers in national and international journals and has received a number of awards for his contribution. He has been awarded Life Time Achievement Certification from the International Geosynthetics Society (IGS) for his outstanding contribution in the field of geosynthetics. He is the pioneer and an acknowledged exponent in the application of Jute Geotextiles in India. He is in the advisory board of the Department of Science and Technology, government of West Bengal (Geoinformatics and Remote Sensing). He has also been named as one of the leading scientists/leading intellectuals by foreign assessment boards and figures in the lists of "Who's Who in Asia," "Leading Scientists of the World," "Leading Intellectuals of the World," and "Leading Professionals of The World."

Chapter 1
Introducing Geotextiles

Abstract Man since the dawn of civilization endeavored to find a solution to tackle distresses caused due to various soil-related problems such as settlement, slips, slides, and erosion. The chapter traces in brief the historical background of man's efforts to address soil-induced distresses. Development of petrochemical derivatives such as polypropylene, polyamide gave man a potent ingredient to manufacture special types of textiles to handle and address such problems. It was a kind of textile which came to be known as geotextile made of artificial fibers that provided one of the desired tools for controlling geotechnical problems.

Jute Geotextiles (JGT) is a natural variant of man-made geotextiles. Use of jute as geotextiles, its suitability in ensuring effective control over soil-related distresses and above all its environmental concordance have been discussed in brief. Nontraditional engineered textile products known as technical textiles developed specifically for other technical end usages have also been mentioned in the chapter.

Keywords Geotextile • Geosynthetics • Technical textiles • Jute geotextiles • Geomembranes

Before dwelling upon the core theme, it would be appropriate to trace the background related to development of geotextiles in brief. Man has been trying to overcome the problems related to soil since the dawn of civilization. The intricacies of soil behavior were not known to man in the distant past. Structures were built and roads constructed on soil based on experience without knowing much of different soil compositions and their behavior under static and dynamic loads and extraneous influencing factors. In fact we realized the importance of soil much later in 1940s under pressure of necessity, as Terzaghi and Peck put it. Soil mechanics, now known as geotechnical engineering, took shape subsequently as a distinct discipline under civil engineering.

Interestingly, use of natural materials to obviate problems posed by "difficult" soils dates back to several centuries. We find evidences of use of woven mats made of reeds in ziggurats (temples) of Babylonia, of tree twigs with leaves in construction of the Great Wall of China, and the like. Such improvised practice is still in vogue in some parts of India. In Kerala there is a convention to spread coconut leaves over sub-grades. Stolons of trees are laid on soft marshy soils to facilitate

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walking in some developing countries. Even developed countries are increasingly favoring the old practice of using vegetation to control erosion of the surface soil.

Application of natural products with improvisations sharply dwindled after discovery of artificial polymeric (synthetic) materials in early 1950s. It was the pressure of commercial necessity that prompted developed countries to utilize man-made polymeric fiber for various technical end uses. They watched the decline in consumption of traditional textile materials arising mainly out of import of a cheaper variety of textile products from the developing countries. Taking the cue from the improvised uses of natural ingredients in overcoming soil-related problems, technologists thought of making fabrics with man-made materials such as polyamide-polyethylene that could address the precise technical requirements to improve soil strength and behavior. This was how the concept of geotextiles originated. The Netherlands was the first country to take the initiative and used man-made geotextiles in 1953 in the massive Delta Project in the country to save it from ravages of floods generated from swell of the North Sea. Other developed countries such as the USA followed suit and started using man-made geotextiles for prevention of soil erosion in particular with other countries in Europe emulating. By the late 1960s, man-made geotextiles became globally popular. It has to be admitted that the effectiveness of man-made geotextiles was established after years of rigorous research, studies, and field trials backed by intensive marketing by the producers before the users felt confident to use the new product.

The major application of man-made geotextiles in the initial stages of development was focused on erosion control in embankments in coastal areas and road construction. Paucity and high price of some of the building materials like gravel, stone, etc. in the developed countries led the planners to think of economizing construction costs. Geotextiles, being cheap, fitted in with the scheme of things. The other factor that influenced increasing acceptability of geotextiles is the high energy cost of extraction and transportation of granular materials used in construction. Subsequently, versatility of man-made geotextiles paved way for its diversified uses such as overlays in roads, lining systems, landfills besides erosion control, and stabilization of soil and other geotechnical applications.

The growth of man-made geotextiles over the last three decades has been remarkable. From 10.2 million sq. meters in 1970, the consumption soared to 2475 million sq. meters in 2006–2007—the growth rate being 10–15 % since 2000–2001. The market for geotextiles is still confined to the USA, Canada, developed countries in Western Europe, Japan, and Australia. These countries account for nearly 33 % of the global consumption. The rate of growth would have been higher had other countries preferred its use during the said period.

The striking part of the growth of the global geotextile sector is that geotextiles made of natural ingredients like jute, coir, sisal, kenaf, and ramie constitute only 5–6 % of the present global consumption. Admittedly there was not much R&D exercise with natural fibers initially. Behavior of natural fibers being markedly different from that of man-made geotextiles rigorous research and studies on each of the potential fibers are called for. The R&D efforts with Jute Geotextiles (JGT) in India started first in Indian Jute Industries' Research Association, Kolkata (IJIRA).

The effort somewhat lacked the desired focus in the initial stages. Nevertheless it was possible to convince some of the end-using organizations such as Calcutta Port Trust to undertake field trials with JGT in the late 1980s. Concurrently some of the overseas technical institutions such as Singapore National University, Bangladesh University of Engineering & Technology, also initiated studies on JGT at about the same time.

One of the major reasons of the insignificant consumption of natural geotextiles could be the lack of systematic and thorough study on performance and behavior in soil of varying characteristics and behavior under different nature and extent of external loads. The studies conducted so far in the field of natural geotextiles were not as intensive as was desired. Things however have started changing in so far as jute is concerned. The mechanism of Jute Geotextiles in transforming soil behavior has been investigated through laboratory studies and more than 260 field trials/applications as of date in India.

The global textile industry is now poised for transformation. Not only geotextiles but a host of other diversified uses of textiles have been conceived. Innovative uses of textiles have opened up new avenues in research and studies in textile technology. Quite a few new textile products have been developed having nontraditional uses. These were first branded as "industrial textiles" and have been subsequently styled as "technical textiles." Geotextiles is a class of technical textiles intended to address soil-related problems. Jute Geotextiles is the natural variant of geotextiles now termed geosynthetics embracing both man-made and natural geotextiles according to international convention.

1.1 Technical Textiles (TT)

Technical textiles, as already indicated, are nontraditional engineered textile products in which aesthetic aspects of the finished products are of hardly any relevance. The Textile Institute, Manchester, UK, proposes the following definition of technical textiles:

> Textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics.

Basically technical textiles are supposed to meet the requisite technical specifications for a specific end use. Technical textiles have emerged as the fastest-growing sector of the textile industry globally. David Rigby Associates, UK, were engaged by Messe Frankfurt GmbH in connection with TechTextil 1997 (The International Trade Fair for Technical Textiles & Non-wovens) to conduct a study and market survey on technical textiles. David Rigby Associates broadly classified technical textiles into 12 groups on the basis of end uses as under

Agrotech—for agriculture, horticulture and forestry
Buildtech—for building and construction

Clothtech—for clothing and components of footwear
Geotech—for geotechnical and civil engineering
Hometech—for furniture components and household textiles
Indutech—for industrial applications
Medtech—for medical applications
Mobiltech—for automobiles and other transports
Oekotech—for environmental protection
Packtech—for packaging
Protech—for protective uses
Sporttech—for sports and recreation

1.2 Geosynthetics

The term geosynthetics, as already indicated, embraces both man-made and natural geotextiles. Earlier the term was used to denote only man-made geotextiles. According to knowledgeable sources, the change in the name was prompted by the fact that the word "textiles" is losing its relevance in the context of the new diversified products that have been developed or are going to be developed in future for soil-related applications. Anyway, we in this treatise prefer to call natural Geotech by geotextiles preceded by the type of natural fiber as ingredient used in their making, e.g., Jute Geotextiles (JGT), Coir Geotextiles, etc.

"Geosynthetics" may be defined as a planar textile fabric or material used in or on soil to improve its (soil's) engineering performance. The clause "engineering performance" has a wide connotation. It signifies basically the capacity of any soil to remain stable by withstanding different kinds of imposed loads. Control of soil erosion and earth slips, prevention of soil migration from under the base of a structure, dissipation of water from soil body, and separation of the base soil from overlying courses are the critical functions which geosynthetics are supposed to perform for improving the engineering performance of soil. In fact the conjunctive functions as indicated lead to improvement of soil performance as a whole. The role of geotextile is that of a change agent. We shall discuss the matter in detail in the relevant chapters that follow.

The reason of inclusion of natural geotextiles under the fold of geosynthetics could be that both man-made and natural types are manufactured from synthesizing polymers—natural or man-made. Synthetic and natural polymeric materials are characterized by their macromolecular construction signifying that large molecules are their basic ingredients. Macromolecules in turn are formed as a result of a combination of monomers that are smaller units with similarity in shape. The process of combination of monomers to form polymers is known as polymerization. Man-made macromolecular materials are broadly of three types—thermoplastics, thermosets, and elastomers. All the three types possess distinct characteristics of their own due to their individual molecular structure. Petrochemical derivatives are the biggest source of man-made polymers.

The basic ingredients of man-made geotextiles are thermoplastics that include polyamide, polyester, polyethylene, polypropylene, PVC (polyvinyl chloride). Man-made geosynthetics are made from converted forms of thermoplastics, i.e., tapes, filaments, and yarns.

Geosynthetics are of two broad types—*woven* and *nonwoven*. Woven geosynthetics with comparatively large openings (open weave construction) are made by interlacing of two or more sets of yarns/fibers/filaments/tapes or other basic weavable ingredients. The sets are woven together with one set running in a lengthwise direction (*warp*) and the other running across (*weft*). Woven geosynthetics are categorized either on the basis of the type of threads or on the basis of the fabric function.

Nonwoven types are manufactured by bonding or interlocking of staple fibers, monofilaments, or multifilaments that are either randomly or specifically oriented. Mechanical, thermal, or chemical means and suitable combinations of these bonding methods achieve the desired bonding or interlocking. Geogrids, i.e., polymer lattices, are also nonwovens, made by perforating extruded polypropylene or HDP sheets. Warp knitting is also resorted to produce a kind of nonwoven. Knitted fabrics are basically made of laterally interlaced parallel threads. The interlacing points are not specially bonded in such fabrics. Natural geogrids are uncommon. It is however felt that natural composites may be tried for manufacture of geogrids. 3-D mats that are manufactured by extrusion of monofilaments or polymers or by application of hot pressure on polymer sheets may be brought under the nonwoven category. These mats are used mainly for drainage.

Both woven and nonwoven geosynthetics are permeable. Impermeable planar sheets of geosynthetics are known as *geomembranes*. The fundamental difference between geosynthetics and geomembranes lies in cross-permeability. Geomembranes are manufactured mainly from thermoplastics.

Natural fibers are obtainable from four sources which may be categorized as (i) wood fiber (soft and hard woods), (ii) vegetable fiber (jute, coir, ramie, kenaf, cotton, etc.), (iii) animal fiber (wool, silk, etc.), and (iv) mineral fiber (asbestos, inorganic whiskers, etc.). Not all fibers are suitable for making of natural geosynthetics. Large-scale availability and physical properties of natural fibers are determinants in regard to suitability of natural geosynthetics. Vegetable fibers are considered the most suitable for making of natural geosynthetics. Jute happens to be the ideal among natural fibers because of its availability, appropriate physical properties, and good spinnability. In fact, jute industry in the Indian subcontinent has behind it a wealth of experience in making of yarns from jute fiber, besides the traditional method of extracting bast fiber from the plant of the same name and other accompanying processes such as *retting* (soaking in water to separate fiber from woody tissues).

Threats arising out of dwindling petroleum reserves and increasing environmental degradation are prompting technologists to opt for natural alternatives wherever possible. Developed countries are now inclined toward adoption of bioengineering measures to address soil-related problems. Plant-derived fibers as a result are now turning out to be the most sought after materials of the twenty-first century (Bledzki and Gassan 1999).

In the chapters to follow we shall dwell upon Jute Geotextile broadly in all its aspects. Versatility of jute fiber has made it possible to manufacture natural Geotech to meet the specific technical requirements. Both woven and nonwoven fabrics can be made out of jute fiber possessing the requisite tenacity, initial strength, extensibility, and other physical properties. Moreover, jute has behind it a sound support of several research organizations that has made innovative developments possible.

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Chapter 2
Jute, Jute Fiber, and Jute Yarn

Abstract The chapter gives an elaborate exposition of jute, its fiber, and the processes involved in making of jute yarns and their conversion to Jute Geotextiles (JGT). Types of jute fiber, its composition, physical features, and characteristics along with the method of extraction of jute fiber from the plant of the same name along with basic operative procedures depicting conversion of jute fiber to jute yarns and their utilization in fabric manufacture are discussed in detail with flow diagram. The system of differentiating jute fiber on the basis of quality known as "grading" of jute has also been stated briefly along with factors affecting the quality of jute fiber.

Keywords Retting • White jute • Tossa jute • Microstructure of jute • Hemicellulose content • Dielectric constant of jute • Grading of jute • Slivers • Carding • Carded slivers • Combing • Doubling • Drawing • Yarn twist • Parallelization • Flyer spinning • Ring spinning • Wrap spinning • Friction spinning • Carbon footprint

2.1 History of Jute

Before we deliberate on jute, it is felt readers should have a brief exposition about the evolution of jute as a commercial fiber. Since the dawn of civilization, man has been trying to overcome odds with the resources at their disposal to make his life safe and comfortable. He took pains to construct stable shelters and pathways and secure his habitat from floods and other natural calamities apart from collecting the basic necessities for sustenance. Agriculture and land cultivation were the first among such efforts of ancient man. There are historical evidences to show that he extensively used natural materials to circumvent the odds that confronted him in those days. Use of natural materials was the only option left to the ancient man. Jute is a very old agricultural produce cultivated mostly in the Ganga-Brahmaputra delta in the Indian subcontinent. Its leaves were consumed as vegetable and used as a household herbal remedy. It was however after setting up of jute mills in the vicinity of Kolkata in the mid-nineteenth century that its cultivation gained importance and was systematized.

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But before that only in the last decade of the eighteenth century, the British (East India Company) first sensed the potential of jute fiber and sent samples of jute plant, then called “Indian Grass” to England. Three decades later, jute fiber was sent to Dundee in Scotland, the global textile hub at that time, for tests and its uniqueness was established after the tests. Experiments at Dundee revealed high initial strength of jute fiber and their improved spinnability by admixture of a softening oil.

The first major commercial breakthrough for jute resulted in 1838 with orders for jute sacks from the Netherlands for carriage of coffee beans to the East Indian Plantation followed by two wars, viz., Crimean war (1854–1856) and American Civil War (1860–1865). After that there was no looking back for jute as the preferred flexible packaging material. By around 1870 jute sack turned to be the most sought-after flexible packaging container due to its low price and good quality and led to setting up of a large number of jute mills in the eastern part of the Indian subcontinent. Monopoly of jute sacks steadily waned after the advent of artificial synthetic fibers in the market in 1950s. Jute industry started looking for jute diversified products to supplement the shortfall in demand for jute sacks. Jute Geotextiles (JGT) is the outcome of such search.

2.2 Characteristics of Jute

Now let us revert to technicalities related to jute, its characteristics, and the different phases of processing right from extraction of fibers from jute plant till its conversion into yarns and fabric in brief. The spurt in use of jute fiber for making of sacks led to improvement of its method of cultivation, development of special extraction process of fiber, conversion of fibers to yarns, and finally manufacture of jute fabrics with the yarns.

Jute belongs to the genus *Corchorus*. There are over 30 species of this genus out of which *C. capsularis* (known as white jute) and *C. olitorius* (known as tossa jute) are utilized for production of fiber.

Jute plant has an erect stalk with leaves. It thrives in hot and humid climate, especially in areas where rainfall is copious. It grows up to about 3 m in height usually and matures within 4–6 months. Jute fiber lying in the peripheral layer of its stem is extracted from the thin bark and woody core of the plant by a special manual process by soaking the jute stalks in bundles in still or mildly flowing water for about 2–3 weeks. The process is known as *retting* (Fig. 2.1). Immersion of jute stalks in water makes fiber extraction easy from jute stem as it softens and dissolves the binding substances, especially pectin. Extraction is done manually followed by washing and drying, to make the fiber suitable for commercial use. Currently mechanical contrivances have been developed for fiber extraction from jute stems.

Fig. 2.1 Jute plant, retting, and drying

2.3 Composition of Jute

The chemical composition of jute is broadly as follows

- α-cellulose—59–61 %
- Hemicellulose—22–24 %
- Lignin—12–14 %
- Fats and waxes—1.0–1.4 %
- Nitrogenous matter—1.6–1.9 %
- Ash content—0.5–0.8 %
- Pectin—0.2–0.5 %

Distribution of lignin is not uniform in jute fiber. There is concentration of cellulose and hemicellulose in the primary and secondary walls. Each fiber element of a raw jute stem incidentally comprises 5–15 ultimate cells bonded together. These ultimate cells are on average 2.5 mm long with tapered ends and a wider middle (18 μm approx.). The cross section of the ultimate cell is polygonal. The layer of the bonding substance between the ultimate cells is called middle lamella.

The cell wall resembles a hollow tube having two different walls—one primary or elementary layer and a thicker secondary wall composed of microfibrils besides a lumen. Lumen is like an open conduit running through the center of the microfibril (Fig. 2.2). Each layer contains cellulose embedded in a matrix of hemicellulose and lumen. Hemicellulose is composed of highly branched polysaccharides including glucose, galactose, xylose, etc. Lignin contains hydrocarbon polymers found

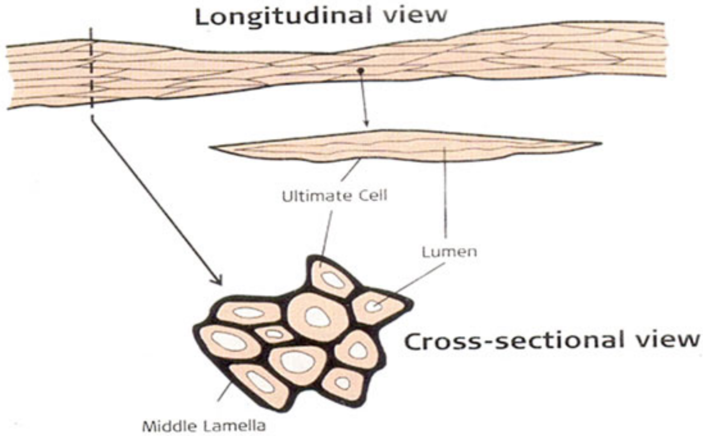

Fig. 2.2 Microstructure of jute fiber

around fibers. The layer with microfibril is the thickest and determines the overall properties of the fiber. The microfibril layer is rich in cellulose molecules.

2.4 Physical Properties of Jute Fiber

The average linear density of single jute filament lies between 1.3 and 2.6 tex for white jute and 1.8–4.0 tex for tossa jute with normal distribution. Coarseness of jute has some role in determining the strength of jute fiber. Coarse fibers are usually stronger.

Jute fiber is usually strong with low extensibility. It has a tenacity range of 4.2–6.3 gf/denier. Tenacity varies with the length of the fiber. Elongation at break of jute fiber is between 1.0 and 1.8 %. Tossa jute is stronger than white jute. Jute fiber breaks within elastic limit and is resilient, which is evident from its recovery to the extent of 75 % even when strained quite a bit (1.5 %). Its flexural and torsional rigidity are high compared to cotton and wool.

Presence of hemicellulose in jute fibers makes it hygroscopic, second only to wool. Tossa jute is slightly more hygroscopic than white jute. Jute fiber swells on absorption of water. Lateral (cross-sectional) swelling of jute fiber (about 30 % on average) far exceeds its longitudinal swelling (0.4 %).

During the process of addition of water, tenacity of jute fiber increases at the initial stages up to the relative humidity of 20 % which does not vary for most of the period of water addition thereafter but exhibits a downward trend when the relative humidity exceeds 80 % or so. This phenomenon implies decrease in flexural and torsional rigidity of jute fiber when moisture absorption exceeds a limit.

Jute is not thermoplastic like other natural fibers. Charring and burning of jute fiber without melting is a feature of jute fiber. Due to high specific heat, jute has

Table 2.1 Properties of jute fiber

Property	Jute
Ultimate cell length, L (mm)	0.8–6.0
Ultimate cell breadth, B (mm)	10–25 μm
Length/breadth (L/B) ratio	110
Fineness (denier)	15–35
Tenacity (gm/denier)	3–5
Specific gravity (gm/cc)	1.48
Coefficient of static friction	0.45–0.54
Refractive index	1.577
Specific heat (Cal/g/°C)	0.324
Thermal conductivity (cal/s/cm.°C/.cm^2)	0.91×10^{-4}
Thermal conductivity (M watt/m.kelvin)	427.3
Heat of combustion (Jules/g)	17.5
Ignition temperature (°C)	193
Elongation at break (%)	1.0–1.8
Density (gm/cc)	1.46
Degree of crystallinity (X-ray)	55–60 %
Angle of orientation (X-ray)	7–9^0
Initial modulus	17–30 N/tex
Flexural rigidity (dynes.cm)	3.0–5.0
Moisture regain (%) at 65 % R.H.	12.5
Moisture regain (%) at 100 % R.H.	36
Diameter swelling (%) at 100 % RH	20–22

(Source: Textile Engineering Department, IIT, Delhi & Indian Jute Industries' Research Association, Kolkata)

thermal insulation properties. Ignition temperature of jute is of the order of 193 °C. Long exposure of jute fiber to hot ambience reduces its strength.

Dry jute is resistant to electricity, but it loses its property of electrical resistance appreciably when moist. Dielectric constant of jute is 2.8 kHz when dry, 2.4 kHz at 65 % RH (relative humidity), and 3.6 kHz at 100 % RH.

Coefficient of friction of jute fiber is usually 0.54 for white jute and 0.45 for Tossa variety. Moisture content in jute influences its frictional property. Properties of jute fiber may be seen in Table 2.1.

Treatment of natural fibers with alkali has been studied by a number of researchers. It has been observed that natural fiber surfaces being rich in hydroxyl groups provides suitability to chemical modification by way of treatment. Mohanty et al. (1998) studied the effects of treatment on two varieties of jute fabric—hessian cloth and carpet backing cloth—with alkali and other chemical processes like de-waxing and grafting. The results reveal that alkali-treated jute fabrics possess higher tensile and bending strength than de-waxed jute fabrics probably due to improvement of the adhesive characteristics of the fabric on treatment. Jute fiber develops crimps like wool when treated with strong alkali (18 %) due to irregular swelling. The process is known *woollenization*.

Acids affect jute fiber adversely and weaken them. Strong acids may destroy jute fiber. Inorganic acids affect jute fiber worse than organic acids. Bleaching agents also affect jute fiber.

2.5 Grading of Raw Jute

The Bureau of Indian Standards (BIS) in its publication no IS:271-2003 recommends grading of raw jute based on the fiber characteristics. The characteristics are strength, freedom from defects, bulk density, color, fineness, and root content. There are sub-features to these characteristics. Based on these features, eight (8) grades of each of tossa and white jute have been conceived, marked as $TD_{1,}$ TD_2 for tossa jute and $W_{1,}$ W_2 for white jute in that sequence. Grading is done giving due weights to physical attributes of jute fiber. Maximum stress is given on fiber strength and root content at the time of evaluation of the grading. For manufacture of Jute Geotextiles (JGT) selection of the appropriate grade of jute is critical to meet the specified strength and fineness criteria of the fabric.

2.6 Jute Yarns

Textiles are manufactured out of yarns, which are transformed forms of fiber, retaining the fiber properties in general in different degrees. Jute fiber is converted into jute yarns which constitute the basic ingredient of any jute based fabric including Jute Geotextiles. Understandably good fiber quality ensures good yarns and consequently good fabrics.

Technically jute yarn or, for that matter, any yarn is an assembly of fibers and/or filaments either in twisted or untwisted form having its length substantially higher than its diameter or width. Yarns may be spun from staple fibers or may be made directly from continuous filaments. Spun yarns may be made out of more than one type of fibers. The spinning system plays an important role in determining the yarn quality. Structurally, yarns made of continuous filaments are simpler. There are other types of yarns, viz., multifold yarns, cabled yarns, fancy yarns. The difference in yarn type is based on the number of fibers/filaments, irregular features, diameter, hairiness, packing density, and the amount of twist exerted in their making.

The basic operations for conversion of jute fiber into yarns are

- Opening, cleaning, and mixing
- Formation of slivers (loose continuous strands of fibers ready for drawing and twisting)
- Thinning of slivers
- Parallelization of fibers
- Packaging

The first operation needs no elaboration. The entangled raw jute fibers are to be de-knotted and freed from impurities by cleaning. Usually mixing of different qualities of fibers is done for commercial as well as technical reasons. This is known as *carding*.

Slivers are produced during carding operation. After disentanglement of jute fibers by carding, each jute strand is cleaned again.

Carded slivers are usually thick and contain a large number of fibers. Thinning of slivers is essentially an operation of pressing through a pair of feed and a pair of delivery roller. But the process causes longitudinal irregularity of slivers. A process known as *doubling* in which slivers are mixed in appropriate proportions helps overcome this irregularity.

Making fibers parallel to each other in sliver is a prerequisite for twist insertion in the next stage. A good degree of parallelization ensures good strength.

To enable the fiber assembly to be stronger and to ensure greater compaction, twists are imposed through special techniques. Yarn twist, defined as the number of turns per unit length, is given either in the clockwise (also known as Z-twist) or in the anticlockwise direction (also known as S-twist). Single yarns are given Z-twist while plied yarns are subjected to S-twist. The angle of twist θ is a factor of turns per unit length and yarn linear density. It may be stated that the mechanisms of twist of spun yarn and filament yarn are different. Anyway the process of imparting twist is a specialized job. Its basic purpose is to increase the transverse force on the fiber assembly to resist slippage under tensile forces.

In this context the issue of yarn irregularity deserves mention. Yarn irregularity is caused by several factors. Random fiber arrangements, defective machinery, variation in fiber length (causes a wavelike variation in yarn thickness), and adherence of extraneous substances are the principal contributors to yarn irregularity. It is pertinent to mention that length, fineness, strength, extensibility, flexural and torsional rigidity, and interfiber friction affect yarn quality. There are mechanical contrivances that help remove most of the irregularities.

Packaging of yarns depends largely on the spinning process. Small packages in a spinning machine are usually converted to bigger packages if deemed convenient for subsequent processing.

2.7 Processing of Jute Yarns

The processing of jute yarns comprise the following basic operations

- Selection of the appropriate fiber
- Softening
- De-knotting and cleaning
- Formation of sliver (continuous strands)
- Reduction of sliver linear density
- Parallelization of fibers
- Packaging

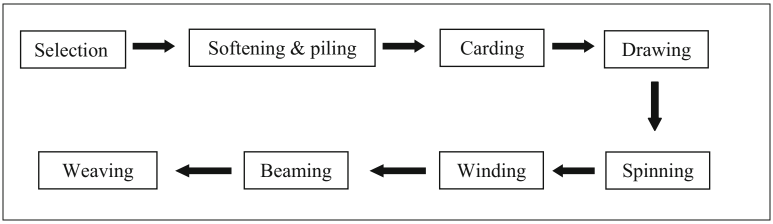

Fig. 2.3 Flow chart showing stages in manufacturing process of jute fabric

After formation of sliver, sometimes fibers of different quality are blended.

There are two spinning systems in vogue. In a long staple system, slivers produced from long jute reeds are processed in the spinning machine. In the second system, known as short staple system, slivers of short jute yarns are fed to the spinning machine. Spinning is usually done following long staple system.

The essential features of spinning process are drafting and winding. Drafting is the process to reduce the bulk and weight of sliver and parallelizing the fibrous components of yarns. Winding is the operation to transfer yarn from one form of packaging to another. The sequential flow chart of different operations is given in Fig. 2.3.

Selection, also called batching, as the name indicates, implies selecting the right grade of fiber in terms of strength, fineness, and quality. Sometimes a combination of fibers of two or more grades is chosen keeping in view the requisite specification of the fabric in question.

Softening of jute fiber has to be initially done to clean and expel extraneous impurities and for disentangling the tangled reeds of jute. Jute reeds are passed through a series of heavy rollers with concurrent oil-water emulsion treatment. The treated jute reeds are kept under a cover for about 3 days. This helps bacterial fermentation and allows distribution of the emulsion into the fiber mass. The process is known as *piling*.

Carding is done for longitudinal splitting and lateral breakage of jute reeds. This helps in delinking of individual filaments and helps produce slivers of uniform linear density. This is a precision operation. After piling, the hard portions of jute reeds are cut to segregate them from the soft and pliable portions. The soft portions are then fed to breaker card, so named as it breaks open the matted structure of jute to produce individual filaments.

The filaments so produced are made to pass through another carding machine called finisher card which makes possible production of finer filaments.

To remove the remnants in fiber irregularity, a process known as *doubling* is resorted to. Doubling is basically combining a number of slivers transversely for drafting to produce single sliver as the output.

Drawing process makes slivers obtained after carding thinner, improving their parallelization and spinnability. It is done three or four drawing frames and a pair of rollers. Winding is essentially removal of deficiencies in spinning mechanically/electronically.

Twisting in textiles parlance also means the process to form yarns with plies Jute slivers are then made to comply with the desired linear density and imparted twisting to make the specified yarn. There are several types of spinning such as *flyer spinning* (in which twisting is done with the help of a machine known as flyer), *ring spinning* (in which twisting is done by a "traveler" moving along a ring), *wrap spinning* (in which parallel jute fibers are wrapped by a synthetic filament for inducing cohesion among the fibers), and *friction spinning* (in which fibers are twisted in layers for improved frictional contacts between fibers).

To achieve the desired yarn characteristics, it becomes necessary sometimes to blend jute fiber with fibers from different sources—natural or man-made. Slivers of staple fibers are usually used in such blends. The respective proportions are predetermined and mixed up in the drawing stage.

With a view to ensuring yarn regularity, elimination of fibers with length less than 25 mm becomes necessary. The process by which the elimination is carried out is called *combing*. Combing also helps in spinning fine yarns. Woven Jute Geotextiles are made by weaving the readied yarns in specially made power looms ensuring conformance to specifications (Fig. 2.4). For making nonwoven fabric, needle punching or chemical bonding of randomly distributed fibers is resorted to. It is different from the process of weaving.

Fig. 2.4 Manufacture of jute fabric in loom

2.8 Yarn Quality

Yarn quality is critical in manufacture of JGT. Tensile strength and pore size of JGT are the two parameters that demand the highest attention during making of JGT. It is common sense that plied yarns adds to the tensile strength of the fabric.

Weaving ease is directly linked with average strength of yarn. Unevenness, hairiness, and other imperfections need be effectively controlled. Unevenness and hairiness of yarns may affect the porometry of JGT. It is also difficult to adhere to the specified weight of JGT if imperfection in yarn quality creeps in. To guard against yarn breaks during weaving, the palpable imperfections are to be removed in advance.

Irregularity in jute yarns cannot be totally avoided due to random disposition of and defects in fiber. There are methods of measuring such irregularity. Drafting wave (wavelike variation in yarn thickness when subjected to attenuation by rollers) also causes yarn irregularity. Hairiness in yarns has direct relation with the number of fibers in a yarn.

Irregularities may be short term and long term. Variation of mass or diameter between successive short yarn segments is called short-term yarn irregularity. For long segments ($>$100 times the average fiber length) the irregularity is long term. Irregularities in yarns are measurable. Yarn irregularity adversely affects the yarn strength. In manufacture of JGT tensile strength is a critical factor. Irregularities in yarn also affect flexural and torsional rigidity. In case of fiber, low flexural and torsional rigidity renders flexibility to yarn formation. Higher flexural rigidity of fibers and also yarns influences spinnability and fabric structure. In case of jute, moisture in the right proportion can help reduce both flexural and torsional rigidity.

Yarn twist, if not imparted properly, may adversely affect some of the fabric characteristics especially drapability, abrasion resistance, and tensile strength. It requires specific attention to predetermine the optimum twist that yields the highest strength to a yarn. Longer or finer fibers require lower optimum twist, while finer yarns need higher optimum twist than coarser ones. The lower the optimum twist, the better the fabric qualitatively.

There are several factors that affect jute yarn quality. As already indicated fiber quality has a direct bearing on yarn quality. In addition to fiber quality, process control is a critical factor in ensuring yarn quality. Irregularity of a yarn depends on the fiber length and its distribution. Finer fibers usually produce yarns with regular features. Fiber length is critical in respect of spinning a good quality yarn. Long fibers are needed for yarns to be strong.

Processing factors also influence yarn quality. Softening, carding, drawing, sliver coherence, spinning, winding, and twisting should be carried out with care and caution. There are specified systems of these operations that ensure retention of the right yarn quality.

Moisture in jute fiber plays a big role in retention of strength, rigidity, and toughness. High moisture content reduces the flexural and torsional rigidity of jute fiber but enhances its toughness. There is thus need for optimizing the ambient moisture content.

Utilization of biomass and adoption of bioengineering measures for addressing soil-related problems have become preferred options at present due to threats of pollution. Cellulosic content of jute fiber is the main source of biomass. Currently the global emphasis is on reduction of carbon footprint in constructions. Life cycle analysis of jute shows that jute plants sequester carbon significantly. Increasing degradation of environment and depleting petroleum reserves are matters of concern. The inherent properties of jute fiber are significant in the context being natural, eco-concordant, and an annually renewable resource. This aspect has been dealt with in more details in Chap. 16.

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Chapter 3
Jute Geotextiles: Its Types and Functions

Abstract The chapter focuses on Jute Geotextiles (JGT) and its types and functions along with constructional features of each of the three major types of JGT in common use, i.e., woven, nonwoven, and open weave. Distinguishing physical properties of jute fiber chosen for making of a specific type of JGT have been discussed in detail. The four basic technical functions of JGT for imparting stability to soil, viz., separation, filtration, drainage, and initial reinforcement, have been explained. Survivability and durability aspects of JGT have also been dealt with. The chapter additionally includes definitions of important geotextile-related terms.

Keywords Warp • Weft • Needle punching • Tenacity • Initial modulus • Elongation at break • Roughness coefficient • Drapability • Spinnability • Separation • Drainage • Filtration • Initial reinforcement • Open area ratio • Blocking • Blinding • Clogging • Filter cake formation • Porometry • Cross machine direction • Machine direction • Permittivity • Transmissivity • Wettability • Mechanical properties of jute

Jute Geotextiles (JGT) are the natural variant of geotextiles ("geosynthetics" is now the accepted term embracing both natural and synthetic variants. In this treatise we have used the terms "jute geotextiles" and synthetic geotextiles to denote jute-based and man-made geotextiles, respectively, to avoid confusion.)

Traditionally, jute has been known as a material for bulk flexible packaging in the form of sacks. Jute industry, perhaps the oldest surviving agro-industry in the world on which more than four million people depend directly and indirectly in India, has thrived on this particular product alone. With intrusion of man-made fiber, monopoly of jute sacks has been on the wane and jute industry has been desperately on the lookout for new avenues for survival. JGT if aggressively promoted could be a viable alternative. Special features of jute fiber have been gainfully utilized in development of JGT matching its man-made counterpart technically in all its features except, of course, durability and tensile strength. Synthetic geotextile is a proven engineering material, but its nonbiodegradability and long life tend to pose apprehensions as to its eco-compatibility. Growing environmental concerns have prompted scientists/technologists to look for natural, biodegradable alternatives for geotechnical applications. JGT fits in with this aim.

T. Sanyal, *Jute Geotextiles and their Applications in Civil Engineering*,
Developments in Geotechnical Engineering, DOI 10.1007/978-981-10-1932-6_3

We shall clarify later in this book that long durability and high tensile strength of geotextiles are application-specific requirements.

Interestingly Jute hessian was applied in a road at Dundee, Scotland, in 1920, in Strand Road at Kolkata in India by Bengal PWD in 1934, and in Myanmar (then Burma) during the Second World War with reported success. The concept of geotextiles did not emerge at that time. There was a long period of lull, so to say, after these sporadic applications. In India JGT was first consciously used for slope stabilization at Sahasradhara, Uttarakhand, by the Indian Institute of Soil and Water Conservation—IISWC (erstwhile CSWCRTI)—in 1987, for control of riverbank erosion at Nayachar island in the Hugli estuary by Calcutta Port Trust in 1989, for restoration of a severely damaged road at Kakinada, Andhra Pradesh, by the Central Road Research Institute (CRRI) under the Council of Scientific and Industrial Research, India, in 1996, and for control of railway track settlement at Madhusudanpur in Howrah-Burdwan Chord line in 2001 by Eastern Railway with technical guidance of Jute Manufactures Development Council (now National Jute Board). Continuing research on JGT and field applications facilitated understanding of the mechanism of its functioning.

3.1 Types of JGT

There are three basic types of JGT based on constructional features similar to synthetic geotextiles. The process of manufacture of each is different as also their end uses. All geotextiles are manufactured for specific end uses with variation in specification. Soil features as well as nature and extent of imposed extraneous load determine the fabric specification especially in regard to tensile strength and porometry.

– Woven
– Open weave
– Nonwoven

3.2 Woven JGT

Woven JGT (Fig. 3.2) are made by traditional weaving processes in which two sets of parallel yarns are interlaced at right angles to each other. The terms *warp and weft* (Fig. 3.1) are used to distinguish between the two different directions of yarns as shown in Fig. 3.1. *Warp* defines the longitudinal yarn, i.e., the direction in which production proceeds (also called *machine direction or MD). Weft* defines the

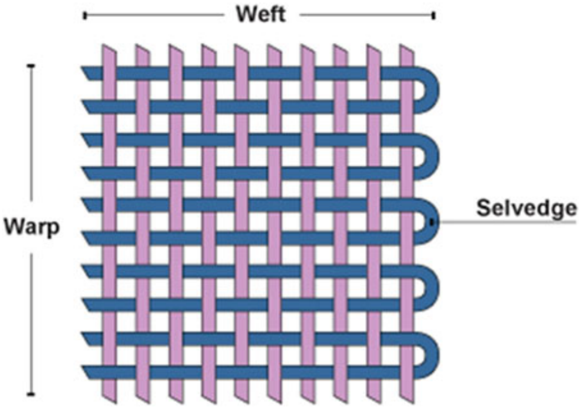

Fig. 3.1 Pattern of weft and warp yarns in a woven JGT

Fig. 3.2 Woven JGT

transverse direction, i.e., running width-wise (also known as *cross machine direction or CD)*. Figure 3.2 show surface texture of a typical woven JGT

3.3 Nonwoven JGT

Nonwoven GT are obtained by processes other than weaving which includes continuous laying of fibers on a moving conveyor belt bonded by mechanical (such as needle punching)/thermal/chemical processes. Fibers are randomly distributed in a nonwoven fabric. Surface texture of a typical nonwoven JGT is shown in Fig. 3.3 which resembles a rug in appearance.

Fig. 3.3 Nonwoven JGT

Fig. 3.4 Open weave JGT

3.4 Open Weave JGT

Open weave JGT has an open structure similar to a net integrally connected two sets of parallel yarns which are interlaced at right angles to each other (Fig. 3.4).

Open weave JGT is usually marketed as "Soil Saver."

Construction techniques as well as properties of the three types of JGT are different. Broadly woven JGT possess higher tensile strength. Its porometric features can be customized. Nonwoven JGT has lower tensile strength but has high hydraulic conductivity. Open weave JGT obviously possesses much lower tensile strength. Being thick it helps in reducing the velocity of overland flow passing over it entrapping detached soil particles in the process. In view of its high tensile strength and tailor-made porometry, woven JGT is used in road construction and riverbank erosion control. Nonwoven JGT is sometimes used in conjunction with the woven type where drainage (more appropriately *transmissivity*, i.e., capacity of lateral conveyance of water) is a concurrent requirement. It is also used in making of concealed drains where good hydraulic conductivity is required. Jute fiber incidentally possesses the highest water-absorbing capacity among all the commonly used natural fibers.

3.5 Properties of Jute Fiber

Physical characteristics of jute fiber as already indicated depends on the quality of jute which is denoted by batch marks such TD_4, TD_5. Broadly the distinguishing features of jute fiber used in manufacture of JGT are as follows:

- *High tenacity*—comparable to man-made fibers. Polyester and polypropylene has tenacity range between 2 and 5.5 g/denier vis-à-vis jute between 3 and 5 g/denier.
- *High initial modulus*—measure of tensile stiffness.
- *Low elongation at break*—lowest among all natural fibers (12–15 %)—provides good membrane reinforcing support under load during its effective life.
- *Highly hydrophilic*—highest among all fibers—absorbs water of about 4.85 times its dry weight.
- *High roughness coefficient*—ensures better load transference. Coefficient of static friction of jute fiber lies between 0.45 and 0.54.
- *Excellent spinnability*—capable of making customized JGT due to high cellulose content of jute.
- *Very high thermal stability*—around 170 °C.

All the three types of JGT possess e*xcellent drapability* enabling the fabric to touch soil contours at all points. In fact JGT ranks the best of all types of fibers—natural and man-made—when wet in so far as drapability is concerned.

Eco-concordance of JGT from cradle to grave is well established by LCA studies. Jute being an annually renewable resource, JGT helps reduce carbon footprint in construction (ref Chap. 12 for more details).

3.6 Basic Functions of Jute Geotextile

The four cardinal functions of JGT and, for that matter, all geotextiles are as follows:

(i) *Separation*
(ii) *Drainage*
(iii) *Filtration*
(iv) *Initial Reinforcement*

Additionally JGT— usually the open weave type—controls erosion of exposed soil (topsoil) by absorbing a part of the kinetic energy of rain drops and effecting partial storage of surface run-off. The weft yarns of open weave JGT act as a series of micro-barriers when laid across the direction of the overland flow because of its thickness thus reducing the velocity of the run-off successively (Refer Chap. 5 for details).

3.7 Explanation of Functions of JGT

Functions performed by JGT are similar to its man-made counterpart. The nature of the functions mostly relate to woven JGT.

3.8 Separation

Separation function implies segregation of two adjacent layers of materials preventing their interpenetration, i.e., intrusion of one layer into another layer having similar/dissimilar materials as shown in Fig. 3.5, which causes reduction in overall design thickness as in the case of pavements and thereby makes it susceptible to failure. When a separating medium is introduced, the interpenetration of the contiguous layers is prevented (Fig. 3.6). Separation is a critical function especially in pavement construction in which the soil sub-grade is required to be kept separate from the overlying layers.

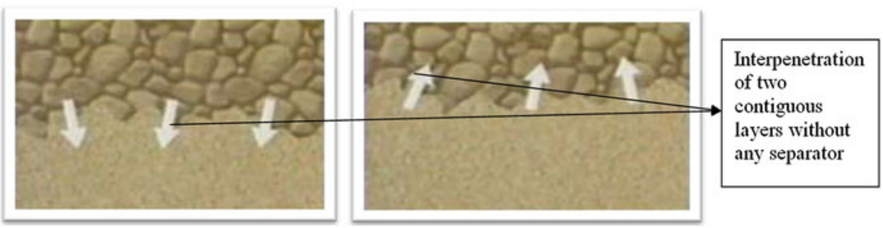

Fig. 3.5 Effect without the separating JGT

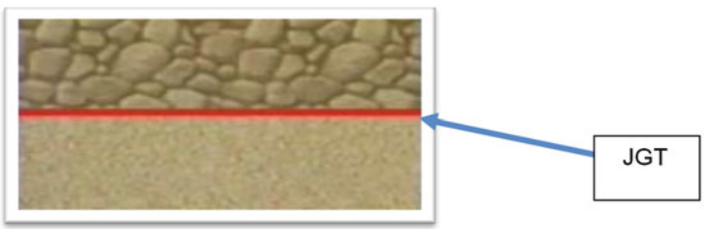

Fig. 3.6 Separation due to JGT

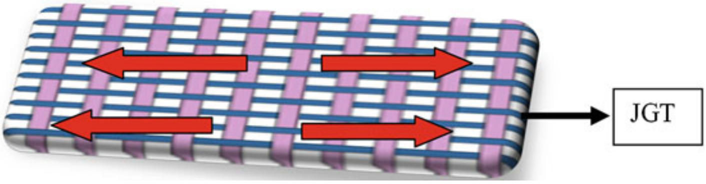

Fig. 3.7 Flow of pore water along JGT plane

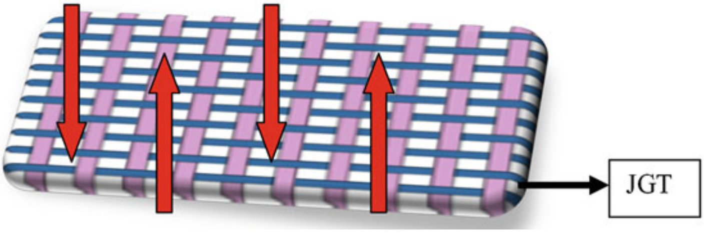

Fig. 3.8 Flow of pore water across JGT plane

Before we discuss two critical functions of JGT or, for that matter, any geotextile, viz., *filtration and drainage*, two terms need be explained—*permittivity and transmissivity*. *Permittivity* denotes the permeability or hydraulic conductivity of a geotextile when thickness of the fabric is considered. It is in essence the capability of a geotextile to allow water to pass *across* its plane (Fig. 3.7). The ease of passage of water *along* the plane of JGT (Fig. 3.8) or any other geotextile is defined as *transmissivity* when the fabric thickness is taken into account. Permittivity is an essential component of *filtration*. Transmissivity is in essence *drainage* or more appropriately lateral dispersion of water along the plane of a geotextile. JGT in fact acts as a drain along its own thickness and drains off the absorbed water in a sustained manner.

3.9 Filtration

Filtration implies performing two contrasting functions:

(a) Soil retention on the one hand.
(b) Facilitating passage of pore water to permeate *across and along the fabric* on the other. Usually permeation of pore water from soil is more across JGT than along it and understandably permittivity plays a more dominant role in the case of filtration.

Filtration comprises two contrasting functions. First, larger pore size of JGT or of any other geotextile will ensure greater permittivity but lower soil-retention capacity. If the pore size is made small enough to ensure retention of soil particles,

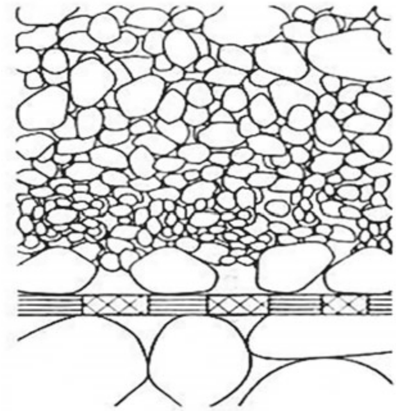

Fig. 3.9 Nature of particle arrangement in filter cake formation in soil

permittivity will be affected. The objective is to rid soil of water to the optimal extent relieving it of pore water to pave the way for development of effective stress within it. A judicious compromise has to be made by close and careful empirical study to decide on the appropriate pore size of a woven JGT in particular. Full retention of fines or free passage of water across the fabric being not practicable, the two sub-functions (a) and (b) above will have to be compromised.

Be that as it may, geotextiles in general are supposed to retain the coarser particles of the soil which have a tendency to veer close to the pores of a geotextile *first* and form an arch over the pores thus blocking smaller ones in soil to move out through the pores. Concurrently the pore water within the soil body gets dissipated as a result of its passage *across* the geotextile fabric gradually helping in dissipation of the pore water pressure within the soil.

The process of soil consolidation is indicated by decrease in air and water voids in a soil body through rearrangement of soil particles in a tighter pack. Release of pore water is an indication of decrease in water voids. The process of dissipation of water thus triggered by geotextiles goes on for years. Ideally effective stress in a soil body develops when air and water voids cease to exist indicating the maximum consolidation of the soil in question. Filtration function along with functions of separation and drainage help adjustment of position of soil particles within the soil body with coarser particles "bridging" over the fabric openings and finer ones reposing over them. The adjusted inter-particulate spaces within a soil body represent a state of consolidation of the soil with gradual expulsion of pore water. The phenomenon is termed *filter cake formation* (Fig. 3.9). The coinage possibly signifies a soil condition with a cake-like formation acting also as filter. The figure below shows how filter cake may look like. Coarser particles in a soil body first try to pass out through the pores of a geotextile under pore water pressure but get obstructed and form arch-like configurations ("bridging network") over the pores and prevent smaller particles from passing out. A denser soil mass is thus formed as a result of geotextile intervention and the process of further consolidation of the soil thus gets triggered and continues.

3.10 Drainage

Drainage is lateral dispersion of pore water along a geotextile. The higher the transmissivity of a geotextile, the more efficient will be the drainage function. JGT, being an excellent receptor of water, holds water initially and releases it gradually along its plane unlike a man-made geotextile which cannot absorb water.

Porometric features of JGT may get affected when the soil is in the process of consolidation. The pores get blocked, blinded, or clogged.

(i) *Blocking*—When soil particles on the surface of a geotextile *partially* obstruct (block) the pore openings.
(ii) *Blinding*—Blinding is almost full blocking of a geotextile due to deposits usually on top of it.
(iii) *Clogging*—When soil particles accumulate *inside* a geotextile, it gets clogged.

Figure 3.10 shows the nature of blocking/blinding and clogging of JGT.

3.11 Initial Reinforcement

When geotextiles are used as soil reinforcement, their prime role is to impart tensile strength to soil which would otherwise be comparatively strong in compression and weak in tension. JGT can resist tension and restrict deformation in the initial stages before its degradation sets in and during optimization of the soil consolidation process. JGT also absorbs part of the installation stresses and strains caused as a result of imposition of extraneous loads. JGT due to its high roughness coefficient can distribute loads over a large area. Friction between soil and JGT ensure distribution of stress in soil. Low extensibility (at-break) of JGT—much lower than man-made geotextiles—and its adequate initial tensile strength (usually of the order of 20 kN/m and up to 40 kN/m) conduces to good "membrane effect" (Refer Chap. 6).

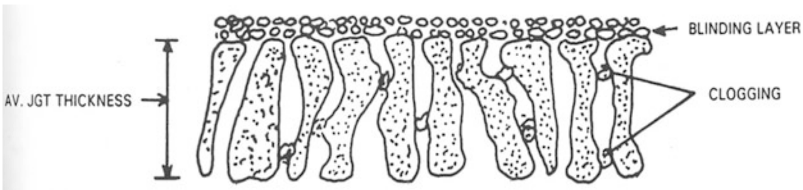

Fig. 3.10 Blocking/blinding and clogging in JGT

3.12 Survivability of Jute Geotextiles

To ensure survivability of JGT, the following precautions need be taken:

(a) Careful storage, handling, transportation, and installation.
(b) Avoidance of open air exposure before installation.
(c) Keeping clear of soil slurry/mud during installation of JGT as it may lead to clogging.
(d) Use of a thin layer of sand (25–50 mm) to guard against puncturing of the fabric from overlying sharp-edged construction materials.
(e) Care should be taken to ensure that armor stones, boulders, etc. are placed softly over the fabric in riverbank protection works.

3.13 Durability of Jute Geotextiles

JGT, because of low lignin content, biodegrades within a year or so depending on type of soil on or in which it is placed. The presence of mildew, moisture, soil acidity, etc. affect its durability. Interestingly it has been observed in laboratory experiments and field applications that soil gets optimally consolidated during the effective life of JGT, triggering the process of soil consolidation and leading to formation of "filter cake." The process of consolidation continues as it is a protracted process by which time soil tries to re-arrange particles in a tighter pack through gradual expulsion of pore water due to concurrent functioning of the three basic functions as well as due to evacuation of air voids as a result of external compressive forces such as vehicular load in roads. In fact all geotextiles including JGT act as *change agent* facilitating formation of *filter cake* within the soil. Once the process of soil consolidation sets off, function of any geotextile—be it man-made or natural—thereafter becomes redundant. Low durability of JGT therefore is not a deterrent as is commonly perceived.

On the contrary, biodegradability of JGT is an advantage when control of surficial soil erosion is considered. It acts as mulch, attenuates extremes of temperature, adds micronutrients to the soil, leaves fibrous residues that improve hydraulic conductivity of soil, and thus eases dissipation of pore water pressure. Increased hydraulic conductivity of soil aids vegetation growth on its biodegradation. JGT in fact plays a critical role in bioengineering measures adopted to control surficial soil erosion.

Be that as it may, a minimum durability period of JGT will be needed depending on the type and nature of application. Durability-enhancing additives should be thought of if the required durability is more than the normal effective life of JGT for a particular application. There have been quite a few studies on this aspect especially the effect of mildew, moisture, and different soil compositions on jute. Influence of salinity, acidity, alkalinity, and persistent exposure to water on jute has also been studied separately by researchers. Earlier copper-based compounds were used to treat JGT for enhancing durability of JGT. The practice has since been discouraged due to apprehension about eco-compatibility of copper-based compounds. Other chemicals have been tried. The space in this book is not adequate to accommodate the results of such studies.

It may be noted that jute fiber lacks uniformity unlike man-made fibers—lack of uniformity in respect of fiber length, diameter, density, and strength. JGT properties, as a result, are apt to vary. Selection of the right batch of jute fiber therefore is extremely important. This is basically the task of jute technologists who should ensure that specification of a JGT prescribed for an application is met.

3.14 Important Geotextile-Related Functional Features

The following features of JGT are critical for specifying any geotextile.

(a) *Apparent opening size* (AOS)—also called *equivalent opening size* (EOS)
It denotes the pore size of a JGT which retains a percentage of the largest particle of a soil mass. Designated as O_n implying that the fabric will retain n% of the particle of the indicated diameter in a particular soil mass.

(b) *Porometry*
Measurement of geotextile pore size and its pattern of distribution in a geotextile

(c) *Open Area Ratio* (OAR)
Ratio in percent between total area of openings and total covered area of a fabric-sample

(d) *Cross machine direction* (CD)
Direction in a fabric perpendicular to the direction of manufacture of a textile, i.e., *weft* direction of a fabric.

(e) *Machine direction* (MD)
Direction in a fabric along the direction of the manufacture of a textile, i.e., the *warp* direction of a fabric

(f) *Permittivity* (y)
The quotient of the coefficient of hydraulic conductivity (also known as the coefficient of permeability) and JGT—thickness.

(g) *Transmissivity* (θ)
It is the product of the thickness of JGT (t_g) and coefficient of in-plane permeability (k_{pg})—also called hydraulic transmissivity (θ).

(h) *Wettability*
It is a hydrophilic property of a geotextile which measures its ability to get saturated under an extremely low waterhead (usually a few millimeters).

(i) *Drapability*
Ability of a geotextile to make contact with the soil-surface without leaving any gap between the two. It is a measure of fabric flexibility. (Refer Chap. 11 for assessing drapability of a geotextile)

The properties can be measured in a laboratory with appropriate instruments according to BIS guidelines if available or by following guidelines of ASTM.

There are several important features of jute fiber/yarn indicating mechanical properties of jute. These are

1. *Tensile strength*
   Maximum tensile stress per unit of initial cross-sectional area applied during stretching of a specimen to break.
2. *Bursting Strength-*
   The force or pressure required to rupture a geotextile specimen by distending it with a force applied at right angles to the plane of fabric under specified conditions.
3. *Young's modulus or elastic modulus of a fabric*
   It is measure of the resistance to extension, i.e., stiffness of a fiber/yarn. It may be defined as the r*atio of stress (force per unit area) along an axis to strain (ratio of deformation over initial length) along that axis expressed as gm/denier*. Low Young's modulus indicates high extensibility and vice versa. Young's modulus is the linear modulus.
4. *Yield point*
   It represents the limiting point in a stress-strain curve beyond which the material ceases to be elastic. Large extensions are produced by relatively low increase in stress.
5. *Rupture*
   It is a measure of toughness of a material. Expressed as gm.cm.
6. *Tenacity*
   Ultimate tensile strength of a yarn/fiber is defined as tenacity. Expressed as mn/tex (force per unit area of an unstrained specimen).
7. *Creep*
   Creep is time-related deformation of a material due to application of continuing constant force.
8. *Secant modulus*
   Elastic or quasi-elastic modulus derived from *a nonlinear* stress-strain curve by taking the ratio of the stress to the strain at a particular point on the curve. Secant modulus is an approximation of modulus of elasticity and generally results in a lower value than that of modulus of elasticity for a particular material.
9. *Extension-at-break*
   It is a measure of extension of a fiber/yarn in relation to its initial length when stretched under force at break point. Expressed as percentage.
10. *Poisson's ratio*
    Ratio of lateral strain and longitudinal strain is defined as Poisson's ratio.

For comprehensive characterization of any geotextile, the following mechanical properties are also measured by standard tests. ASTM test methods are usually followed:

– Index puncture resistance
– Trapezoid tear strength, soil-fabric interfacial friction
– Abrasion resistance

Index puncture resistance quantifies the capacity of a geotextile to withstand puncture, trapezoid tear strength denotes anti-tearing resistance of the fabric, soil-fabric friction test indicates the “roughness” of a geotextile, while abrasion resistance is a measure of resistance of the fabric against abrasion. It may be noted that fatigue resistance test is not usually carried out in JGT given the fact of its low durability.

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Chapter 4
Soil Basics

Abstract As Jute Geotextiles are meant for addressing soil-related problems, knowledge of the engineering basics related to soil behavior is indispensably necessary. The chapter which is intended to acquaint the readers with the fundamentals of behavioral characteristics of soil deals with soil classification, grain size distribution in a soil body, and its properties along with critical factors that influence its behavior in brief. Practical suggestions for exercising checks on soil have also been incorporated.

Keywords Classification of soil • Atterberg's limits of soil • Plasticity of soil • Dispersivity of soil • Optimum moisture content (OMC) • Angle of internal friction • Capillarity • California bearing ratio (CBR) of soil • Uniformity coefficient of soil • Compaction and consolidation of soil • Effective grain size of soil • Grain size distribution of soil • Internal erosion • Suffusion • Pore water pressure • Void ratio • Hydraulic conductivity

Users are required to be conversant with the fundamentals of soil as geotextile design and applications are based on properties and behavior of soil. An attempt has been made here to refresh the memories of the practicing civil engineers and to acquaint technologists of jute and other disciplines about the fundamentals of soil mechanics in a nutshell. The interested readers are advised to go through a standard textbook on geotechnical engineering to know more about this specialized branch of civil engineering.

4.1 Classification of Soil

Soil is commonly classified on the basis of the grain size though there are other criteria of classification and is broadly divided into two categories—coarse and fine. Sand belongs to the coarse category while clay falls under the fine category. Silt considering the grain size comes in between the two. Table 4.1 shows the categorization of soil according to the grain size.

Assessment of geotechnical characteristics of the soil on which JGT is to be laid is one of the prerequisites for selecting the right type of JGT for a specific site. The

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Table 4.1 Description of soil types

Soil description	As per BS 1377 (in mm)	As per ASTM (in mm)
Coarse-grained soils		
A.		
(i) Coarse sand	2.0–0.6	2.0–0.25
(ii) Medium sand	0.6–0.2	
(iii) Fine sand	0.2–0.06	0.25–0.05
B.		
(i) Coarse silt	0.06–0.02	
(ii) Medium silt	0.02–0.006	0.05–0.005
(iii) Fine silt	0.006–0.002	
Fine-grained soils		
(i) Clay	Under 0.002	Under 0.005

following properties of soil need be considered before designing JGT for any construction founded directly on soil such as roads and protective works for remedying soil-related distresses.

4.2 Grain Size Distribution of Soil

It is represented by a semilogarithmic curve which is a plot of particle size to logarithmic scale against the percentages, by weight, of the different particle sizes (Fig. 4.1).

There are a number of ways to characterize the particle size distribution of a particular soil sample. The porometry of JGT (distribution of pore sizes in a JGT sample) is decided considering the distribution pattern of grains in a soil in consonance with the desired separation and filtration requirements. This is a matter of empirical exercise.

4.3 Salient Properties of Soil

Some of the salient properties of soil are stated below:

(a) *Plasticity of soil*

Plasticity indicates cohesiveness of a soil. Plasticity is usually denoted by plasticity index (PI) which is the numerical difference between liquid limit (LL) and plastic limit (PL). Liquid limit, plastic limit, and shrinkage limit of a clay sample are known as consistency limits or *Atterberg*'*s limits*.

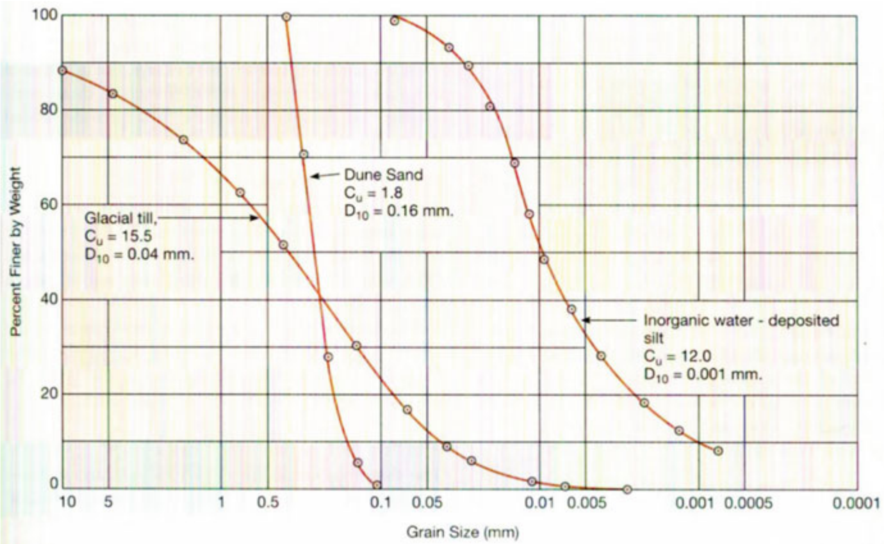

Fig. 4.1 Typical grain size distribution graph

(i) *Liquid limit of soil* (*LL*)
Water content of a remolded soil sample in transition between liquid and plastic states of a soil determined by a standard laboratory test.

(ii) *Plastic limit of soil* (*PL*)
Water content of a remolded soil sample in transition between plastic and semisolid states determined by a standard laboratory test.
P I value less than 10 indicates a soil of low plasticity, while P I value between 10 and 30 indicates normal plasticity of a soil. PI beyond 30 indicates a highly plastic soil.

(iii) *Shrinkage limit of soil* (*SL*)
Maximum water content at which a reduction of water content will not cause any further decrease in volume of the soil.

Clays are plastic in nature. Settlement of a clayey soil is a function of its water content and stress history. Usually the process of settlement of clay is long drawn as it tends to hold free water in addition to the “adhered” water. Draining of water from clayey soil is time-consuming compared to granular nonplastic soil which drains off water far more quickly. Clays are prone to shrinkage which may be as high as 20 % by volume unlike granular soils which hardly shrink on drying.

It is to be noted in this connection that soil undergoes transformation and becomes weaker with addition of water. Solid soil enters into *semisolid state* when some water is added to it. With more addition of water, soil enters into *plastic state* and, after further addition of water, soil becomes *viscous liquid*. Plastic limit of soil represents inception of plastic state while liquid limit marks the beginning of viscous liquid phase of soil. Plasticity index denotes a state of soil bounded by liquid and plastic limits.

(b) *Dispersivity of soil*
It is a measure of sensitivity of a soil to erosion. The more is the content of fines in a soil, the more dispersive the soil is. Dispersivity therefore, is indicated by the pattern of grain size distribution of the soil. Besides cohesiveness (indicated by PI), the mineralogic nature of clay also influences dispersivity of a soil. Soda clays are more dispersive than calcareous clays.

The US Department of Agriculture has developed the pinhole test for determining dispersivity of a soil. A pinhole of 1 mm dia is perforated in the soil sample (25 mm long) through which distilled water is allowed to pass under 0.05 m hydraulic head. The content of fines in water, flow rate, and the change in the hole diameter finally are then assessed to determine the dispersivity of the soil.

(c) *Density of soil*
Density of a soil depends on voids within it and is a function of the void ratio. A dense soil is a strong soil. Compressibility of a soil depends on its density and water content.

In geotechnical engineering, attainment of dry density of a soil is critical for its stability. In laboratory, it is the weight of a unit volume of a soil sample after drying it at 105 °C. Dry density of a soil becomes the highest at a specific percentage of moisture content within it. This percentage of moisture content in a soil which produces the maximum dry density is called *optimum moisture content* (*OMC*) of that soil. When soil reaches the maximum dry density, it becomes less vulnerable to *internal erosion*. OMC is usually 8 % for sands, 15 % for silts, and 15–20 % for clays. Soils without having attained its state of maximum dry density may cause clogging in JGT.

(d) *Permeability (hydraulic conductivity) of soil*
Permeability of a soil is a measure of the rate of flow of water through a soil. The flow depends on the hydraulic gradient and grading of soil (fineness modulus).

4.4 Other Important Soil Parameters

- *Angle of internal friction*
  In simple terms it is the steepest angle to the horizontal at which a heaped soil-surface will stand under stated conditions.
- *California bearing ratio* (*CBR*)
  It is the ratio of the resistance of a soil to a standard plunger of area 19.35 cm^2 having penetration made to 2.5 mm to the corresponding resistance in crushed rock expressed as percentage. A standard test developed by the California State Highways Department, USA, in 1929 was used which is a measure of the bearing capacity of a subgrade, subbase, and base in a pavement.

- *Capillarity*
  It is the property of water in soil to rise in capillaries above the static level of fluid in an open vessel. In soils, water rises between $^1/_{eD}$ and $^5/_{eD}$ cm, where e denotes void ratio and D effective diameter of the soil.
- *Coefficient of permeability of soil* (K_S)
  The flow (V) through the total area of soil (voids and solids) is under the unit hydraulic gradient, i.e., $k_S = v/i$, where i is the hydraulic gradient. The preferred term in modern usage is hydraulic conductivity of soil.
- *Uniformity coefficient* (C_U) *of soil*
  It denotes the ratio between the grain diameter corresponding to 60 % by weight of finer particles in a soil sample to that corresponding to 10 % by weight of finer particles ($C_U = d_{60}/d_{10}$). Apparently, larger C_u means the size distribution is wider and vice versa. $C_u = 1$ means uniform grain size distribution, i.e., all grains are of the same size.
- *Compaction of soil*
  It indicates a condition of soil, the dry density of which has been artificially increased by deflating *air voids* (usually through mechanical means like rolling, vertical drains, vibro-floatation, and impact methods).
- *Consolidation of soil*
  It is a condition of soil having been subjected to processes of gradual reduction of water content from voids of a soil (pore water) at constant load. This is a long-drawn process.
- *Effective grain size of soil*
  The effective grain size of a soil is denoted by $d_{n.}$ It implies that n% of the particles are finer than the effective diameter of soil particles. For instance d_{50} means 50 % of the soil particles are smaller than this diameter.
- *Fineness modulus*
  It is an indicator of the fineness of a soil which is calculated by determining the percentage residues on each of a series of standard sieves, summing them up and dividing the total by 100.
- *Internal erosion*
  Loss of soil particles with a significant range of sizes within a soil body, creating voids within it and making it vulnerable to collapse
- *Suffusion*
  It represents a condition of soil when the finest particles in a soil body are in a state of migration through the rest of the soil matrix which however remains more or less *undisturbed*.
- *Piping*
  It is a condition of soil subjected to subsurface "boil" or erosion—a phenomenon when the velocity of water flowing up through a soil is high enough to make it "boil" or float.
- *Pore* water *pressure*
  It denotes the pressure of water present in the voids of a porous medium (e.g., soil, geotextile).

Fig. 4.2 Phase diagram of constituents in soil

- *Porosity*
  It is the ratio between volume of voids and total volume of soil.
- *Void ratio*
  It is the ratio between volume of voids and volume of solids in a soil.

Explanation:

If V denotes total volume of a soil, Vs volume of solids in it, Vw represents volume of water in the said soil, and Vv volume of voids in it, then Porosity "n" is Vv/Vt and void ratio "e" is Vv/Vs (refer to phase diagram in Fig. 4.2). In other words

$$e = \frac{Vv}{Vs} = \frac{Vv}{V - Vv} = \frac{\frac{Vv}{V}}{1 - \frac{Vv}{V}} = \frac{n}{1 - n}$$

$$n = \frac{Vv}{V} = \frac{Vv}{Vs + Vv} = \frac{\frac{Vv}{Vs}}{1 + \frac{Vv}{Vs}} = \frac{e}{1 + n}$$

Thus e is greater than n for the same phase distribution of a soil sample. Evidently when the porosity is 0.5 (50 %), the void ratio is 1.0.

4.5 Some Important Points Regarding Soil

1. In geotechnical engineering it is important to ascertain the relative proportions of clay, silt, and sand. This necessitates conducting weight-volume relationship tests. Clay and silt can be distinguished by assessing their relative plasticity which in essence is determination of their "affinity" with water. Tests for consistency limits (Atterberg's limits) help in the matter.
2. Shear strength is an extremely important engineering property of soil which is essentially its frictional property and cohesiveness needed for inter-particulate bond.
3. Sometimes organic soils are encountered at sites. Such soils with organic matter are worse than inorganic soils in so far as geotechnical behavior is concerned.
4. It should be borne in mind that pores in a soil body are interconnected which implies that pore water can travel through these pores. Such movements of

subsoil water are important. Flow of water through soil may be assessed by using Darcy's law.

5. Water can rise above the ground water table by capillary action. It is thus important to know the level of subsurface water table.
6. Soil takes time to consolidate. Consolidation depends on the nature of soil, especially its capacity to retain water. Clay takes most time to consolidate—even years or sometimes decades.
7. Consolidation analysis is usually based on Terzaghi's theory of consolidation according to which rate of consolidation of soil is based on rate of dissipation of excess pore water pressure from it.
8. Coefficient of consolidation according to Terzaghi's theory is a factor of hydraulic conductivity of soil which varies widely from site to site. The coefficient of consolidation is very small in clay and very large in respect of sand.

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Chapter 5
Control of Soil Erosion Caused by Rain and Wind with Jute Geotextiles

Abstract Erosion of topsoil is the most common of soil-related distresses. Rains and, at places, high wind are the agents for causing topsoil erosion. The chapter discusses in depth the mechanism of topsoil erosion by precipitation with pointed reference to hillslope erosion. It explains the mechanism of erosion of hillslope due to rain and postulates a technical concept to control such erosion with the help of Jute Geotextiles (JGT).

The technique of soil bioengineering has been explained in depth justifying the role of JGT with its advantages for adaptation in the technique which is now favored worldwide for environmental reasons. Design principle on erosion control incorporating JGT for rain-induced erosion has been explained along with the determinant factors. Considerations for selecting the appropriate JGT under different conditions at site have been indicated. Procedure for installation of JGT has also been explained.

Keywords Universal hydrologic equation • Kinetic energy of raindrops • Erodibility of soil • Erosivity • Mass wasting • Cascading • Soil bioengineering • Overland storage • Moderation of velocity of surface run-off • Seelye chart

Erosion of soil on the surface is basically detachment and consequent displacement of soil particles from its initial position. It has two distinct stages—(i) detachment of soil particles due to extraneous causes such as kinetic energy of raindrops and (ii) transport of the detached particles mainly with the help of rain-induced run-off and wind. Before we discuss the mechanism by which JGT controls erosion of soil on the surface, it is pertinent to have an idea of the factors responsible for causing erosion. Incidentally stabilizing a vulnerable hill slope and controlling surficial soil erosion in the slope of an embankment call for separate remedial approach as the nature of the underlying causes is different in the two cases.

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5.1 Rain-Induced Soil Erosion

Soil particles get detached as a result of impact (kinetic energy) of raindrops on soil or due to high winds. In both cases, the type of soil, its nature of "attachment" to the main soil body (cohesiveness), and "erosivity" of the agents (impelling forces causing transport of detached particles) are important factors. Precipitation and wind are the two principal agents of erosion of exposed topsoil. The extent of rain-induced erosion depends on the intensity and duration of rainfall, erosion proneness of topsoil (erodibility), hydraulic conductivity of the fill that controls the extent of penetration (infiltration) of rainwater into it, ground gradient that influences the velocity of surface run-off, and also overall stability of a slope. Erosion, in principle, can be significantly controlled if transportation of soil particles can be reduced by slowing down the velocity of surface run-off and/or by effecting on-land storage. The detached soil particles and debris are carried by the run-off and accumulate at the toe of the slope downhill choking the natural drainage. If erosion is allowed to sustain, it could trigger slides in the future. Erosion of topsoil in slopes should therefore be taken seriously and controlled at the earliest opportunity as otherwise it may also destabilize the hillslope on a larger scale.

The other critical factor in slope erosion is gradual buildup of pore water pressure inside slope fill which has to be dissipated by suitable measures. Slope inclination is also an important factor. It is a common knowledge that the steeper is the slope, the higher is the velocity of surface run-off which influences the rate of transport of detached soil particles.

5.2 Wind-Induced Soil Erosion

In wind-induced erosion, the problem is less complicated. The question of penetration of rainwater run-off into the soil interior is not there. There is thus no need for groundwater storage to impound a part of surface run-off. The influencing factors in the case of wind-induced erosion are the velocity of wind and erosion proneness of the exposed soil. Desert soil, fly ash, and non-cohesive soils are prone to erosion. Deforestation is considered as a major contributing factor to soil erosion as absence of tree cover exposes topsoil to natural erosive forces. Denuded ground without grass or any vegetative cover is also vulnerable to erosion for understandable reasons.

5.3 Mechanism of Soil Erosion Due to Precipitation

Erosion of soil on the surface caused by precipitation as already indicated is in essence a two-stage process, viz., (a) detachment of topsoil and (b) transportation of detached soil particles by run-off resulting from precipitation. The kinetic energy of raindrops on its direct impact on the ground disintegrates soil particles on the top. The extent of disintegration understandably depends on the erodibility of the topsoil as already indicated. Rain, after striking the ground, flows over the surface as a sheet of water (surface run-off) and the soil particles so detached are carried away with the run-off.

The volume of surface run-off depends on the intensity and duration of rainfall in the first place and also on the hydraulic conductivity of the ground soil that experiences the rainfall and the amount of on-land storage. Higher hydraulic conductivity of soil will allow greater in-soil penetration of rainwater. The mechanism is best understood by the fundamental concept represented by the *Universal Hydrologic Equation* (UHE). The equation considers three principal modes for dissipation of precipitation. These are:

(i) In-soil penetration
(ii) Surface run-off
(iii) Overland storage

In-soil penetration depends on the hydraulic conductivity and the extent of saturation of the soil. The larger is the hydraulic conductivity of soil and the lower is the saturation level of soil, the greater will be the in-soil penetration and correspondingly the lower will be the volume of surface run-off.

Impact of raindrops disintegrates the topsoil. Detachment of soil particles as a result of impact of raindrops, run-off generation, and their transport by the overland flow take place in sequence.

Run-off usually flows, as already stated, in the form of sheet ("sheet flow") following the ground gradient. In the slope, the run-off picks up velocity as it flows down following the ground gradient. Understandably the steeper is the slope, the higher is the velocity of surface run-off, and consequently the greater is its capacity to displace disintegrated soil particles. Erodibility of soil (a measure of vulnerability or ease of disintegration of soil) is a critical parameter in the phenomenon of topsoil erosion.

Overland storage is interception of run-off on the ground. If a portion of the overland flow can be intercepted as storage, the volume of surface run-off will get reduced and consequently migration of soil particles will be less.

Providing a cover over soil is very important to put surficial erosion on check. Adequate cover over soil will obstruct its direct disintegration by raindrops. A properly designed cover made of an appropriate material can help entrap the disintegrated soil particles and can reduce the velocity of surface run-off by posing successive cross-barriers on its downward flow path and with choice of suitable material for ground cover and partial overland storage can be ensured. At the same time, it is important to keep an eye on the costs for providing such a cover and on its eco-compatibility.

Dependence on such cover if placed at the initial stages will cease when vegetation takes firm roots into the soil. In fact this is the most desirable solution from the point of view of economy as well as eco-concordance.

The nature of topsoil erosion in the slope is depicted in Fig. 5.1.

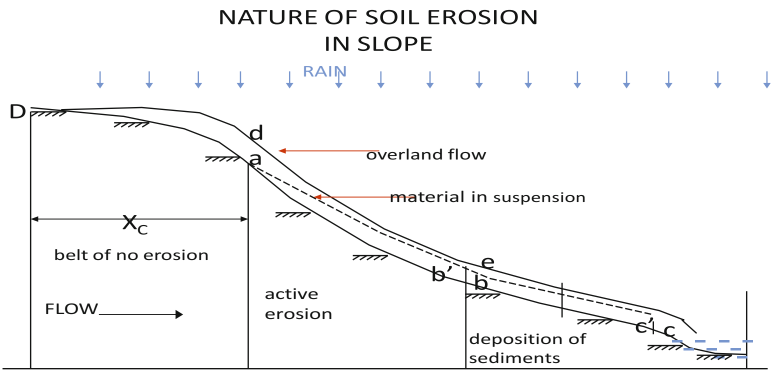

Fig. 5.1 Nature of soil erosion in the slope

5.4 Destabilization of Hillslope

Hillslopes qualitatively differ from the usual man-made earthen slopes in earthen embankments built for roads and railways. Stability is commonly disquieted due to lateral dispersion of the slope fills fully or partially. Such dispersion if massive takes the form of landslides. Terzaghi (1950) and Varnes (1978) investigated the causes of landslides. Varnes identified five principal types of mass soil movement. According to him landslides are in general caused by a combination of a number of soil movements. There could be geological, geotechnical, natural, and anthropogenic factors behind soil movements and landslides. Remedial measures depend on the causes triggering such mass soil movements.

Causes behind failure of hillslopes are in fact far more complex. The processes that trigger movement of soil in a hillslope are more than one and are generically known as “mass wasting” or “mass movement.” They take place on a range of time scales. Sudden failures occur when the stresses imposed on the slope materials outstrips the strength of resistance of the hillslope system for short periods.

The principal cause of stress is the gravitational force which is related to the slope angle and the weight of hillslope sediment and rock. The relationship may be expressed as

$$F = W \text{ Sin } \alpha$$

where F is the gravitational force, W is the weight of the material occurring at some point on the slope, and α is the slope angle.

Shear strength of a hillslope system depends on the shearing resistance of the slope fill. The presence of excess moisture inhibits development of the inter-particulate stress and disturbs the cohesive bond between particles. Prolonged precipitation not only disturbs the inter-particulate bond but also adds to the dead weight of slope materials enhancing the gravitational force.

The other major cause is seismic disturbances which, by shaking up the slope materials, can increase downward stress or decrease the shearing resistance of the hillslope fills.

The principal agent behind surface soil erosion is surface run-off which moves in a continuous layer ("sheetwash") carrying with it loose and detached particles on a hillslope. Sometimes topographic irregularities transform sheetwash into small channels called "rills." Several rills may converge to form larger channels generating turbulence and velocities sufficient to transport slope materials.

Two common forms of mass movements in hillslopes are rotational slides/slips and mudflow. Rotational slides occur along clearly defined curved planes of weakness and are aided by erosion at the slope base. Supersaturation of slope materials leads to near liquefaction of slope materials propelling a mud-like flow along the hillslope.

It is advisable to conduct both geological and geotechnical investigations prior to planning any anti-erosion-protection measure. Geological features such as bedding planes, joint planes, faults, folds, shear zones, type and quality of rocks, location of soft pockets/beds if any, and orientation of the discontinuities are to be investigated. Geomorphological features such as erodible and accretion zones are to be noted.

Geotechnical investigation should include determination of the average grain size, Atterberg's limits, hydraulic conductivity, angle of internal friction, natural moisture content, etc. of the slope materials. Seasonal variation of water table should also be investigated.

There is a need for undertaking standard stability analyses of slopes on the basis of the data collected during the investigations.

5.5 Structural Corrective Measures in Hillslopes

In severe cases of slope erosion, structural corrective measures are sometimes required. The basic principles underlying the remedial measures are twofold, viz.:

- Reduction of the forces propelling failures
- Augmentation of the resisting forces

To reduce the intensity of propelling forces, the first step would be to ensure an efficient drainage system both on the surface and under it. It may often be necessary to guide rainwater through a safe path along the slope in the shape of open conduits ("cascading").

This may need structural modifications in the slope. The safe path should follow the contours. The other measure would be to prevent direct and easy ingress of rainwater on the slope. A cover of vegetation should greatly reduce penetration of water into layers below. Sealing of tension cracks on the slope is also done for prevention of intrusion of water inside.

Subsurface drainage is more difficult. The main objective is to drain off the water from inside. Concealed horizontal drains, trench drains, and vertical drainage systems may be put in place for this purpose. Installation of horizontal drains is a conventional practice to off-load overpressure inside.

Reduction of imposed weight is done by flattening of slopes and providing relief benches/berms. Segmenting long slopes is a conventional method of relieving the stress burden. Removal of unstable soil mass and easing of slopes could be additional options.

Structural measures are adopted to enhance the resisting forces. Balancing berms/counterweight fills is constructed at the toe of the slope. Cuts and fills are effective in correcting deep-seated slides provided the overall slope stability is not impaired.

Construction of reinforced earth fill, sausage walls with geogrids, and restraining structures is also resorted to in appropriate cases.

The conventional practices to ensure stability of vulnerable slopes are aimed at structural corrections with gabions (wire crates), mortared or dry masonry, soil nailing, reinforced earth, mass concrete, and wall built on bored piles. But there are limitations to adoption of such measures.

Hill Roads Manual (IRC: SP: 48 – 1998) published by the Indian Roads Congress (IRC) provides detailed guidelines for conventional remediation practices.

There are however practical difficulties in executing structural corrections. Howell et al. (2006) have listed the difficulties that are encountered in resorting to geotechnical corrections only. These are:

- Lack of working space in hillslopes
- Difficulty in reaching the deep-seated bedrock for foundation
- Variation in material strength of fill over depth
- Site-specific drainage design that requires regular maintenance
- Lack of geotechnical skill on the part of the executing engineers

The global experience in this direction suggests adoption of a combination of the conventional low-cost geotechnical corrections aided by bioengineering measures. Such exercises are reported to have been carried out successfully in Nepal. The key lesson learnt through these experimentations is that geotechnical and bioengineering measures need be integrated for effective hillslope management.

5.6 Soil Bioengineering with JGT in Controlling Topsoil Erosion

Soil bioengineering is basically utilizing nature to overcome distresses caused by it. Jute has many attributes that foster vegetation. Its capacity to absorb water and release it in a sustained manner helps moderate the temperature extremes, besides keeping the soil moist and adding micronutrients after its biodegradation. In fact JGT creates a congenial microclimate that accentuates growth of vegetation. Roots of vegetation, usually grass with deep root system, bind the soil in the slope. In trials conducted in semiarid zones (near Kharagpur, West Bengal, India), the plant growth on JGT-treated ground was found four times higher than that observed in the control plot. In another trial conducted by the Forum of Scientists, Engineers and Technologists (FOSET) at Garhbeta in the same district recently with nonwoven JGT produced encouraging results converting a vast denuded arid land into a fertile crop-producing tract.

The current global trend to combat soil erosion in all types of soil is to adopt soil bioengineering measures. The emphasis is on creation of an appropriate vegetative cover that is sturdy and capable of exerting a binding action on soil through the roots. Vetiver grass, a type of perennial grass with far-reaching roots and tall densely tufted grass blades, could be the ideal species of grass if the soil type and climatic conditions suit (Fig. 5.2). Its deep roots penetrate deep into the soil and can bind it. The major advantage is to provide a cover on slopes so that rains cannot strike the slope soil directly and disintegrate it and can also moderate the velocity of run-off. Jute Geotextiles (JGT) can provide an excellent support in the initial stage by its threefold actions, viz., as a cover over the slope, as a contrivance to lessen the velocity of surface run-off, effecting partial overland storage and trapping detached soil particles within the fabric openings.

Soil bioengineering is a technology that judiciously combines vegetation and plants as the principal remedial agent, often in association with conventional structural measures, for control of erosion of soil on the surface. The stress is on exploiting hydro-geological aspects of soil consolidation. It is a natural way of stabilization of exposed vulnerable and failed soil encountered in slopes and riverbanks. Additionally the technology is concordant with the ambient ecosystem.

The concept is not new. It was tried in ancient civilizations such as China centuries back. Plants in the shape of fascicles were used to protect soil against erosion. Only in the early part of the twentieth century, some of the European countries such as Italy, Holland, Germany, Austria, and Switzerland experimented with the technique and evaluated performance of such efforts. The technology underwent refinement over the years and is now considered as a viable alternative to exclusive structural intervention being done with the help of man-made inert

Fig. 5.2 Vetiver grass

constructional materials to control soil distresses. Soil bioengineering is considered as an important component of sustainable development strategy. Now countries such as the USA and Brazil are favoring the technology for ecological reasons primarily.

The basic objectives are three, viz.:

- Technical, i.e., reduction of erosion through soil consolidation
- Ecological, i.e., eco-compatibility by providing space for natural dynamics
- Economical, i.e., cost-competitiveness

The use of man-made constructional materials cannot help growth of vegetation and also poses questions about eco-compatibility. Soil bioengineering technique uses “nature” to remedy the malady created by it and JGT is essentially a product of nature.

5.7 How Soil Bioengineering Helps in Erosion Control

As already indicated in the preceding, soil bioengineering in erosion control is basically the use of suitable types of vegetation that helps control soil erosion in slopes singly or in conjunction with structural measures when the situation so demands. The most types of vegetation perform five functions:

- Covering, i.e., providing a cover of vegetation
- Reinforcing, i.e., providing a network of roots that increases the resistance of soil against shear
- Catching, i.e., intercepting soil particles disintegrated as a result of precipitation or otherwise such as high wind in deserts
- Anchoring, i.e., holding weak soil
- Draining, i.e., dissipation of surface and subsurface water pressure.

Each part of a plant incidentally performs distinct functions. Roots reinforce soil and also make it more permeable helping greater interpenetration of rainwater into the subsoil. Stems play interceptive role, while leaves help storage over the ground. Wind effects are also partially attenuated by plants.

Vegetation should be planted in such a way as will facilitate surface drainage and intercept dissociated soil particles. Pore water pressure in the underground is eased off due to transpiration through the roots.

It is pertinent to mention that soil bioengineering measures, besides being environmentally concordant, substantially reduce accumulation of soil particles at the slope toe and prevent clogging of roadside drains.

Vegetation plays an important role in so far as its hydrological and mechanical effects are concerned. Plants used in groups in a suitable configuration show better effects. It has been found that plantation of vegetation at an angle to the slope inclination is more effective than plantation across the slope (Howell et al. 2006).

Vegetation improves the integrity of a slope as a whole and strengthens the top 500 mm or so of the ground which is its most vulnerable part.

Parameters governing slope stability cannot be generalized. The governing parameters are site specific. Selection of vegetation will depend on local climate, soil characteristics, and other factors. Vegetation with deep roots and high survivability rate should be chosen considering the climatic and geotechnical ambience.

Different parts of a plant perform specific functions. Roots increase hydraulic conductivity of soil and reinforce them by performing functions of anchorage, absorption, conduction, and storage. Stems help in interception. Leaves aid storage and enhance esthetic appeal. In fine vegetation helps dissipate the kinetic energy of raindrops, attenuates the effects of wind, and helps moderate the velocity of overland flow. Vegetation propagates a self-sustaining ecological cycle. The most critical aspect of biological intervention is the choice of plants and vegetation.

5.8 Discussion on the Role of Jute Geotextiles (JGT) in Soil Bioengineering

Jute Geotextiles (JGT) may be conveniently used in quite a few of the remedial measures as indicated as supplement.

As already indicated jute is a natural lignocellulosic bast fiber. The cellulose in jute fiber facilitates absorption and retention of water. Open weave JGT is considered the ideal fabric for control of topsoil erosion for economy and effectiveness. The weight (gram/sqm) and thickness of open weave JGT are decided principally on the basis of the rainfall distribution, its intensity, and the type of the slope fill at the location in the case of rain-induced soil erosion. Open weave JGT may not be suitable for controlling wind-propelled soil erosion for which any close weave JGT would be suitable (usually nonwoven).

Open weave JGT, which can be made sufficiently thick to pose as micro-barriers against the run-off, when laid on the slope surface initially provides a partial cover over soil reducing chances of soil disintegration due to the direct impact of raindrops on soil. Because of the thickness (diameter usually 4–6 mm), weft yarns of the JGT laid across the direction of flow act as successive “micro-barriers,” more aptly “speed breakers,” against the path of overland flow transporting disintegrated soil particles. Besides moderation of the run-off velocity, the apertures of the fabric entrap the disintegrated soil particles that start being carried away by the run-off. Additionally hygroscopic nature of jute yarns in the JGT cause them to swell by around 20–30 % on average when wet. This is an additional advantage both in respect to velocity moderation and particle entrapment. The moisture in JGT creates a congenial microclimate and conduces to growth of vegetation. Within 1 or 2 months, vegetation starts sprouting. Ultimately after about 1 year, JGT coalesces with the soil on biodegradation, adding nutrients to the soil at micro-levels and augmenting the soil permeability.

It is interesting to note that JGT and vegetation act in tandem. In the initial phase, JGT's role is dominant. With the passage of time, JGT starts losing its features on way to degradation, while vegetation starts coming up to protect the topsoil against erosion. Vegetation binds the soil with its roots. JGT sets the stage, so to say, for its sure and quick growth. The choice of vegetation is also very important. Vegetation with deep and dense root systems that thrives in the native climate is to be selected in consultation with botanists/agronomists.

The extent of control over soil erosion depends principally on the capability of JGT in reducing the velocity of surface run-off and in effecting storage due to its hygroscopic nature. A full cover over soil will protect the soil from direct impact of raindrops and disintegration of the topsoil, but this is a costly proposition. The other effect could be that the upper portion of the run-off may glide over the fabric. Water absorption by JGT will also be less as it will not get sufficient time to absorb the flowing water.

Open weave JGT has triple advantages:

1. Firstly, its weft yarns will pose successive mini-hurdles on the path of the sheet flow and will thus reduce the flow velocity at every crossing on its way down the slope ("speed breakers").
2. Secondly, the pores of open weave JGT will help better water absorption due to transient stagnation of water within the pore spaces.
3. Lastly, the growth of vegetation will be more facile if there are openings in the fabric. It is advisable to opt for an open weave JGT that can allow vegetation to sprout by the time the fabric degrades.

The specification for the open weave JGT needs be decided with an eye to the intensity of precipitation in that area, the ground gradient or slope angle, and the nature of topsoil. The thicker is the open weave JGT, the more effective it is for reduction of the velocity of surface run-off. The question that obviously surfaces is about the limit up to which jute yarn bundles in open weave JGT that are normally prescribed and used can withstand a certain velocity of surface run-off considering its extensibility and tensile strength for a specified opening and the extent of fixity of weft yarns of the fabric. The imposed stress on open weave JGT is also a factor of the nature of "fixity" of the fabric nodes. The yarns of open weave should be able to resist the stress induced by the velocity of run-off. This aspect has not been studied as yet.

It is, therefore, important to determine the raindrop diameter and the drop velocity to assess the kinetic energy of raindrops that can disintegrate the soil particles along with the expected nature of sheet flow. The next step will be to have a realistic idea of the soil, its erodibility, and saturation. The vulnerability of soil depends on its composition especially its cohesiveness. The third step will be to assess the terminal velocity of the overland flow which is a factor of the soil gradient, the slope length, the soil saturation, and the intensity of precipitation.

On the basis of the above inputs, the open weave JGT should be designed. The design should specify the thickness of the fabric, i.e., the diameter of jute yarn bundles, their tensile strength and the size of the opening—which could be different in warp and weft directions considering the nature and direction of run-off—for a particular area based on data such as maximum intensity of rainfall, the gradient of the ground with length to be covered, and the soil characteristics, especially its cohesiveness and hydraulic conductivity. Saturated soil understandably will experience lesser in-soil penetration of rainwater.

Drains which need to be covered or concealed require a permeable fabric all around so that water can penetrate through the cover. Nonwoven JGT is an ideal material for the purpose. Perforated pipes may serve the purpose but chances of blocking will remain. The problem may be obviated if nonwoven JGT is wrapped around the perforated pipes for prevention of entry of extraneous particles/aggregates into the pipes.

Disposal of water flowing down the hillslopes often pose problems. Usually hill roads run along one edge of a hill with the uphill slope on one side of such roads and the downhill slope on the other. Cross drains are necessary to dispose the water collected at the toe of the uphill to the other side. This can best be done by installing subsurface concealed rubble drains encapsulated by nonwoven JGT under the road.

For subsurface drainage deep trench drains may be constructed with a permeable gravel/rubble core with wrapping of jute nonwoven fabric. In fact jute nonwoven fabric will serve the dual purpose of prevention of blocking/clogging of such drains and of facilitating seepage water to penetrate through it to reach the drain.

It has been found from studies that open weave JGT with an open area of 65 % provides plants freedom to grow and allows sufficient light for germination. JGT decomposes within its ecological cycle and unlike its man-made counterpart does not pose maintenance problems.

The choice of vegetation as already indicated is very important. Roots of vegetation add to the increase in soil shear strength. Roots generally contribute to enhanced soil cohesion. The overall soil improvement depends also on root morphology especially root density and root length (Mickovsky and van Beek 2009).

Seeds of appropriate plants/grass or other suitable vegetation may be sown directly on prepared hillslopes after being overlain by open weave JGT. Hydroseeding, i.e., spraying of an emulsified mixture of seeds, fertilizer, growth hormones, enzymes, and soil bacteria on soil, may be done where the soil is not congenial for vegetation growth.

A recent trend in developed countries is to go in for TRMs (turf-reinforced mats) for erosion control over slopes. The combination consists of turf/grass grown on jute mats/blankets and confined soil layer. Such a product with jute backing awaits commercial development. The ready-to-use mats in the form of rolls can be installed at the site by just unrolling them on the hillslopes. But the cost is certainly higher than plain open weave Jute Geotextiles.

The role of JGT is that of a facilitator for growth of vegetation after withstanding the initial phase of vulnerability of the soil against rain-induced erosional processes. On biodegradation jute enhances the hydraulic conductivity of soil, besides the mulching effects. Ingold (1991) in his internal report to the International Trade Center listed the following advantages of JGT in erosion control:

- Protection against rain splash detachment
- High absorbing capacity of water
- Reduction of the velocity of surface run-off
- High ground storage capacity
- Creation of congenial humidity for plant growth
- Mitigation of extremes of temperature
- Protection against direct sunrays and desiccation of soil
- Providing a sufficiently open structure that does not inhibit plant growth
- Biodegradation adding useful fiber to the soil
- Providing an environmentally acceptable appearance
- Posing no problem for future maintenance

5.9 Design Principle for Erosion Control

The process of erosion is complicated in the sense that many variable parameters govern the phenomenon. The impact of raindrops on soil depends on the intensity and duration of precipitation and angle of incidence of raindrops, besides aspects of variability of ground conditions such as hydraulic conductivity and saturation of soil, its inclination, frictional resistance of the ground, and on-land storage of surface run-off. It is for this reason that it is difficult to generalize the phenomenon. Broadly the design principle for slope management boils down to three-pronged measures which are:

– To increase overland storage
– To reduce the velocity of run-off
– To entrap the detached soil particles

As already indicated, a part of the downpour will infiltrate into the soil. The extent of infiltration will depend on hydraulic conductivity of the soil. The remaining part of the precipitation will flow over the ground as surface run-off and carry with it partly the soil particles detached after the raindrop impact. One of the components of the remediation principle is to entrap a part of the detached soil particles. JGT is the ideal material for the purpose because of its capacity to absorb water and three-dimensional construction (unlike man-made geotextiles which are almost wafer-thin—not grids or composites) that helps in reducing the velocity of overland flow successively while moving under the action of gravity following the declivity of the ground and also in entrapping a part of the detached soil particles:

(i) *Overland storage by open weave JGT*
As the UHE in the preceding paragraph under "Phenomenon of Soil Erosion" reveals, the effect of erosion can be reduced if overland storage by some means can be ensured even partially. JGT can play an effective role in this respect in view of the inherent capability of jute to absorb water up to about five times its dry weight. However it may be noted that after saturation, jute

loses its capacity to absorb water. Any way the phenomenon has been explained mathematically later in this chapter.

(ii) *Moderation of velocity of surface run-off by open weave JGT*
As already stated weft yarns, i.e., yarns across the direction of run-off of open weave JGT, pose a series of micro-barriers or "speed breakers." Velocity of surface run-off gets successively reduced as a result. But we need to consider all the forces in play. The resultant velocity reduction will thus depend on (a) the slope of the ground on the one hand and (b) the barrier effect of the weft yarns of the fabric, (c) ground friction, and (d) interpenetration of water into the soil on the other. At every stage of the flow, the value of the resultant velocity of run-off will get altered.

(iii) *Entrapment of detached soil particles*
The extent of entrapment of soil depends on the thickness of the yarns placed across the direction of run-off. Jute swells with addition of water up to about 30 % in some cases. This is an additional advantage of JGT.

However it is admitted that the phenomenon is a bit complicated. As indicated in the preceding paragraph, there are several indeterminate factors that regulate the run-off, e.g., hydraulic conductivity of slope fill, frictional coefficient of the topsoil, and effect of gravity on the velocity of run-off. It is difficult to determine the magnitude of resistance posed by the weft yarns of open weave JGT lying across the direction of run-off. There are two other factors to reckon with in this connection. These are:

(a) Change in volume of run-off after passing over a stretch of weft yarn of open weave JGT. This is due to the fact that weft yarn (and also warp yarn) absorbs a part of the run-off depending on its dryness. After the yarns get saturated with water, there will be no further absorption of water. So long the phenomenon of on-land storage by JGT will continue; the run-off will slide over the plane of the stored water.
(b) Reduction of run-off velocity in sequence as the overland flow crosses over each micro-barrier posed by the weft yarns of JGT.

There is a need for a simulation study on all these aspects for determining the net effect of open weave JGT although its effectiveness for slope erosion control stands established in all applications so far. Attempts have been made to assess the parameters separately in the following.

5.10 Elements of Design for Slope Erosion Management with JGT

The design concept in assessing contribution of open weave JGT for topsoil erosion control is based primarily on its water-absorbing capacity for overland storage and the fabric thickness across the direction of run-off caused by precipitation for effecting successive reduction of run-off velocity. The kinetic energy of raindrops causing detachment of topsoil particles has also been considered The aspect of interpenetration of water into the soil has not however been considered in this case being dependent on the hydraulic conductivity and saturation of the soil which is apt to vary with the nature of slope fill. It is assumed that at some point on its path following the ground gradient, the velocity of run-off gets too weak to transport the detached soil particles. Thick strands of JGT (open weave) also entrap and confine the detached soil particles partially. The theoretical relations developed below will lead to design the appropriate JGT for the purpose. It may be seen that the most important component of the fabric is the thickness of weft yarns both for overland storage and successive reduction of velocity of the run-off. There are other factors also in play such as ground friction and saturation of JGT. In fact the phenomenon is complex calling for comprehensive simulation study. The major factors have only been analyzed in the following text individually.

The design principle may be represented mathematically with a few assumptions. The entire process of surficial soil erosion caused by precipitation is complex as already indicated. The most realistic design of open weave JGT for the purpose should aim at determining the diameter of weft yarns and the pore size of the fabric considering the rainfall intensity and duration in the first place and ground friction and hydraulic conductivity of the soil on the other. We present below a simplistic analysis of the process treating each of the phenomenon separately:

(i) Impact of raindrops on soil
(ii) Overland storage by JGT
(iii) Partial reduction of run-off velocity by open weave JGT

Assumptions:

1. Only run-off component of precipitation is considered.
2. Hydraulic conductivity of soil, ground friction, and interpenetration of water into the soil are neglected.
3. Soil characteristics such as plasticity index and angle of internal friction of the fill material are also not considered.

5.10.1 Impact of Raindrops on Topsoil in the Presence of OW JGT

Mass of water per unit area impacting a *bare* soil surface (Gabet and Thomas 2003):

$$\text{Mass/area} = \boldsymbol{\rho}.\mathbf{i}.\mathbf{t}\ \mathbf{cos\theta} \tag{5.1}$$

where:

$\boldsymbol{\rho}$ is density of water (1000 kg/m^3).

i is rainfall intensity (m/s).
t is storm duration (s).
θ is hillslope.

Substituting Eq. (5.1) into familiar equation for kinetic energy,
Kinetic energy per unit area $\mathbf{E}_k$ is expressed as

$$\mathbf{E}_k = \frac{\boldsymbol{\rho}.\mathbf{i}.\mathbf{t}\mathbf{v}^2\cos\boldsymbol{\theta}}{\mathbf{2}} \tag{5.2}$$

where **v** is terminal velocity (m/s) of raindrops caused by precipitation.

The relation is modified by introducing $\mathbf{C}_v$, aerial coverage by JGT in percentage, considering the fact the area covered by JGT will provide protection against impact of raindrops before touching the ground.

Equation 5.2 after introducing $\mathbf{C}_v$ stands modified as under with introduction of open weave JGT:

$$\mathbf{E'}_k = \frac{\boldsymbol{\rho}\mathbf{itv}^2(\mathbf{1} - \mathbf{C}_v)\cos\boldsymbol{\theta}}{\mathbf{2}} \tag{5.3}$$

where $\mathbf{E'}_k$ is the effective kinetic energy and $\mathbf{C}_v$ is percentage of area covered by JGT.

Understandably, the larger is the percentage of cover over soil, the less will be the extent of detachment and migration of soil particles.

5.10.2 Overland Storage by OW JGT

Overland storage is interception of run-off. If a portion of the overland flow can be intercepted as storage, the erosive force will get somewhat reduced. It may be seen that the most important component of the fabric is the thickness of weft yarns both for overland storage and successive reduction of velocity of the run-off (Fig. 5.3).

The aspect of overland storage has been analyzed by Sanyal (2008) which is reproduced below.

Figure 5.3 represents a cross section of an embankment slope inclined at an angle β° (1:n shown in the figure above) to the horizontal. “d” is the diameter of the weft yarns of the open weave JGT, while “L” represents the base of the storage triangle on the slope. It is assumed that surface run-off will get hindered by the weft yarns and will take the shape of a triangle minus the area covered by half of the weft diameter (semicircle):

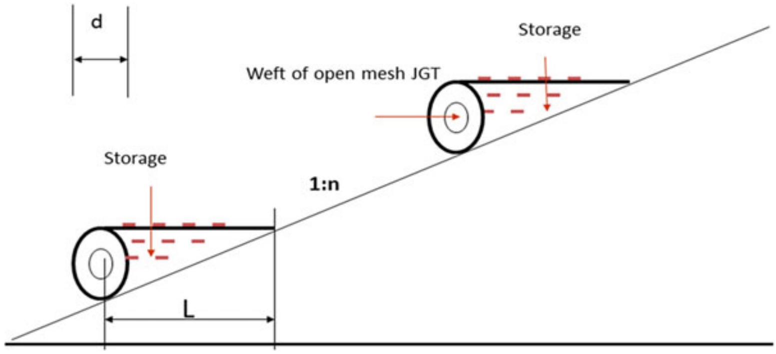

Fig. 5.3 Overland storage by open weave JGT

$$\text{Storage 'S'} = \frac{L \times d}{2} - \frac{1}{2}\pi\frac{d^2}{4}$$
$$= \frac{4 \times L \times d - \pi\, d^2}{8}$$

For N wefts/meter,

$$S = \frac{N \times \left(4 \times L \times d - \pi\, d^2\right)}{8}$$

Substituting $L = d \times \cot\beta$

$$S = \frac{N \times \left(4 \times d^2 \cot\beta - \pi\, d^2\right)}{8}$$

$$\text{or, } \frac{N \times d^2\, (4\ \cot\ \beta — \pi) 10^3}{8} \text{mm}^3/\text{m}^2$$

Taking cot β as 'n' i.e., with slope as 1:n (1 vertical to 'n' horizontal units)

$$S = \frac{N \times d^2\ (4n — \pi)\ 10^3}{8} \text{mm}^3/\text{m}^2 \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

With a slope of 1:2, d = 4 mm & N = 45, it can be deduced that **storage S is 0.437 litres/m²**.

The precondition of the theoretical deduction is that JGT should be perfectly drapable. This could be possible as JGT is the most drapable of all geosynthetics especially when wet (report of Thomson and Ingold—1986—prepared for International Trade Center).

The storage capacity of JGT is further enhanced due to jute's inherent capability to absorb water even to about five times its dry weight. It is assumed that 450 % is the capacity of dry JGT to absorb water. When an open weave JGT of 500 gsm is installed, this would mean an additional storage of 4.50 times 500 gsm, i.e., 2250 g/sqm of water or 2.25 l/sqm taking JGT as dry. In other words, the total volume of water that can be stored overland by JGT stands theoretically at (0.437 + 2.25) liters per sqm or 2.687 l/sqm when the slope is 1:2, the diameter of weft yarns is 4 mm, and there are 45 yarns per sqm in the weft direction. JGT therefore has the highest capacity of water storage leading all other geotextiles.

5.10.3 Reduction in Run-Off Velocity in the Presence of OW JGT

Assumptions:

1. Run-off component of precipitation is considered only.
2. Neglecting storage of water by JGT.
3. Hydraulic conductivity of soil and interpenetration of water into the soil is neglected.

Now consider an object of mass **m** moving down an assumed plain surface with acceleration **a** meeting a barrier on way posed by weft yarns of JGT in the instant case. Assuming no ground friction, the barrier effect (posed by jute yarns) denoted by $\boldsymbol{\mu_k}$ may be found from the following relation:

$$\mathbf{a}=\mathbf{g}\ \mathbf{sin}\,\theta - \boldsymbol{\mu_k}\mathbf{gcos}\theta \qquad (5.5)$$

As derived from the free body diagram (Fig. 5.4): $-\sum F_x = ma = mg\ \sin\theta - \mu_k mg\ \cos\theta$

The component $\boldsymbol{\mu_k}$ may be assumed to be equal to the number of barriers of JGT and its thickness along the length of slope. This may be expressed as

$$\boldsymbol{\mu_k} = \mathbf{N{*}h} \qquad (5.6)$$

where **N** is number of weft yarns of JGT and **h** is thickness/diameter of weft yarns of JGT (m).

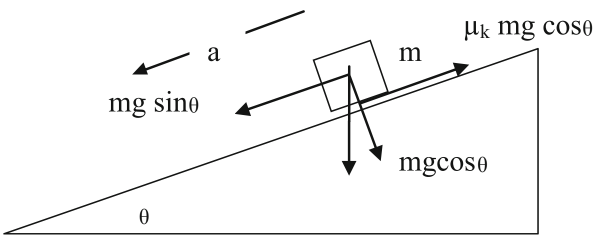

Fig. 5.4 Free body diagram

Now for assessing the run-off velocity on meeting the micro-barrier posed by a JGT weft yarn running across the direction of flow, we revert to the basic relation

$$v^2 = u^2 + 2as$$

Substituting **a** from Eq. 5.5 and combining Eqs. 5.5 and 5.6,

$$\mathbf{v^2 = u^2 + 2\{gsin - Nhgcos\theta\}s} \tag{5.7}$$

where **s** is distance between consecutive weft yarns (m).

The terminal velocity of raindrops depends on the severity of precipitation. In reality however there is impedance in flow due to ground friction, partial reduction of run-off volume due to penetration of a part of it into soil (depending on the hydraulic conductivity of the slope fill), and storage by successive micro-barriers posed by weft yarns of open weave JGT which act in combination against movement of run-off down the slope or in the direction of lower ground gradient due to gravity. These opposing forces slow down the velocity and reduces the rate of its change (acceleration). Theoretically with sufficient length of the slope, it could be possible to have a situation when positive acceleration could tend to be nil or in extreme cases is counteracted by negative acceleration. Equation 5.7 above would need modification in such cases. The point of contention is that successive reduction of run-off velocity due to open weave JGT gradually slows down the erosivity of run-off. It necessitates a separate model study with the following variants:

(a) Rainfall intensity vis-à-vis erodibility of topsoil
(b) Hydraulic conductivity of slope fill and ground friction
(c) Slope angle
(d) Thickness of weft yarns of OW JGT and their moisture regain

It is necessary to quantify the resultant effect of all the aforesaid variables to assess with an allowable degree of precision the extent of moderation of the run-off velocity. Situation may call for review of fabric design (pore size, thickness of weft yarns) in certain cases.

Table 5.1 indicates the terminal velocity of usually varying diameters of raindrops (source: Physics Fact Book edited by Glenn Elert), while Table 5.2 shows rainfall type vis-à-vis intensity and kinetic energy of raindrops.

Travel time of overland flow may be roughly determined by using Seelye chart (Fig. 5.5) also shown below. This is a nomograph which considers parameters such as the length of travel of overland flow, coefficient of imperviousness of soil (indicated by the type of vegetation), and percentage of the slope. Results are usually indicative.

Equation 5.7 above however does not fully indicate the extent of successive moderation of the run-off velocity as it crosses the successive micro-barriers posed by open weave JGT following the ground inclination. The thickness of the weft yarns, the number of weft yarns in a meter, and their spacing are to be adjusted

Table 5.1 Raindrop vis-à-vis velocity

Bibliographic entry	Result (with surrounding text)	Standardized result (m/s)
Corbert, John H. *Physical Geography Manual*. 1974. 5th ed. N.p.: Kendall/Hunt, 2003. 127	"A large drop of about 5 mm (3/16 in.) diameter reaches a maximum speed of about 9 m/sec"	9
"Climate." *Encyclopedia Britannica*.2007, Encyclopedia Britannica Online. 25 May 2007	"Large raindrops, up to six millimeters in diameter, have terminal velocities of about 10 meters per second and so may cause considerable compaction and erosion of the soil by their force of impact"	10
Holladay, April. Falling raindrops hit 5–20 mph speeds. Wonderquest. Albuquerque: 19 Dec 2001	"At sea level, a large raindrop about 5 millimeters across (housefly size) falls at the rate of 9 meters per second (20 miles per hour). Drizzle drops (less than 0.5 mm across, i.e., salt grain size) fall at 2 meters per second (4.5 mph)"	9

Table 5.2 Rainfall type and their intensities

Rainfall type	Intensity (mm/h)	Diameter of raindrop (mm)	Kinetic energy (j/m^2/h)
Drizzle	<1	0.9	2
Light	1	1.2	10
Moderate	4	1.6	50
Heavy	15	2.1	350
Excessive	40	2.4	1000
Cloudburst	100	2.9–6.0	3000–4500

Adapted from Geotextile and Geomembrane Manual by T S Ingold (1994)—(Elsevier Advanced Technology, UK)

suitably in relation to the overflow for maximizing the gradual slowdown of the velocity of surface run-off. This is in fact an empirical exercise.

In a recent prototype study conducted by IISWC (erstwhile Central Soil and Water Conservation Research and Training Institute), an institute under ICAR, Ministry of Agriculture, Government of India, at its farm in Ooty, Tamil Nadu, where three types of OW JGT (500/600/700 gsm) were used in slopes of different inclinations with grass as vegetation, 700 gsm was found the most effective considering soil and nutrient loss prevention and reduction of run-off. It may be noted that the three types of open weave JGT stated above (see Chap. 11) are usually in use.

The added advantage of all the three types of OW JGT is its mulching and soil-nourishing properties which ensure quick growth of vegetation. Application of JGT for the purpose is in fact a bioremediation technique which is being increasingly encouraged for environmental reasons all over the world. In fact JGT scores over all

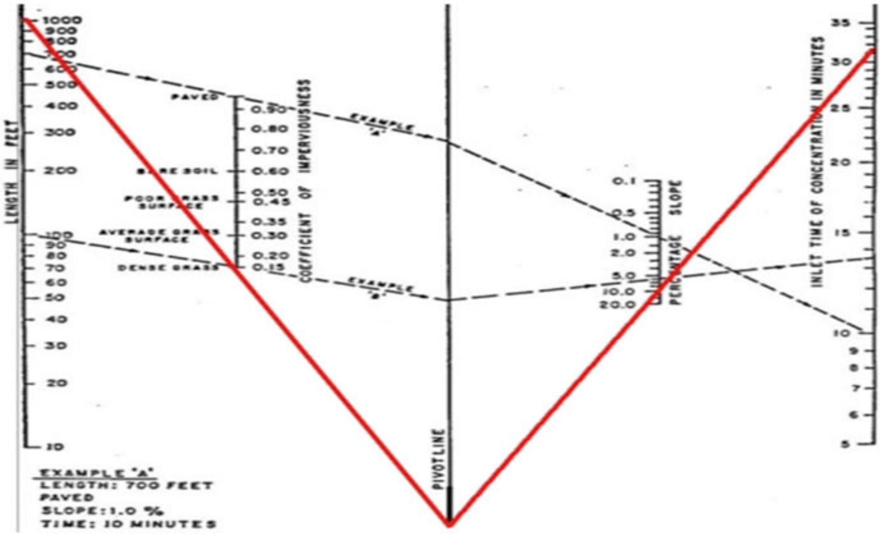

Fig. 5.5 Seelye chart

other types of geotextiles in respect to run-off reduction and vegetation establishment in accordance with the comparative studies conducted by Thomson and Ingold (1985) and Rickson (1988).

5.11 Prototype Studies with JGT in Hillslope

In the prototype studies conducted by IISWC in hillslope with open weave JGT at Udhagamandalam, Nilgiri hills, 500 gsm, 600 gsm, and 700 gsm varieties of open weave JGT were used, and a number of parameters under identical rainfall (1098.4 mm) for a full calendar year January 2014 to December 2014) are tested. A control section was also set aside for comparison. The following data reveal the results:

- Area covered—240 m^2.
- Slope profile—12.5°.
- Average annual rainfall—1200 mm.
- Structural intervention—nil
- Run-off %—7.513 % for 500 gsm, 6.578 % for 600 gsm, and 5.405 % for 700 gsm open weave JGT. For the control section, run-off% is 15.548 %.
- Soil loss in t/ha—0.35 for 500 gsm, 0.30 for 600 gsm, and 0.21 for 700 gsm open weave JGT, while for the control Sect. 1.1.
- Rill formation—there has been no rill formation in JGT-treated slopes. Control section developed rills.

5.12 Selection of JGT

The purpose of using open weave JGT for control of topsoil erosion is twofold—economy and effectiveness. Understandably open weave JGT is much cheaper than either the woven type or the nonwoven type. The cost of nonwoven JGT is less than that of woven variety. Dense variety of nonwoven JGT is usually not recommended as it tends to inhibit vegetation growth compared to the open weave type in view of the fact that the soil underneath gets only diffused sunlight, and seeds get suppressed besides its low tensile strength. It has been observed that open weave JGT is the preferred option than its woven and nonwoven counterpart both for effectiveness and economy.

It is also to be recognized that the purpose of using open weave JGT is to slow down the velocity of run-off for curbing and controlling transport of detached soil particles, though admittedly it provides less aerial coverage than the other two varieties reducing chances of soil detachment.

Precise design methodology cannot be worked out without assessing the net effect of various controlling parameters. This would be possible only after a detailed simulation study as indicated. Pending the outcome of such study and based on the experience gained as a result of a large number of field applications nearly 60, the following open weave JGT types are recommended considering the intensity of rainfall in consideration of the intensity of precipitation as a thumb rule on the basis of field experience (see Table 5.3).

5.13 Installation of JGT

JGT is usually supplied in rolls either directly by the jute mills or through agents. The fabric is anchored at the top of a slope by making an anchor trench (say 300 × 400 mm), placing the fabric in such a way as to ensure its contact with the three sides of the trench, stapling and filling the trench with rubbles. The fabric is then rolled down the slope, stapling with a U-nail at suitable intervals (say 200 mm both ways with extra stapling over the laps) and passed over and through the trench drain usually constructed at the toe of a slope with adequate securing arrangement with staples (see Fig. 5.6).

Vegetation can either be planted through the openings or by seeding. It takes about a couple of months for the vegetation to sprout and establish its roots. The

Table 5.3 Rainfall intensity and recommended JGT

Nature of precipitation	Intensity (mm/h)	Recommended type of OW JGT
Light	1	292 gsm
Moderate	4	500 gsm
Heavy	15	600 gsm or 700 gsm
Excessive	40	1000 gsm

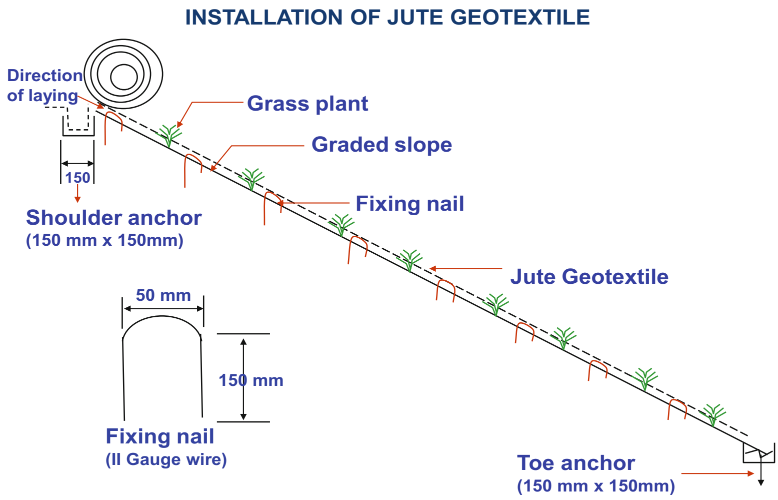

Fig. 5.6 Method of installation of JGT

preferred practice in the Indian subcontinent is to complete installation of JGT and seeding prior to the rainy season.

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Chapter 6
Strengthening of Road Sub-grade with Jute Geotextiles

Abstract Roads usually get distressed due to several reasons of which sub-grade failure is a frequently occurring phenomenon when constructed without paying due attention to the nature of the sub-grade supporting the overlying pavement. This chapter discusses in depth the functional requirements of a road sub-grade supporting a flexible pavement with low to moderate traffic volume. The analytical concept of static and dynamic loading effects has been explained. It also expounds the role of Jute Geotextiles (JGT) in strengthening it when laid over the sub-grade resulting in increment of the value of its *CBR%* (California bearing ratio). Salient laboratory findings by Profs Ramaswamy and Aziz have been cited to validate in situ response of the sub-grade soil with and without application of JGT.

A new design concept with application of JGT in the sub-grade has been developed following Burmister's two-layer theory. The theory has been modified by introducing a factor of load repetitions and a "constant" for different ESAL (equivalent single-axle load) and *CBR* ranges. The results have been compared with the recommendations made in IRC:SP:72:2015 of the Indian Roads Congress by adjusting the value of the constant under different ESAL ranging from 10,000 to 1,000,000 applicable for low volume roads and *CBR%* of the sub-grade.

Design curves to determine the pavement thickness with *CBR* value of 2–7 % and ESAL value range as stated above have been incorporated in the chapter.

Keywords Membrane reinforcing effect • Geotextile modulus • Filter cake • Undrained shear strength of soil • Burmister's two-layer concept • Rut depth • ESAL • *CBR%* • Stiffness factor • Logarithm of load repetitions • Static and dynamic loading effects on road

In the conventional design, flexible pavement comprises three distinct layers above its sub-grade, viz., a subbase course, a base course, and a top overlay which provides the riding surface. A subbase course is usually a granular construction, while a base course could be either a bituminized and/or a non-bituminized granular layer duly compacted by rolling. The top layer, the riding surface, is invariably bituminized to withstand the dynamic load and abrasive forces caused by moving vehicles. The stability of any pavement hinges on the capacity of sub-grade to withstand moving vehicular loads. The purpose of providing a subbase and a base course is to distribute the wheel load over a larger area to reduce stresses at the top

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of the formation. Woven geotextiles are used on sub-grades to supplement its capacity to bear the design dynamic load.

The major function of a geotextile in road construction is to separate the sub-grade from getting mixed up with the overlying GSB/base course layers. Absence of a separating medium could result in interpenetration of the overlying subbase course into the sub-grade and vice versa reducing the design pavement thickness.

Besides separation, functions of filtration and drainage also are concurrently active helping to dissipate pore water pressure from within the sub-grade. With reduced pore water in sub-grade, soil particles tend to veer closer to each other. If by dynamic compaction the air-voids can be removed from sub-grade, a condition close to effective stress could be reached. Sub-grade continues to gain in strength gradually because it takes time to reach the effective stress level or at least close to that level. Consolidation of soil is a protracted process. All geotextiles—be man-made or jute—trigger the process of consolidation of sub-grade as change agent. Capacity of JGT to absorb water is an advantage. Pore water cannot easily find its way up as jute in JGT absorbs it first before releasing the absorbed water in a sustained manner across and along its plane.

Geotextiles can effectively absorb shear stress. Besides the vertical stress, the wheel load also calls into play horizontal shear stress which spreads out from the wheel. This horizontal component reduces the vertical stress. Geotextile may absorb a part of this horizontal shear stress. This enables the sub-grade to bear higher loads. In this case the modulus of geotextile is an important factor. Functionally JGT has hardly any difference with its polymeric counterpart.

6.1 Functional Requirements

6.1.1 Separation

As already indicated, separation function of any geotextile is intended to prevent intermixing of its underlying and overlying granular layers. To ensure the desired separation effect, it is critical to specify the AOS (apparent opening size) of a geotextile in commensurate with the grain size distribution of the sub-grade for retention of the bulk of the soil particles.

It is important to ensure that the selected geotextile remains intact during the process of rutting (deformation) in the construction phase. The chosen geotextile is supposed to adjust to local deformations as well. Tensile strength of a geotextile should be decided keeping this aspect in view. The fabric should also be able to resist puncturing and tearing caused by sharp edges of the granular materials overlying it.

The fabric helps spread the imposed load to cause the whole layer to act together as in a flexible beam. As a result the geotextile is under tension locally and gets stretched. As geotextile possessing a specified tensile strength has a limit to its extensibility, a state of equilibrium is reached when the downward “sag” or deformation of the overlying base and subbase courses due to imposition of external load, which is essentially deformation due to rutting, is countered by upward reaction resulting out of stretching of the geotextile like a membrane. The phenomenon is known as *membrane reinforcing effect*. By the state of equilibrium, we mean the limit of the imposed load without further deformation of the sub-grade. The imposed load is thus distributed over a larger area. Till such time the state of equilibrium is reached, rutting and the resulting spread of load continue. This point of equilibrium varies from one type of geotextile to another. JGT is less extensible than man-made geotextiles. The process takes place in different scales. In sub-grades with varying load bearing capacity, geotextile can relieve stresses at weaker points. It may be noted that membrane reinforcing effect posed by geotextile can reduce the sub-grade deformation but cannot eliminate or prevent it. The effect will be more pronounced with high modulus geotextiles. JGT possesses high initial modulus. Load distribution with such geotextile will be better with less track deformation.

There are two points of consideration in this context: first, the tensile strength of geotextile (in our case JGT) and, second, the extension at which tensile strength develops. It is in this context that the geotextile *modulus* assumes importance, i.e., its tensile strength vis-à-vis strain it undergoes. The other factor is the capacity of a geotextile to absorb shear stress. Besides the vertical stress induced by wheel loads, there is also a concurrent horizontal component radiating from imposition of wheel load. The horizontal stress so induced dissipates the vertical stress to some extent. The coefficient of roughness (rugosity) has a role to contribute in this process. The higher is the roughness coefficient of a geotextile, the better will be the transference of stress. JGT possess high roughness coefficient.

If horizontal shear stress is large, a pavement can withstand higher loads. Geotextile also exerts an inward horizontal shear stress to the sub-grade. This is a kind of confining action acting against the outward horizontal shear stress developed due to imposition of loads.

JGT may be manufactured to attain tensile strength of 25–30 kN/m usually. Higher tensile strength of JGT up to 40 kN/m is attainable by careful selection of jute batch and fiber length and also by imparting twists to yarn. Usually tensile strength of 25 kN/m is considered adequate for the majority of roads. Extensibility of JGT normally is of the order of 12 % which is much lower than its man-made counterpart. Lower extensibility of JGT induces higher reactive forces to JGT when stretched under load.

6.1.2 Filtration

All geotextiles, apart from performing the function of separation, concurrently act as a filter. Pore water of the sub-grade finds its way through the pores of the geotextile used across its plane (permittivity), and a part of it may flow along its plane (transmissivity). Reduction in moisture content of the sub-grade helps in bringing soil particles in the sub-grade to come closer. Compaction of sub-grade due to imposition of dynamic loads expels air void within sub-grade. The two processes trigger the process of consolidation of the sub-grade. Initially a portion of the smaller particles (d_{50} of soil $< O_{95}$ of the geotextile) pass out of the fabric. Bigger particles thereafter veer near the fabric pores and form "arches" to block passage of the remaining soil particles. As already indicated, the situation leads to formation of a pattern of particulate disposition within sub-grade known as *filter cake*. Migration of soil particles is thus restrained but passage of pore water is not curbed. Thus the "cake," i.e., the soil with spatial adjustment of positions of its particles, also acts as "filter." "Filter cake" is thus a condition of soil.

One of the preconditions is that the geotextile permeability should be greater than the hydraulic conductivity of the adjacent sub-grade, and concurrently O_{95} of the geotextile should be larger than d_{50} of soil. Usually the relation between the two can be expressed as $K_{\text{geotextile}} > 5\ K_{\text{soil}}$. Some researchers suggest that apart from the pore size of the geotextile, the spacing between the pores is equally important in as much as closer spacing of pores may not help form the arches as mentioned by bigger particles bridging over pores in filter cake. Pore-size distribution of geotextile, i.e., its porometry, therefore deserves special attention.

In case of JGT, it is difficult to maintain the pore diameter as prescribed in view of inherent nonuniformity of jute fiber coupled with its hairiness warranting a judicious compromise about the fabric porometry. Understandably, unlike man-made geotextiles, there is room for leniency in pore size for JGT. Similarly the spacing between pores can hardly be maintained. But JGT scores over its man-made counterpart in respect of dissipation of pore water from the sub-grade. Jute being highly hydrophilic, the major portion of water is absorbed by the fabric which is drained off laterally in a sustained manner subsequently along the fabric plane. Transmissivity of JGT is much higher than that of man-made geotextiles.

6.2 Analytical Concept

6.2.1 Static Loading Effects on Road

Wheel load on the top of a road is distributed through the underlying base and subbase courses. The stress intensity (q_o) on the sub-grade as a result of imposition of wheel load is inversely proportional to the thickness of the base and subbase courses (H_o). In other words q_o will be less when H_o is more. The maximum allowable value of q_o is limited by the maximum *elastic* bearing capacity of soil which is *π times the undrained shear strength of soil* (C_u), i.e., $q_o = \pi \times c_u$. If q_o is greater than $\boldsymbol{\pi} \times \boldsymbol{c_u}$, the sub-grade is supposed to yield under load.

When a geotextile is placed over the sub-grade with subbase and base course on top of it, it will act both as a separating and supportive layer. Wheel load can then be increased to the value of *ultimate* bearing capacity of the soil, i.e., $(\pi + 2) \times c_u$. The geotextile will get deformed under the imposed load and tensile stress will be induced in it. There will be an upward component to counteract the wheel load acting downward (*membrane reinforcing effect*). The upward support from the geotextile is a function of the rut depth and geotextile stiffness. Pavement thus can be constructed with thickness less than what is required for conventional design in view of the upward thrust of the geotextile and also as a result of gradually increasing consolidation of the sub-grade with corresponding increase in its shear strength. Moreover the stress induced at the top of a pavement gets gradually reduced as it reaches the sub-grade due to the existence of the subbase and base courses overlying the sub-grade (Burmister's two-layer concept). With geotextile placed on the sub-grade, the stress is partially absorbed. It may be noted that filtration and drainage functions remain concurrently active to help dissipate pore water within sub-grade.

Figure 6.1 indicates how geotextile helps reinforce the sub-grade by inducing lateral restraint, shifting the shear surface and through an upward reaction caused as a result of its stretching under load.

6.2.2 Dynamic Loading Effects on Road

When dynamic load on road is considered, the situation will be different. In static loading concept, the number of passes of vehicles is not considered. Giroud and Noiray (1981) carried out experiments and established empirical relations for determining the aggregate thickness vis-à-vis number of passes of an axle load and undrained shear strength of the soil. The method is suitable for roads on cohesive sub-grade applicable to roads subjected to light to medium traffic. It was inferred that inclusion of geotextile (man-made) helps the sub-grade to reach its ultimate bearing capacity. The researchers considered the membrane effect, the number of passes of standard axle load of 80 kN, the rut depth, and, of course, the undrained shear strength of the sub-grade. Giroud and Noiray based their concept on the ultimate bearing capacity of the sub-grade and assumed parabolic deformation of the geotextile. The concept satisfied a number of cases.

The relation evolved by Giroud and Noiray is as under

$$H'_o = \frac{119 \log N + 471 \log W - 279R - 2285}{C_u^{0.63}}$$

where

N is number of axle passes.
R is rut depth (m).

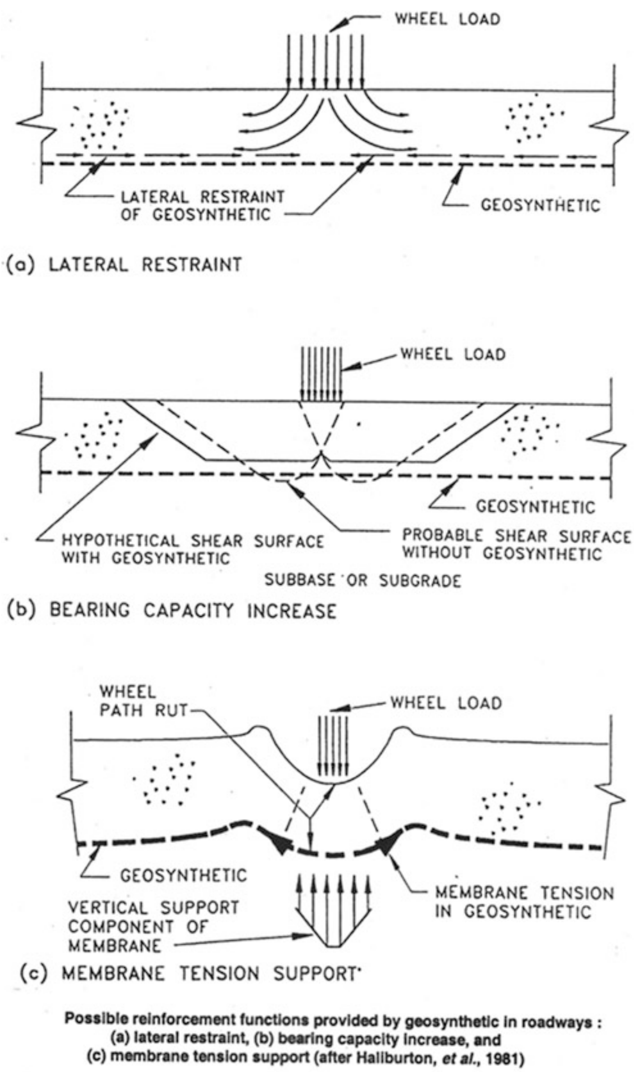


Fig. 6.1 Effects on sub-grade by JGT. Possible reinforcement functions provided by geosynthetic in roadways: (**a**) lateral restraint, (**b**) bearing capacity increases, and (**c**) membrane tension support (After Haliburton and Barron 1983)

C_u represents undrained shear strength of soil (Pa).
W represents axle load (N).

If $CBR\%$ of the sub-grade is known, it can be converted to the equivalent undrained shear strength value by using the empirical relationship between C_u in N/m^2 and $CBR\%$ which runs, thus

Table 6.1 Bearing capacity improvement with and without JGT

Reference	Unreinforced	Reinforced with GT	Improvement ratio
Giroud and Noiray (1981)	3.14	5.14	1.64
Milligan et al. (1989)	2.57	5.14	2.00
Houlsby and Jewell (1990)	3.07	5.69	1.85

$$C_u = 30,000\ CBR\%$$

Some researchers use C_u in kN/m^2 as equivalent to 23 times *CBR%* (TRRL Lab Report 1132).

There are other studies on the behavior of geotextiles under a road. Mention may be made of studies by Giroud and Noiray (1981), Milligan et al. (1989), and Houlsby and Jewell (1990). All the researchers have found that bearing capacity factors increased with incorporation of geotextile (man-made) over the sub-grade. Table 6.1 reveals.

6.3 Approach to Design of Roads with Jute Geotextiles (JGT)

Ramaswamy and Aziz (1989) were the first to study the effects of Jute Geotextiles in roads in the laboratory. They found from the experiments conducted in the laboratory of the State University of Singapore after placement of JGT on sub-grade that the soil gets stiffened and consolidated in less than a year under the action of granular subbase surcharge, self-weight of pavement, rolling, and traffic loads. With time the sub-grade becomes less and less dependent on fabric for its stability making long-term durability of JGT somewhat redundant. The said researchers noted that high initial strength and tear resistance of jute made JGT to act as support membrane redistributing traffic loads over a wider area of the sub-grade. The most important observation of their experiment is that the gain in strength of the sub-grade with time is compensated by the loss of strength of JGT within the same time frame. The observation negates the common perception that long-term durability of geotextiles is essential for stability of the road.

6.4 Salient Findings of Ramaswamy and Aziz

There is hardly any difference between synthetic (man-made) geotextiles (SGT) and Jute Geotextiles (JGT) functionally. As in the case of SGT, JGT perform the four major functions, viz., separation, filtration, drainage, and initial reinforcement, albeit for a shorter duration. The question often raised by civil engineers is as to how JGT could function after biodegradation. This aspect was studied by Profs S D

Ramaswamy and M A Aziz of Singapore National University way back in late 1980s (vide their paper presented in the International Workshop on Geotextiles held on 22–29 November 1989). Their findings were:

- *Percentage elongation at break of JGT is significantly lower than that of synthetic geotextiles (maximum 15 % against more than 50 % of SGT).*
- *Substantial reduction (more than 50 %) in rut depth under dynamic load tests with JGT.*
- *Loss of strength of JGT after a year is not a deterrent as, by that time, JGT is seen to have helped in providing a self-sustaining sub-grade for most type of soils.*
- *The gain in strength of the sub-grade with time is compensated against the loss of strength of JGT within the same time frame.*

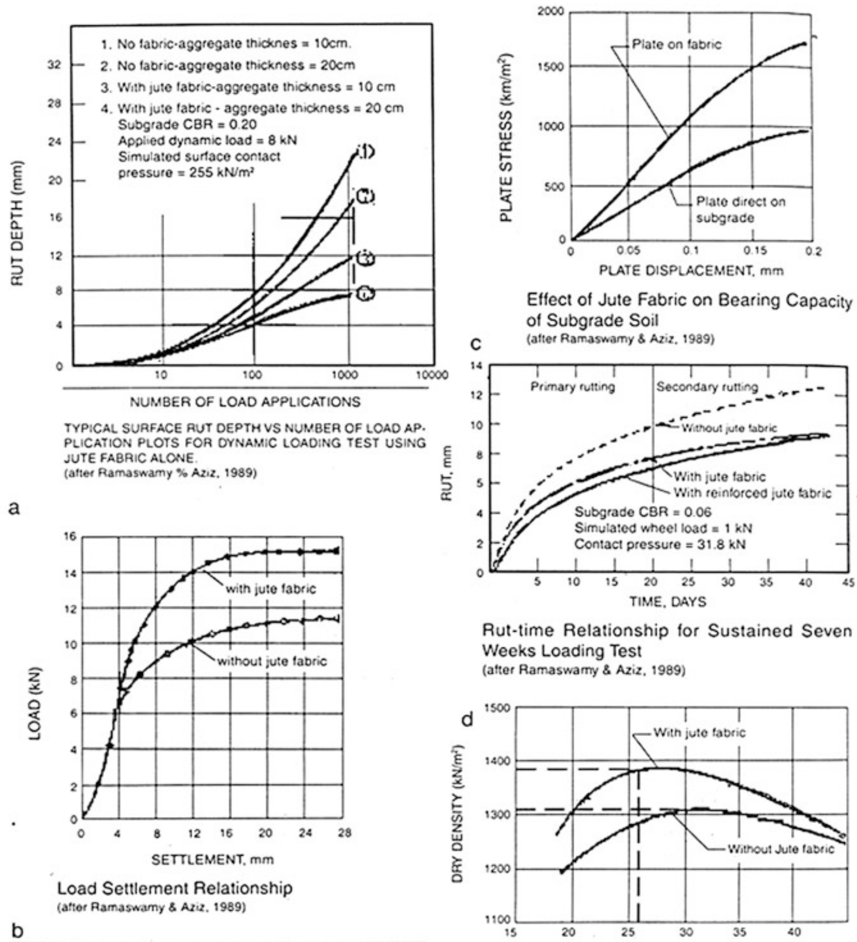
Graphical representations of their salient findings may be seen in Fig. 6.2.

In another project undertaken by Jadavpur University, Kolkata, headed by Prof N Som in 2005 with sponsorship of the National Jute Board (then Jute Manufactures Development Council), the last inference was corroborated. The findings are pointer to the fact that JGT and, for that matter, all geotextiles act *as change agent to soil* and trigger soil consolidation process to the sub-grade within about 6–7 months as found by Ramaswamy and Aziz in the laboratory. The conclusion that long-term durability of geotextiles is of secondary concern and that shear strength gain due to consolidation fulfills the minimum required factor of safety stands supported by an independent prototype study in a road embankment in Andhra Pradesh of India conducted by the Central Road Research Institute (CRRI), Govt of India, led by P J Rao et al. as a part of the UNDP Project on JGT. In fact soil consolidation gets optimized after a brief initial period varying between 7 and 12 months usually depending on the soil type, extent, and frequency of load imposition and other relevant associated factors. In all the field trials conducted so long, sub-grade *CBR%* increased by at least 1.5 times the control value after about the period stated. Interestingly *CBR%* was seen to have progressively increased even after biodegradation of JGT (three to four times) in these applications.

All the studies and field applications especially in road construction substantiate that biodegradation of JGT is **not** a technical disadvantage as is commonly perceived.

6.5 Design Elements for Low Volume Roads with JGT

Considering the tensile strength and durability limitations of JGT, a different design principle for JGT on *CBR%* of the sub-grade and ESAL (equivalent single-axle load) as recommended in the Indian Roads Congress Standards for low volume roads, IRC:SP:72:2015, has been followed. It is required to consider the strength of base and subbase courses and distribution of normal stress on application of load on



Water Content (%)	20	25	30	35
CBR VALUE (%)				
Without fabric	5.0	4.7	3.5	2.6
With fabric	8.0	6.8	5.2	4.5

Effect of Jute Fabric on CBR Value

Fig. 6.2 Behavior of JGT (After Ramaswamy and Aziz)

top of the pavement. The nature of behavior of JGT under high volume of traffic has not been studied. More than 60 field applications have been carried out on low volume roads in India so far.

The methodology developed for use of JGT in low volume roads follows a semi-theoretical semiempirical design concept. The thickness of base course of low volume roads is developed considering mechanical property of the base course material, elastic moduli of sub-grade and JGT, distribution of normal stress following Burmister's two-layer theory, traffic volume, wheel load, and tire pressure. In this method, the required base course thickness is calculated using a relation which takes into consideration the number of passes in terms of equivalent standard axle load (ESAL) over 10 years. Design curves have been drawn for a range of *CBR* % of sub-grade (2–7 %). Nearly 65 field applications have been done with JGT in low volume roads in India so far. The relationship developed for design with JGT has been compared with the conventional design method in the relevant IRC standards.

6.5.1 Traffic

The design traffic is considered in terms of cumulative number of standard axle to be carried by a low volume road during its design life.

Assuming a uniform traffic growth rate (r) over design life (n), the cumulative ESAL applications (N) over design life can be computed using following formula

$$N = T_0 \times 365 \times \left[\frac{(1+0.01r)^n - 1}{0.01r}\right] \times L \tag{6.1}$$

where

r = traffic Growth rate
T_0 = ESAL per day = number of commercial vehicles per day × vehicle damage factor
L = lane distribution factor = 1 for single lane
n = design life

6.5.2 Axles and Loads

Different wheel patterns exist for truck axles: single and dual. The wheel load "P" is considered to be half of the standard axle load of 80 kN.

6.5.3 Properties of Base Course Material and Sub-grade

The base course modulus and sub-grade soil modulus may be calculated from *CBR* % as recommended in the Indian Roads Congress Standards—IRC:37:2001.

$$E_{sg}(MPa) = 10 \times CBR_{sg}(CBR \leq 5) \tag{6.2}$$

$$E_{sg}(MPa) = 17.6 \times CBR_{sg}^{0.6}(CBR > 5) \tag{6.3}$$

where E_{sg} denotes elastic modulus of the sub-grade and CBR_{bc} is the value of CBR % of the base course. Similarly E_{bc} can also be ascertained from the following relation.

$$E_{bc}(MPa) = 36CBR_{bc}{}^{0.3} \tag{6.4}$$

where CBR_{sg} denotes California bearing ratio of sub-grade and CBR_{bc} California bearing ratio of base course.

It may be noted that when CBR of sub-grade is high—usually 7 %—no geotextile intervention is called for. It is for this reason that the results of the design methodology for JGT have been validated with the CBR range of 2–7 %. Other assumptions are:

1. Cumulative traffic ESAL range 10,000–1,000,000.
2. No slip between fabric and sub-grade soil.
3. Biodegradibility of JGT beyond 7 months has not been considered for reasons indicated in the preceding.

6.6 Design Methodology for Determining Pavement Thickness Using JGT

Approaches to design of flexible pavement could be done.

(a) Empirical method—based on field and laboratory results.
(b) Theoretical method—based on theoretical considerations.
(c) A combination of the above two, i.e., a semi-theoretical semiempirical method, which is essentially evolving a theory to be validated with the field findings. This often calls for "fine-tuning" of the adopted theoretical basis.

It may be noted that the degradability aspects of JGT have not been considered in view of the fact that most of sub-grades of low volume roads become self-reliant before degradation of JGT sets in.

6.7 Computation of Pavement Thickness

Studies carried out by the US Army Corps of Engineers establish a relationship between pavement thickness, wheel load, tire pressure, and CBR value within a range of 10–12 %. Therefore, it is possible to extend the CBR design curves for various loading conditions, using the following expression:

$$T = \sqrt{P}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \tag{6.5}$$

where P = wheel load (kg), T = base course thickness (cm), p = tire pressure (kg/cm^2), and CBR = California bearing ratio of sub-grade(%).

The design thickness is considered for single-axle load up to 8200 kg. Limitations of the *CBR* method are:

1. Total thickness of pavement is determined without considering the properties of the component layers which are of different materials having different moduli and *CBR%*.
2. Total thickness of pavement does not consider the aspects of load repetitions for designed period.

6.7.1 Burmister's Two-Layer Concept

According to the theory proposed by D. M. Burmister (1958), the top layer has to be the strongest as high compressive stresses are to be sustained by this layer due to imposition of wheel loads directly on the top surface, while the lower layers have to withstand load-induced stresses of decreasing magnitude. The effect of layers above sub-grade is to reduce the stress and deflections in sub-grade so that moduli of elasticity decrease with depth. According to Burmister, stress and deflection are dependent upon the strength ratio of layers E_1/E_2, where E_1 and E_2 are the moduli of reinforcing and sub-grade layers.

The Kansas State Highway Department (1947) and the US Navy (2000) modified the aforesaid relation (Eq. 6.5 above) taking into account a stiffness factor $(E_{sg}/E_{bc})^{1/3}$. This modification is, in fact, refinement of Burmister's concept.

$$T = \sqrt{P}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \times \left(\sqrt[3]{\frac{E_{sg}}{E_{bc}}}\right) \tag{6.6}$$

If JGT is placed between the base course and the sub-grade, the stiffness of the composite pavement gets modified. JGT acts as a reinforcing material. If comparative stiffness between sub-grade and JGT and that between base course and JGT is considered following the modification approach proposed by the Kansas State Highway Department and the US Navy, the resultant stiffness factor stands modified as $\left(\sqrt[3]{\frac{E_{sg}}{E_{bc}+E_{JGT}}}\right)$. Thickness of pavement is accordingly modified as below:

$$T = \sqrt{P}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \times \left(\sqrt[3]{\frac{E_{sg}}{E_{bc} + E_{JGT}}}\right) \tag{6.7}$$

where E_{JGT} = elastic modulus of woven JGT (MPa), E_{sg} = elastic modulus of sub-grade (MPa), and E_{bc} = elastic modulus of base and subbase (MPa) (refer to Annex III for E_{JGT} property).

6.8 Effect of Number of Passes on Thickness of Pavement

Thickness of base course should also be sufficient to withstand the deformation caused by design number of passes. Based on performance data, it was established by Yoder and Witczak (1975) and Hvbeem and Carmany (1948) that base course thickness varies directly with logarithm of load repetitions (N). Therefore, Eqs. 6.6 and 6.7 can be refined as

$$T = \sqrt{P}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \times \left(\sqrt[3]{\frac{E_{sg}}{E_{bc}}}\right) \times k \log N \tag{6.8}$$

$$T = \sqrt{P}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \times \left(\sqrt[3]{\frac{E_{sg}}{E_{bc} + E_{JGT}}}\right) \times k \log N \tag{6.9}$$

where N = cumulative equivalent standard axle load (ESAL) over 10 years and k = numerical constant which varies with ESAL.

6.9 Determination of Value of Constant “K”

The value of constant “k” varies with ESAL. Values of “k” for different ranges of ESAL and CBR5 of the sub-grade have been determined through checks and trials in Eq. 6.8 above by matching the pavement thickness recommended in IRC: SP:72:2015 for validation. Values of the constant “k” so obtained are then applied to Eq. 6.9 above to determine the pavement thickness with JGT on the sub-grade for a specified range of ESAL and value of *CBR%* of the sub-grade (see Annex II for details and Table 6.2 showing values of the constant “k” for specified ESAL range and *CBR%* (2–7 %)).

6.10 CBR vs. Pavement Thickness Curves Under a Set of “ESAL” Range

Applying Eqs. 6.8 and 6.9, thickness of pavement can be determined for a range of low *CBR* values and ESAL taking wheel load (P) = 4100 kg, tire pressure (p) = 7.134 kg/cm^2, elastic modulus of JGT (E_{JGT}) = 100 MPa, and elastic modulus of

Table 6.2 Value of "*k*" under different ESAL ranges

CBR (%)	Cumulative ESAL						
	10,000–30,000	30,000–60,000	60,000–100,000	100,000–200,000	200,000–300,000	300,000–600,000	600,000–1,000,000
2	0.197	0.2	0.22	0.235	0.255	0.28	0.318
3	0.115	0.148	0.167	0.181	0.2	0.211	0.224
4	0.152	0.195	0.22	0.24	0.263	0.278	0.296
5	0.14	0.186	0.196	0.202	0.211	0.231	0.252
6	0.153	0.204	0.215	0.221	0.232	0.254	0.277
7	0.14	0.153	0.187	0.216	0.228	0.234	0.26

base and subbase (E_{bc}) = 100 MPa. Design curves have been drawn with different ranges of ESAL (from 10,000 to 1,000,000) vs. values of sub-grade *CBR%* (from 2 to 7). Thickness of pavement can be directly read from the graph (see Annex I for graphs).

6.11 Selection of JGT

After deciding on the pavement thickness, appropriate woven JGT has to be selected. Determination of choice of JGT is essentially an empirical exercise supported by practical experience. Retention criterion being the governing function of any geotextile including JGT in case of road construction and tensile strength of JGT having been settled at 25 kN/m for most of roads based on CFGG Manual (French Committee for Geotextiles and Geomembranes), the design of JGT is about finalizing its porometric feature which is a factor of grain size distribution of sub-grade soil considering retention as the critical criterion in regard to roads. It has also been observed in field applications that *fulfillment of retention criterion of JGT also concurrently achieves the desired value of JGT permittivity*. Parameters of deciding on the pore size of JGT from functional standpoint are indicated below.

6.11.1 Retention

To achieve maximum retention of topsoil particles, the following relationship may be used.

If $d_{85} \leq 75\ \mu$, then $O_{95} \leq 2\text{–}2.5\ d_{85}$.
If $d_{85} \geq 75\ \mu$, then $O_{95} \leq d_{85}$.

6.11.2 Filtration

Fabric permeability (or permittivity) vis-à-vis soil permeability can be determined considering the following relationship.

If $d_{85} \leq 75\ \mu$, then $\psi_{JGT} \geq 10\ k_{soil}$.
If $d_{85} \geq 75\ \mu$, then $\psi_{JGT} \geq k_{soil}$.

where ψ_{JGT} is permittivity of fabric, d_{85} is 85 % of soil particles finer than that size, O_{95} denotes fabric aperture in JGT 95 % of which is less that size, and k_{soil} is hydraulic conductivity of soil.

Recommended tensile strength and porometry range for low volume roads may be seen in Table 6.3.

Table 6.3 Recommendations for deciding woven JGT features for roads

Type of roads	Recommended type of JGT		
	Tensile strength	Porometry range	Treatment
Low volume roads up to ESAL 1,000,000	25 kN/m	100–300 μ	Gray
For ESAL 1–5 msa	≥30 kN/m	100–300 μ	Gray
High volume roads	Await field trials		

N.B. The mentioned range of porometry usually fulfills both retention and filtration criteria

In case of low volume roads, the following specification of woven JGT may be adopted in general (Table 6.4). The focus should be on determining the porometry of JGT that can address the required retention and permittivity criteria as indicated above.

The design based on the above approach may be cross-checked by a handy method developed on purely empirical considerations. Backed by experience gained through a large number of field applications in low volume roads as well as laboratory studies, the following guidelines for strengthening road sub-grade may be followed to determine the pavement thickness based on the relevant IRC Guidelines for design of flexible pavements with low volume roads

- Porometry of any geotextile is decided on the basis of the extent of retention of soil particles desired. Porometry of JGT will depend on average grain size diameter (d_{50}) of sub-grade soil. The fabric porometry (O_{95}) should be less than d_{50}. Usually, porometry between 150 and 400 μ serves the purpose as endorsed by the French (CFGG Manual).
- Recommended tensile strength of JGT (CFGG Manual) → 25 kN/m.
- Care should also be taken to ensure that hydraulic conductivity of JGT is greater than hydraulic conductivity of soil.
- Recommended puncture strength of JGT → 400–500 N/cm^2.
- Experience suggests that the conventional design of a road may be followed by *increasing the control CBR value by 1.5 times and determining the pavement thickness (base and subbase) accordingly in accordance with the extant standards* (e.g., IRC:SP::72:2015 for low volume roads recommended by the Indian Roads Congress).

6.12 Installation Method of JGT in Roads

- The sub-grade is to be excavated to the required level, cleared of all foreign materials, and compacted to OMC (optimum moisture content).
- JGT as selected should be laid by unrolling, ensuring proper drapability (i.e., JGT should touch the sub-grade surface at all points) with overlaps of 100 mm

Table 6.4 Typical specification of woven JGT for low volume roads

Nomenclature	Woven JGT 25 kN/m (for road construction)
Construction	1/1 DW plain weave
Weight (gsm) at 20 % MR $\geq$	724
Width (cm) $\geq$	100
Ends x picks/dm $\geq$	94×39
Thickness (mm at 2 kPa)	$1.85 \pm 10\,\%$
Tensile strength (kN/m) MD $\times$ CD $\geq$	25×25
Elongation at break (%) MD $\times$ CD $\geq$	12×12
Puncture resistance (kN)	$0.500 \pm 10\,\%$
Burst strength (KPa)	$3500 \pm 10\,\%$
Permittivity at 50 mm constant head (/s)	$350 \times 10^{-3} \pm 10\,\%$
A O S (micron) O_{95}	150–400

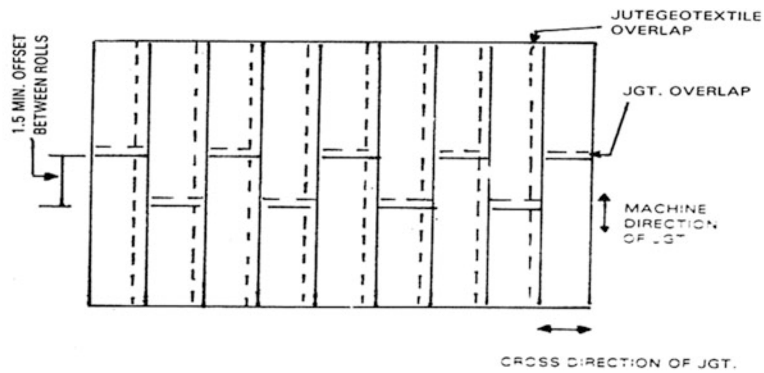


Fig. 6.3 Laying of JGT with overlaps

crosswise and 300 mm longitudinally duly secured to sub-grade by U-shaped staple (usually 11 guage)/round head country nail of 150 mm length/Y-shaped wooden pegs at an interval of 750 mm as per direction of engineer in charge.

- A thin cushion of sand layer (about 25 mm) should preferably be spread below and above JGT to prevent puncture/damage of JGT. Sand will also serve as an additional filter layer and add to the longevity of JGT (the reason could be the fact that microbes find it difficult to move within sand).
- Parallel rolls of JGT should be overlapped and stapled (Fig. 6.3).
- Any rut that developed during construction should be filled in and properly compacted.
- For application in curves, JGT should be folded or cut or overlapped in the direction of turn. Fold in JGT should be stapled at an interval of 300 mm (Fig. 6.4).

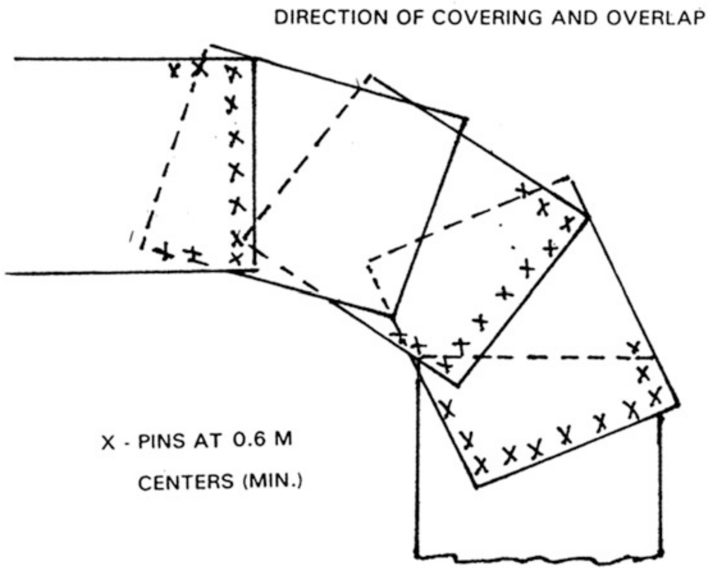


Fig. 6.4 Laying of JGT in curves with overlaps

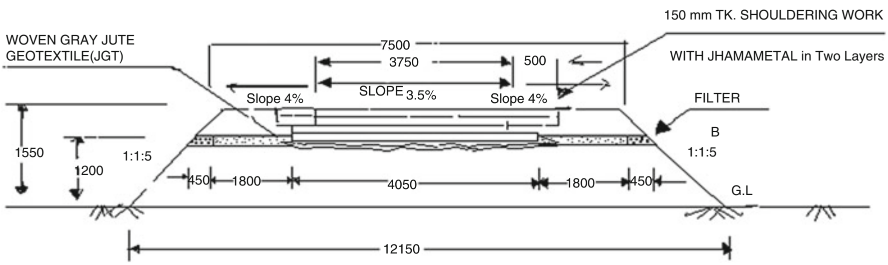


Fig. 6.5 Typical cross section of a low volume road with JGT

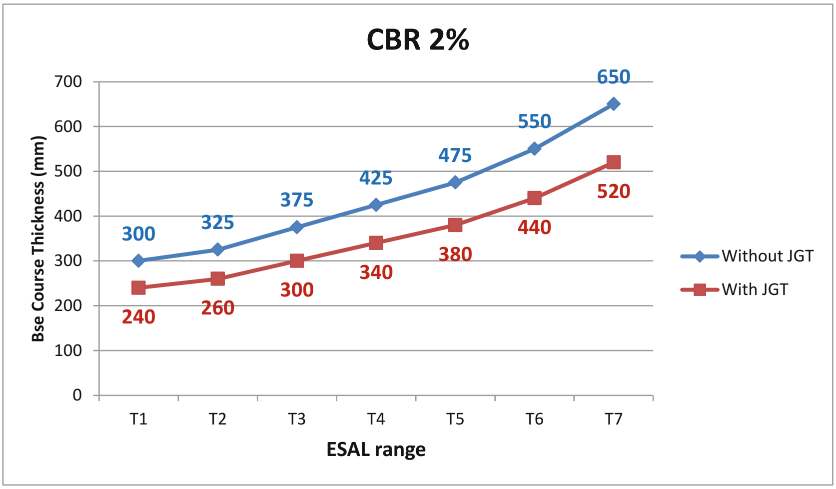
- Before covering up the JGT, its condition is to be assessed. Damaged portions may be covered by pieces of JGT fully over damaged portion plus at least 75 mm beyond, on all sides (Fig. 6.5).

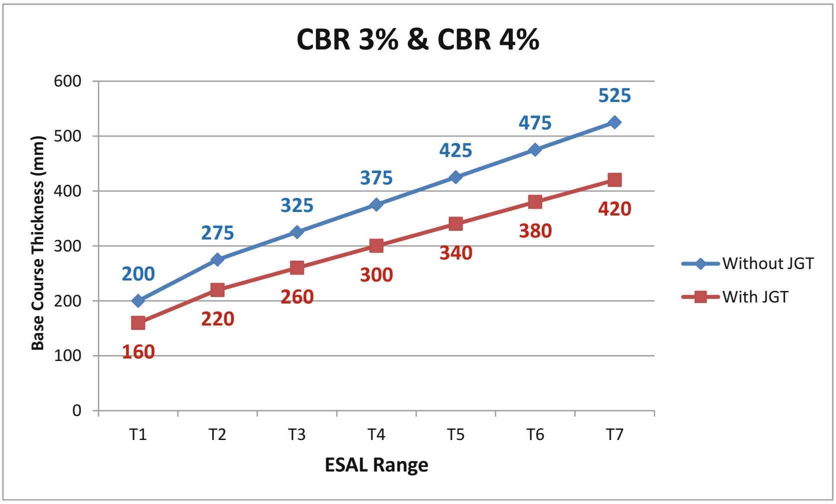
Annex I: Design Graphs for Determining Pavement Thickness for Low Volume Roads Under a Range of *CBR%* of Sub-grade

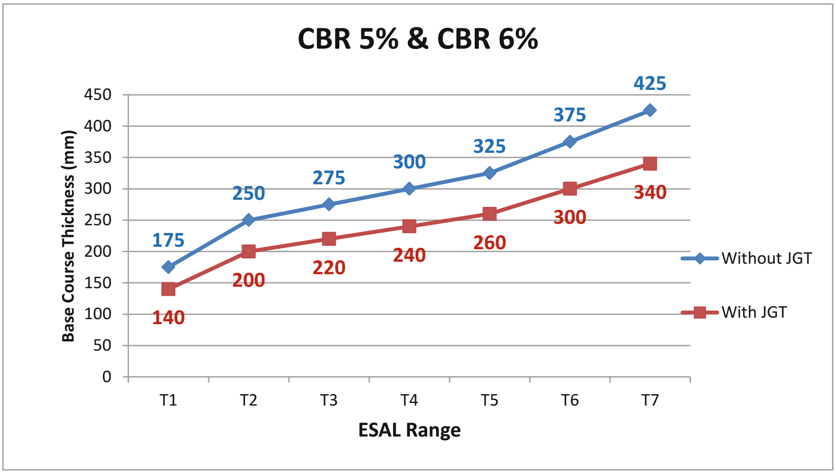
Design pavement thickness with JGT for range of **CBR 2–7 %** and **ESAL range 10,000–1,000,000.** In the graphs shown below, ESAL range along X-axis is categorized as

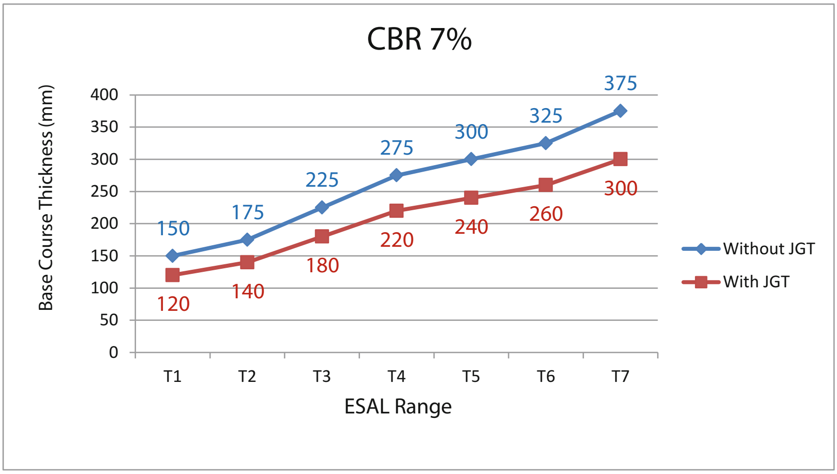
T1, 10,000–30,000; **T2**, 30,000–60,000; **T3**, 60,000–100,000; **T4**, 100,000–200,000

T5, 200,000–300,000; **T6**, 300,000–600,000; **T7**, 600,000–1,000,000









Annex II: Comparison of Pavement Thickness with and Without JGT Determined with the Modified Relations (Eqs. 6.8 and 6.9) Based on Burmister Theory

1. ESAL: 10,000–30,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement *without* JGT as per the design equation developed on the basis of Burmister theory (Eq. 6.8) in mm	Thickness of pavement *with* JGT as per the design equation developed on the basis of Burmister theory (Eq. 6.9) in mm
2	300	$301 \approx 300$ (with $k = 0.197$)	$238.96 \approx 240$ (with $k = 0.197$)
3	200	$201.13 \approx 200$ (with $k = 0.115$)	$159.62 \approx 160$ (with $k = 0.115$)

(continued)

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement *without* JGT as per the design equation developed on the basis of Burmister theory (Eq. 6.8) in mm	Thickness of pavement *with* JGT as per the design equation developed on the basis of Burmister theory (Eq. 6.9) in mm
4	200	$201.2 \approx 200$ (with $k = 0.152$)	$159.72 \approx 160$ (with $k = 0.152$)
5	175	$175.98 \approx 175$ (with $k = 0.14$)	$139.72 \approx 140$ (with $k = 0.14$)
6	175	$175.34 \approx 175$ (with $k = 0.153$)	$139.23 \approx 140$ (with $k = 0.153$)
7	150	$150.78 \approx 150$ (with $k = 0.14$)	$119.7 \approx 120$ (with $k = 0.14$)

2. ESAL: 30,000–60,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	325	$326 \approx 325$ (with $k = 0.2$)	$258.8 \approx 260$ (with $k = 0.2$)
3	275	$276 \approx 275$ (with $k = 0.148$)	$219.2 \approx 220$ (with $k = 0.2$)
4	275	$275.54 \approx 275$ (with $k = 0.195$)	$219 \approx 220$ (with $k = 0.195$)
5	250	$249.6 \approx 250$ (with $k = 0.186$)	$198.1 \approx 200$ (with $k = 0.186$)
6	250	$249.5 \approx 250$ (with $k = 0.204$)	$198.1 \approx 200$ (with $k = 0.204$)
7	175	$175.95 \approx 175$ (with $k = 0.153$)	$139.54 \approx 140$ (with $k = 0.153$)

3. ESAL: 60,000–100,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	375	$375.32 \approx 375$ (with $k = 0.22$)	$297.88 \approx 300$ (with $k = 0.22$)
3	325	$326.2 \approx 325$ (with $k = 0.167$)	$258.85 \approx 260$ (with $k = 0.167$)
4	325	$325.6 \approx 325$ (with $k = 0.22$)	$258.28 \approx 260$ (with $k = 0.22$)
5	275	$275.184 \approx 275$ (with $k = 0.196$)	$218.54 \approx 220$ (with $k = 0.196$)
6	275	$275.2 \approx 275$ (with $k = 0.215$)	$218.44 \approx 220$ (with $k = 0.215$)
7	225	$224.96 \approx 225$ (with $k = 0.187$)	$178.6 \approx 180$ (with $k = 0.187$)

4. ESAL: 100,000–200,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	425	424.88 ≈ 425 (with $k = 0.235$)	337.5 ≈ **340** (with $k = 0.235$)
3	375	374.85 ≈ 375 (with $k = 0.181$)	297.4 ≈ **300** (with $k = 0.181$)
4	375	376.32 ≈ 375 (with $k = 0.24$)	298.56 ≈ **300** (with $k = 0.24$)
5	300	300.98 ≈ 300 (with $k = 0.202$)	238.76 ≈ **240** (with $k = 0.202$)
6	300	299.89 ≈ 300 (with $k = 0.221$)	238.00 ≈ **240** (with $k = 0.221$)
7	275	275.4 ≈ 275 (with $k = 0.216$)	218.6 ≈ **220** (with $k = 0.216$)

5. ESAL: 200,000–300,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	475	476.85 ≈ 475 (with $k = 0.255$)	378.2 ≈ 380 (with $k = 0.255$)
3	425	427.8 ≈ 425 (with $k = 0.2$)	339.6 ≈ 340 (with $k = 0.2$)
4	425	426.0 ≈ 425 (with $k = 0.263$)	338.2 ≈ 340 (with $k = 0.263$)
5	325	324.52 ≈ 325 (with $k = 0.211$)	257.63 ≈ 260 (with $k = 0.211$)
6	325	325.26 ≈ 325 (with $k = 0.232$)	258.22 ≈ 260 (with $k = 0.232$)
7	300	300.50 ≈ 300 (with $k = 0.202$)	238.76 ≈ 240 (with $k = 0.202$)

6. ESAL: 300,000–600,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	550	552.16 ≈ 550 (with $k = 0.28$)	438.2 ≈ 440 (with $k = 0.28$)
3	475	476.22 ≈ 475 (with $k = 0.211$)	377.9 ≈ 380 (with $k = 0.211$)
4	475	475.0 ≈ 475 (with $k = 0.278$)	376.97 ≈ 380 (with $k = 0.278$)
5	375	374.91 ≈ 375 (with $k = 0.231$)	297.53 ≈ 300 (with $k = 0.231$)

(continued)

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
6	375	375.92 ≈ 375 (with $k = 0.254$)	298.196 ≈ 300 (with $k = 0.254$)
7	325	325.3 ≈ 325 (with $k = 0.234$)	258.1 ≈ 260 (with $k = 0.234$)

7. ESAL: 600,000–1,000,000

CBR (%)	Thickness of pavement as mentioned in IRC: SP:72:2007 (mm)	Thickness of pavement without JGT as per Eq. 6.8 (mm)	Thickness of pavement with JGT as per Eq. 6.9 (mm)
2	650	650.95 ≈ 650 (with $k = 0.318$)	516.75 ≈ 520 (with $k = 0.318$)
3	525	525.056 ≈ 525 (with $k = 0.224$)	416.64 ≈ 420 (with $k = 0.224$)
4	525	525.1 ≈ 525 (with $k = 0.296$)	416.768 ≈ 420 (with $k = 0.296$)
5	425	424.62 ≈ 425 (with $k = 0.252$)	336.92 ≈ 340 (with $k = 0.252$)
6	425	425.47 ≈ 425 (with $k = 0.277$)	337.663 ≈ 340 (with $k = 0.277$)
7	375	375.44 ≈ 375 (with $k = 0.26$)	297.96 ≈ 300 (with $k = 0.26$)

Annex III: Elastic Modulus of Woven Jute Fabric

1. Warp direction

Tensile Strength (MPa)	Tensile Modulus (GPa)	Strain (%)	Flexural Modulus (GPa)
81±13.5	1.12±0.034	3.8	4.3±0.10

2. Weft direction

71±8.7	0.78±0.063	4.1	3.6±0.08

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Chapter 7
Controlling Riverbank Erosion with Jute Geotextiles

Abstract Rivers flowing across unconsolidated terrain are susceptible to erosion of the banks in their effort to find the most convenient course. Besides, erodibility of bank soil and fluctuation of water level contribute largely to bank erosion. This chapter elaborates technical as well as economical advantages of using **treated** Jute Geotextiles (JGT) over the conventional granular filter for controlling riverbank erosion.

The perception of low effective life of JGT and its assumed ineffectiveness in riverbank erosion control has been countered with reasons. The chapter explains the elements of design with focus on aspects of soil retention, permeability, and transmissivity of JGT and clogging. Parameters for design of riprap overlying JGT have also been indicated. Installation procedure of JGT has been explained with sketches.

Keywords Granular filter • Erodibility of bank soil • Soil tightness • Unidirectional flow • Hydraulic conductivity of bank soil • Coefficient of uniformity • Gradient ratio test • Hydraulic conductivity ratio test • Riprap • AOS of JGT

Bank erosion is a common phenomenon in rivers flowing through areas that are yet to attain stability from geological and geotechnical considerations. The Ganga-Brahmaputra delta (West Bengal, Assam, Bangladesh) is one such region which has grown on alluvial deposition. Before deciding on the remedial measure, it is important to ascertain the causes(s) of erosion. High velocity of flow hugging the bank and exerting a tractive force on it, vortices at the toe of the bank, waves induced by wind and big vessels on move, large fluctuation in water level, and erosion proneness (erodibility) of bank soil are the contributory factors to bank erosion. Rivers moving along unsettled terrain often follow tortuous courses developing meanders of varying sinuosity in their attempt to follow the most "convenient" course. The concave end of any meander is prone to erosion, while the convex end on its opposite experiences accretion of sediment. The process of meandering of a river is complex. We desist from elaborating the causes here.

Understandably mere bank protective measures may not provide a long-term solution in cases where the influencing parameters causing erosion are several and variable. In such cases there is need to adopt appropriate structural measures such as spurs, apron, and the like for counteracting the erosive forces of a river in

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conjunction with bank protective measures. For instance repelling spurs can push the direction of flow away from the bank, submerged spurs can neutralize the vortices near the bank toe, and apron can reduce the chances of bank-toe collapse.

In majority of the cases of localized riverbank erosion, the prime cause of bank erosion is fluctuation of river water level. Bank erosion seldom takes place when the water level is on the rise. Bank starts eroding when the water level recedes. Water above the ambient level has a tendency to make ingress into the bank soil. The extent of intrusion of water into the bank soil depends mainly on the hydraulic conductivity of the bank soil. When water level starts subsiding, water that entered the bank soil while the level of water was on the rise tries to force its way back to the main stream. In the process the bank soil gets dislodged. The principle of prevention in such a case is to have an adequate filter medium to facilitate release of the water entrapped within the bank interior and at the same time control detachment and migration of the soil on the bank.

7.1 Conventional Granular Filter

It has been the common practice in India to use granular filter to prevent bank erosion as stones are easily available in this region. Unfortunately not much attention is paid usually to compliance of the specified grading and individual weight of granular aggregates to be placed over the affected bank stretch. The result is obvious. The bank in such cases may ultimately yield to erosive forces in play. The basic objective is to ensure the desired filtration by using conventional granular filter or by using appropriately designed geotextile over the eroded riverbank with an armor layer over the fabric. The armor overlay comprising boulders or precast concrete blocks of such weight as would withstand the uplift forces and resist the tractive force (shear force) has to be placed over the filter.

7.2 Advantages of Geotextiles Over Conventional Graded Filter in Riverbank Protection

Granular filter can be replaced by appropriately designed geotextile with both cost and technical advantage. The advantages of using geotextile including JGT treated with durable eco-friendly additive are several.

- Cost is less than that of conventional filter which consists of bulk of materials (thick filter) which belong to different grades.
- Transportation is easy and less costly.
- Weight and thickness are much less.
- Installation/laying is easier and less time-consuming saving construction time.

- Ensuring inversely graded (inverted filter) granular requires very close and strict supervision.
- Separation between soil and stone-boulder/brick-block/cement concrete blocks is ensured by using geotextile.
- Quality check is easy.
- Execution is much faster.

7.3 Bank Protection with JGT

The basic issue on use of JGT for riverbank protection is about its durability as jute degrades quicker when in contact with water. Considering the experience gained over the years, it may be stated with confidence that bank soil stabilizes within about two season cycles when the flow of river is unidirectional. In tidal rivers more time is needed for the JGT-treated riverbank to stabilize, usually about three season cycles. This suggests that the fabric must be able to play its role as a filter for that period. Eco-friendly water-repellent additives/treatment processes have recently have been developed by the Indian Institute of Technology Kharagpur and also by the Indian Jute Industries' Research Association (IJIRA), Kolkata. The treatment developed by IIT Kharagpur is claimed to prolong the fabric durability by about 4 years in water under varying degrees of salinity. The results are claimed to have been statistically analyzed and fitted with an equation based on an exponential model for treated and untreated JGT. Laboratory-based trials revealed that the half-life (assumed service life) of the treated woven JGT was enhanced by 2.5–4.5 times over untreated JGT. JGT treated with both the additives have been applied on an eroded stretch of the river Bhagirathi in West Bengal, India. The performance is being monitored.

When filtration is the critical function, design of JGT should focus on two factors, i.e., AOS of woven JGT in relation to average grain size distribution of bank soil and permittivity of JGT vis-à-vis hydraulic conductivity of bank soil. There exist empirical relations for man-made geotextiles which have the advantage of having uniformity in yarn features and dimensions unlike JGT. It is suggested that AOS of JGT should be given a larger tolerance (say 15 %) considering its lack of dimensional uniformity and for "hairiness" of its yarns. Tensile strength of JGT should concurrently be sufficient to withstand installation stresses. 20 kN/m tensile strength of JGT is sufficient for the majority of riverbank applications.

Besides AOS of JGT, it is necessary to design the armor layer over JGT laid on the prepared bank slope to lend stability to the bank against uplift forces. It requires to be ensured that displacement of armor layer should be minimal and JGT should not turn into plane of sliding. Armor layer as well as JGT itself should be allowed to slide along the bank.

7.4 Design Concept

At the outset it is important to point out that the selected woven JGT must be durable enough to last till the bank soil stabilizes to an acceptable degree. Bank erosion caused due to complex hydraulic milieu may take longer time for stabilization necessitating extended effective life of JGT. Bank soil may stabilize sufficiently if filtration is effective for at least two seasons usually. As already indicated in the preceding paragraph, stabilization of bank soil depends on several factors, viz., severity of flow—especially its velocity, proximity to bank, change of direction as in tidal rivers, vortices at the bank toe, waves, and nature of influencing agents such as wind and tides. Bank protective measure with JGT may not be singly enough to withstand the impact of all the factors stated above for which structural interventions such as spurs may be necessary concurrently. It is important to ensure durability of JGT till such time bank soil stabilizes optimally, say, for three seasons.

The criteria for design therefore rests on the following:

(a) Deciding the specification of JGT under site-specific conditions
(b) Ensuring durability of JGT till such time the bank soil shows signs of stabilization
(c) Design of armor/riprap over JGT ensuring overall stability of treated bank considering the tractive forces in play

7.5 Elements of Design

The critical parameter for riverbank erosion control with JGT is the *filtration efficiency* of the selected woven JGT. For filtration function to be effective under given hydraulic and geotechnical parameters, fabric design demands determination of optimal pore size of JGT that can retain the maximum soil particles ("soil tightness") on the one hand and ensure allowable permittivity to dissipate the pore water pressure in bank soil on the other. The design therefore should focus on AOS of woven JGT in relation to average grain size distribution of bank soil and permittivity of JGT vis-à-vis hydraulic conductivity of bank soil principally. There exist empirical relations for man-made geotextiles to address both the criteria. But then unlike man-made geotextiles, JGT does not possess dimensional uniformity. Considering its lack of uniformity and for "hairiness" of its yarns, it is suggested that AOS of JGT should be given a *larger tolerance* (say 15 %) over the design value. The matter deserves a more intensive study.

Conceptually, designing a geotextile filter is no different from designing a graded granular conventional filter. For a geotextile to act as a filter, it is essential that a condition of equilibrium is established at soil-geotextile interface as soon as possible after its installation. A filter should prevent migration of soil particles to an acceptable degree while at the same time allow pore water to flow *across* and also *along* the filter layer to prevent development of overpressure in bank soil. The situation leads to a state of equilibrium of soil particles ultimately after initial migration of finer particles inducing filter cake formation at the soil-geotextile interface (Lafleur et al. 1989).

JGT filter design depends on the following:

(a) The size of the largest pore in the geotextile filter should be *smaller than the average grain size of soil* while taking care to ensure that hydraulic conductivity of the fabric should be such as to relieve soil of pore water pressure contemporaneously across the fabric (*permittivity*). Besides flow of water across JGT, flow along the fabric (*transmissivity*) has also a role in dissipating pore water pressure. It may be noted that the extent of transmissivity varies with the pressure imposed on the fabric.
(b) Care is needed to ensure that JGT does not “block” or “clog.” There are standard tests to predict such probability (hydraulic conductivity ratio test and gradient ratio test).
(c) JGT must have adequate strength to survive installation stresses (*survivability criterion*).

7.6 Soil Retention Criteria for Different Flow Conditions

In *unidirectional* flow conditions, larger soil particles virtually form an archlike configuration over JGT pores and restrain smaller particles which, in turn, successively contain smaller soil particles. The altered disposition of soil particles in bank soil assumes a state of compactness (filter cake). In reversing flow conditions, filter cake formation in bank soil is usually partial when the cycle time does not allow sufficient time to form a graded soil filter. In rapidly reversing flow conditions, even partial filter cake formation in bank soil may not be attainable. In such conditions, *granular* filter is used in conjunction with JGT. Lightweight JGT is adequate for unidirectional flow conditions, whereas thick GT should be suitable for rapidly reversing flow conditions (Haore 1984). *Geotextiles and Geomembranes Manual* edited by T S Ingold recommends:

> unlike static design where flow is unidirectional, flow through bank soil occurs under reversing, dynamic hydraulic gradients. Consequently the bank soil cannot be assumed to develop filter cake and so the pore size required for retention will be *smaller* that for a dynamic flow regime than it might be for static flow.

PIANC (1987), Lawson (1982), Rijkswaterstaat in the Netherlands, Veldhuijzen (1986) and Working Group 14 of the German Society for Soil Mechanics and Foundation Engineering (GSSMFE), and Franzius Institute for Hydraulic Research have developed separate design criteria for riverbank application. Of all the designs, the one suggested by Lawson is the simplest.

It states that when C_u (coefficient of uniformity) is less than 5, the following criteria may be adopted.

– For retention criterion $O_{90} < d_{50}$.
– For permeability criterion $O_{90} > d_{15}$.

GSSMFE has suggested that retention criteria depend on the soil type and its grading. The following types of soil are prone to downslope migration.

(i) Particle size is finer than 0.06 mm and uniformity coefficient (d_{60}/d_{10}) is less than 15.
(ii) More than 50 % particles are in the range of 0.02–0.1 mm.
(iii) PI (plasticity index) is greater than 15.
(iv) Clay size fraction is less than 50 % of the silt size fraction.

The recommendation for retention criteria is as under which may be adopted for JGT.

(a) If **d_{40} is $\leq$0.06 mm**, then **O_{90}** should be **less than d_{90}**, **$10d_{50}$**, and **300 μm** separately.
(b) If **d_{40} is >0.06 mm**, then **O_{90}** should be **less than1.5 d_{10} $U^{1/2}$**, **d_{50},** and **500 μm** separately.

7.7 Permeability Criterion

- The general requirement of permeability criterion is $k_{geotextile} \geq i_s k_{soil}$ (Giroud 1988):

The principle of all permeability criteria is that as long as the permeability of the geotextile (k_g) is greater than the permeability of the soil (k_s), the flow of water will not be impeded at the soil-geotextile interface. Figure 7.1 shows permeability of different soil fractions under different hydraulic gradients.

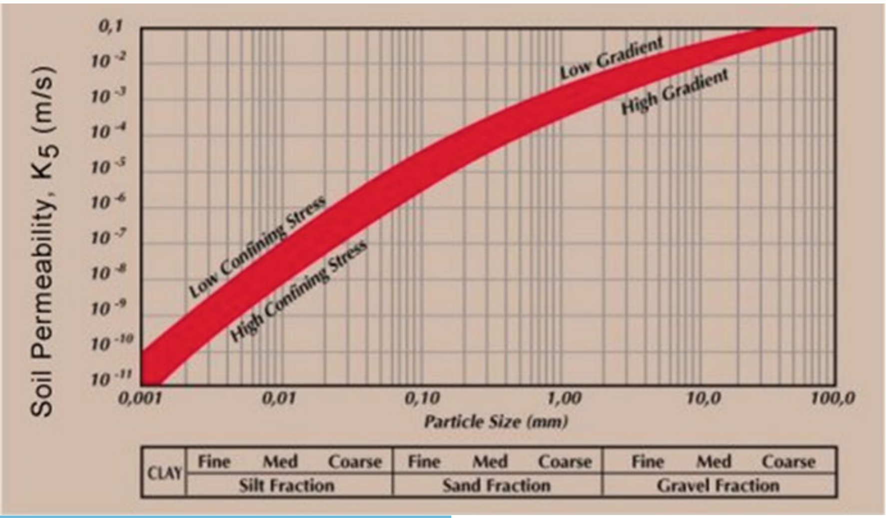

Fig. 7.1 Typical soil permeabilities

The relationships between permeability of JGT and soil have been derived from Netherlands Coastal Works Association (1981), Franzius Institute in Germany (1981), and Calhoun (1972). Since jute fiber is rich in cellulosic content, the absorption and transmission capacity of water along and across the fabric are well pronounced. The general principle should be

$$\boldsymbol{\Psi}_{\mathbf{JGT}} \geq \boldsymbol{k}_{\mathbf{soil}}$$

Where

Ψ_{JGT} = permittivity of JGT(/ sec) $= \frac{k_{\mathrm{JGT}}}{t_{\mathrm{JGT}}}$
t_{JGT} = thickness of JGT (cm)
k_{JGT} = permeability across JGT (cm/s)
k_{soil} = permeability of sub-grade soil, i.e., hydraulic conductivity (cm/s)
(N.B. permeability and hydraulic conductivity are synonymous).

Soils which are prone to down slope migration require additional protection either in the form of a granular sub-layer or thick high transmissivity geotextile (Ingold). JGT is itself a natural high transmissivity geotextile. For practical purposes, the following indicators may be adopted for JGT as recommended in *Geotextiles and Geomembranes Manual* (1994).

- *If d_{40} is $\leq$0.06 mm,*
  then 300 μm $<O_{90}<$1,500 μm and 5 mm $<t_{JGT}<$15 mm.
- *If d_{40} is >0.06 mm,*
  then 500 μm $<O_{90}<$2000 μm and 5 mm $<t_{JGT}<$20 mm.

To select the appropriate woven JGT, the recommendations for retention and permittivity are to be contemporaneously fulfilled.

7.8 Transmissivity Criterion for Drainage Function

JGT acts as a drain allowing transmission of water along its plane. Values of transmissivity of 627 gsm woven JGT that were measured in IIT Chennai under Prof K Rajagopal with a range of kPa values may be seen at the end of this chapter (Annex III). If the situation so demands, especially in very problematic bank soils, use of a thicker variety of woven JGT may be considered. Incidentally 627 gsm woven JGT is designed to possess tensile strength of 20 kN/m. It may be noted that for JGT, if permittivity criteria are satisfied, transmissivity criteria are usually fulfilled.

Table 7.1 MARV for survivability of JGT

S.No.	Property	ASTM	Units	Values
1	Wide width tensile strength	D 4595	kN/m	20
2	Puncture strength	D 4833	kN	400 (±10 %)
3	Burst strength	D 3786	kPa	3100 (±10 %)

7.9 Survivability Criteria

For survivability, JGT shall have the minimum average roll values (MARV) for armor layer as shown in Table 7.1 considering weight of individual stone about 50 kg with drop height of 1 m.

7.10 Anti-clogging Criterion

To obviate probability of clogging and blocking of JGT, gradient ratio test (GR test) or hydraulic conductivity ratio test (HCR test) should be conducted prior to deciding on the fabric porometry (AOS). To minimize the risk of clogging, the largest opening size (O_{95}) that satisfies the retention criterion should be checked for anti-clogging potential by conducting HCR (hydraulic conductivity ratio) test as per ASTM D5567 or GR (gradient ratio) test as per ASTM D5101-90. Clogging and piping potential of JGT may be roughly estimated by the following indications:

- Clogging: probability when flow rate continues to decrease with time
- Piping: probability when flow rate continues to increase with time

Figure 7.2 depicts the nature of disposition of particle clogging and blinding a geotextile.

Selected JGT for a particular site shall be such as to fulfill the criteria regarding the grain size of the bank soil, hydraulic conductivity of soil, and permittivity and transmissivity of the fabric. Besides, the fabric shall pass the anti-clogging predictive test. The exercise may call for adjustments by trial and error methods.

It is evident from the discussion in the preceding that pore size of woven JGT to be used for riverbank protection is critical as it controls filtration function. The design can be cross-checked by ascertaining if permissible stress on the channel imposed by flowing water (tractive force) is less than the permissible shear stress for bank soil (both cohesive and non-cohesive) overlain by JGT. Interested readers may go through the paper of Chen and Cotton (1988) for details.

It is relevant to mention here that pore size distribution in JGT is not uniform in view of several inherent features of jute, namely:

(a) Fiber lengths are at variance.
(b) Irregular arrangement of fibers.
(c) Wavelike variation in yarn thickness.

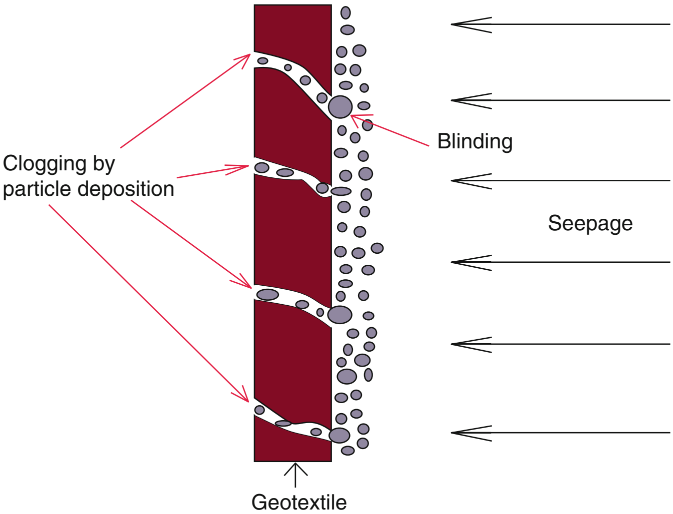

Fig. 7.2 Method of clogging and blinding (After Bell and Hicks 1980)

Lack of uniformity of jute fiber warrants larger tolerance in pore size of JGT (at least +15 %).

Indian Standard IS:14262:1995 in the Annexure recommends the following regarding criteria for selection of geotextiles. For granular materials containing 50 % or less fines by weight, the following relation is to be satisfied.

$$\frac{85\%\,\text{passing size of bed material}\,(\text{mm})}{\text{Equivalent opening size of fabric}\,(\text{mm})} \geq 1.0$$

The said Standard also recommends that the minimum allowable opening size of the geotextile shall be 0.149 mm. When the bed material size is between 50 and 85 % by weight, maximum allowable opening size of the geotextile should be 0.211 mm. If the bed material contains fines with more than 85 % by weight, it is advisable to use nonwoven geotextiles. However, the recommendations require modification considering the fact that physical features of JGT and man-made geotextiles have inherent physical dissimilarities.

7.11 Design of Armor or Riprap

Proper design of armor over JGT is critical to prevent uplift and to withstand the tractive force (shear stress) as a result of flowing water. This implies determination of the thickness of the armor as well as dead weight (specific gravity) of individual granular ingredient used as armor.

Design of riprap involves determination of thickness of pitching, weight, and also diameter of individual boulders. The Standard published by the Bureau of Indian Standards IS:14262-1995 provides guidelines for determination of the said parameters. There are several other standards as well published by research institutions elsewhere. It may be noted that bank slope, specific gravity of stone to be used for riprap, and its angle of internal friction of the stone to be used are important for design. The other critical criteria are cohesion of bank soil under saturated conditions and height of the bank to be stabilized. For high bank a relief berm may be necessary. The bank stability may be cross-checked by using the classic slip circle method. JGT and riprap should be placed on a stable bank base. Usually 2H:1V is safe. Specific gravity of stone for riprap should be in the range of 2,000–3,300 kg/m^3. Thickness of armor recommended in IS:14262:1995 is as below

$$T(\text{in metre}) = V^2/2g(S-1)$$

where

T: minimum thickness of armor
V: maximum velocity during flood m/s
G: gravitational constant = 9.81 m/s^2
S: specific gravity of riprap

The aforesaid Indian Standard also presents a nomograph for calculation of the weight of stone.

Brown and Clyde (1989) recommend minimum riprap thickness normal to bank slope to be

$$T = 1.5\ \mathrm{D}_{50}$$

where T stands for the riprap thickness and D_{50} is the mean diameter of rock/stone used as riprap in meter.

It may be noted that wave action is not a usual feature in rivers and waterways excepting near the sea or where there is high wind. The weight of armor stones in rivers is decided on the basis of nature and magnitude of velocity of flow close to the bank. It is safe for practical purposes to adopt the equivalent diameter of stone as 0.1 m (of specific gravity at least 2.7) for flow velocity of the order of 1 m/s. In rivers current velocity seldom exceeds 3 m/s for which an equivalent diameter of 0.25 m of armor stone is usually sufficient. Interested readers may also go through the Indian Standard IS:14262:1995 for additional information regarding riprap design.

The specifications of woven JGT shown in Table 7.2 are supposed to satisfy the hydraulic design principles on permissible shear stress on the bank. Care should be taken to decide on the pore size of the fabric. Water-repellent treatment in all river-related applications is a must.

Table 7.2 Typical specification of untreated/gray woven JGT for riverbank protective works

Nomenclature	Woven JGT 20 kN/m (untreated)
Construction	1/1 DW plain weave
Weight (gsm) at 20 % MR ≥	627
Width (cm) ≥	100
Ends × picks/dm ≥	85 × 32
Thickness, (mm at 2 kPa)	1.7 ± 10 %
Tensile strength (kN/m) MD × CD ≥	20 × 20
Elongation at break (%) MD × CD ≥	12 × 12
Puncture resistance (kN)	0.400 ± 10 %
Burst strength (KPa)	3100 ± 10 %
Permittivity at 50 mm constant head (/s)	$350 \times 10^{-3} \pm 10\,\%$
AOS (micron) O_{95}	150–400

For unidirectional waterways, woven JGT with the above features may be adopted. In rivers with two-way flows (tidal rivers), it is advisable to use a heavier type JGT—say of weight 760 gsm which proved effective in a field application in the Hugli estuary off Haldia Docks.

7.12 Installation Procedure of JGT on Riverbank

- Bank should first be cut to stable slope at the angle of internal friction of bank soil.
- The surface should be leveled and made free from angular projections, undulation, soil slurry, or mud.
- Anchoring trench (usually rectangular) for holding JGT should be excavated at the top of bank slope. The recommended dimensions of trench are 500 mm deep and at least 250 mm wide at the bottom as shown in the above diagrams.
- JGT should be unrolled across the trench and along the slope from top down to the lowest low water level.
- JGT should be stapled with U-shaped nails (usually 11 gauge) within anchoring trench as well as along the slope.
- Care should be taken to ensure that JGT does not suffer damage due to puncture, tear, or other operational stresses. It should be ensured that armor stones/ boulders are not dropped on JGT but are carefully placed. A thin layer of sand over JGT is recommended to avoid puncture of fabric.
- Recommended overlap is 150 mm (minimum). The overlapping portion should be stapled at an interval of 300 mm.

- Anchoring trench at the countryside should be filled with boulders for protecting JGT. It must be ensured that JGT touches the bank slope at all points (drapability).
- An improvised beam at the toe of slope should be made by folding JGT, usually 500 mm in diameter, and packing the hollow of the cylinder-shaped folded portion with sand. Alternatively a V-shaped recess at the river end (see Fig. 4.1—Type B below) may be made. The recess may be utilized for anchoring JGT at the river end.
- Locally thriving suitable grass seeds should be then spread on treated bank. Attempt should be made to grow deep-rooted vegetation on slope if practicable.

Overall stability of the bank with Jute Geotextiles may be checked with the help of any suitable software (say BSTEM version 5.0) by inserting values of several critical bank-related and hydraulic parameters to determine the factor of safety. BSTEM version developed by Andrew Simon and Robert Thomas et al. of USDA-ARS National Sedimentation Laboratory, Oxford, MS, takes into account bank profile, bank material properties, soil layer thickness, flow parameters, bank vegetation and its effects, and shear strength of geotextile used for bank protection (Fig. 7.3).

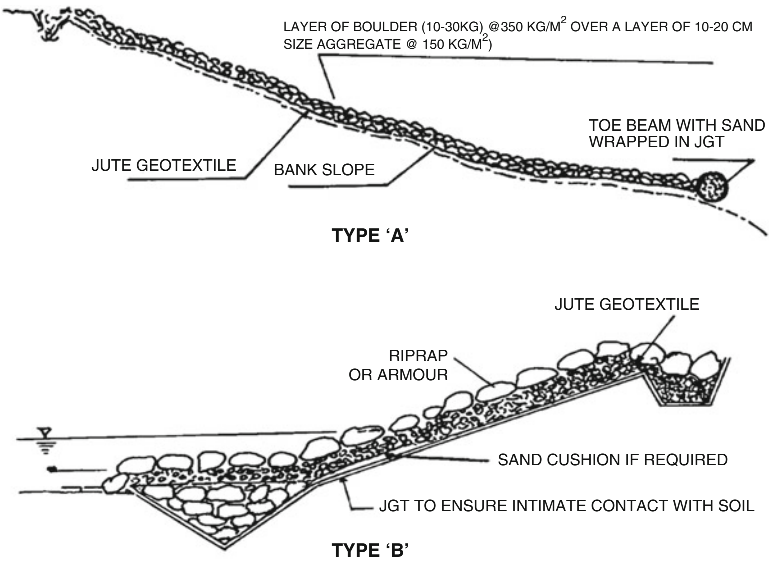

Fig. 7.3 Methods of installation of JGT on riverbank

Annex: Transmissivity of Woven JGT (627 gsm/20 kN/m)

Table 7.3 627 gsm JGT at 5.6 kPa

Gradient	Discharge rate q_w (m^2/s)	Transmissivity θ (m^2/s)
0.25	1.11×10^{-6}	3.62×10^{-6}
0.5	1.66×10^{-6}	2.72×10^{-6}
1.0	6.66×10^{-6}	5.25×10^{-6}

Table 7.4 627 gsm JGT at 11.12 kPa

Gradient	Discharge rate q_w (m^2/s)	Transmissivity θ (m^2/s)
1.0	4.63×10^{-7}	3.64×10^{-7}

Table 7.5 627 gsm JGT at 16.67 kPa

Gradient	Discharge rate q_w (m^2/s)	Transmissivity θ (m^2/s)
1.0	3.61×10^{-7}	2.84×10^{-7}

Source: IIT, Chennai (Prof. K Rajagopal)

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Chapter 8
Stabilizing Embankments with Jute Geotextiles

Abstract Instability of earthen embankments stems usually from poor quality of the fill material, inadequate compaction, entrapment of water within, etc. The contents of this chapter explain the technical advantages in using Jute Geotextiles (JGT) appropriately in an earthen embankment by using it as a basal reinforcement and at different levels within the embankment as preventive checks against settlement and rotational slides and for draining out entrapped pore water. The principle of reinforced earth has been briefly explained and design approach indicated. The properties of woven JGT to be used in embankments have also been mentioned. Installation guidelines have been provided supported by sketches.

Keywords Vertical settlement • Lateral dispersion • Downslope migration • Rotational slide • Reinforced soil • Global stability • Elastic deformation • Slip failure • Basal reinforcement

Earthen embankments (levees) should first be checked for stability under its own weight. Almost all embankments have to withstand extraneous loads apart from the dead weight. Road and railway embankments are subjected to moving loads on roads constructed usually on its top inducing dynamic stresses within. Flood control embankments are subjected to withstand lateral thrusts of rising water which may seep into the embankment body and enhance the moisture content in it. The basic approach for stabilizing an embankment is to reinforce the fill by inserting reinforcing elements such as the appropriate geotextiles. JGT can be used *selectively* in such cases.

8.1 Causes of Instability of Embankments

Before deciding on the measure for stabilization of embankment, it is necessary to know the causes of its instability. The probable reasons are as under.

- Saturation of soil with entrapped moisture
- Expansive or compressive soils used as fills in embankments which may lead to:

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– Vertical settlement
– Lateral dispersion
– Downslope migration
– Rotational slides

8.2 Principle of Reinforced Soil

Let us consider a soil element in the earth fill of any embankment. Application of vertical stress deforms the element leading to development of horizontal stress as a result of lateral compression. In other words, the soil element undergoes “tensile deformation.” When a reinforcing element is inserted in the fill, tensile strength develops in it due to the vertical stress which in turn produces a horizontal stress inducing a confining action counteracting the horizontal force. A suitable geotextile element is supposed to absorb a part of the induced horizontal stress and also the resultant strain helping reduce the stress due to imposition of vertical loads. The state of stress gets modified when the reinforcing element lies at an angle instead of being vertical.

When JGT is inserted inside the fill, the stress-strain development scenario does not change in the initial stages. In fact due to the higher roughness coefficient of JGT, the confining action exerted by it is better than that of its man-made counterpart *in the initial phase*, and the confinement so induced is usually sustained unless there are disquieting forces subsequently.

8.3 Advantages of Using JGT in Stabilizing Embankments

The advantages of using JGT for stabilizing earthen embankment are:

- JGT absorbs stress and strain induced due to moving loads on embankments.
- Good soil-JGT friction effectively harmonizes the induced stress and strain.
- JGT can directly reinforce the soil mass in an embankment during its useful lifespan by exerting a confining action on soil besides acting as a separating, filtration, and drainage medium for dissipation of pore water.
- JGT may be interposed at suitable intervals within the embankment as intervening medium against failure planes caused by rotational slides/slips.
- Woven JGT may be used as basal reinforcement prior to construction of an embankment for prevention of settlement by distributing loads over a wider area.
- And lastly JGT protects the slope of embankment better than other geotextiles.

8.4 Design Approach

The steps to ensure overall embankment stability besides control of surface erosion in slope are (i) selection and control of appropriate fill material, (ii) checking the bearing capacity of the ground soil on which the proposed embankment is to be founded and measures to improve it by use of JGT or other measures for prevention of vertical settlement (such as by providing basal reinforcement of JGT), and lastly (iii) if the fill is made of dominantly clay, provisions for draining out water entrapped within the embankment by constructing JGT-encapsulated concealed drains or, in extreme cases, by use of prefabricated vertical jute drains (PVJD) as in areas with marine clay deposits.

When an earthen embankment is subjected to moving loads, stresses and strains develop which may lead to its failure if the permissible limits are exceeded. JGT when placed on appropriate levels within the embankment can absorb these stresses to a substantial extent at initial stages and control the failure of embankment. JGT acts as a medium of transference of induced stress and strain to soil. It resists tensile deformation as explained in the preceding, but a word of caution. JGT can directly reinforce an embankment only during its useful life-span (not more than 3 years after rot-resistant treatment). The reinforcing function of JGT under dynamic loads thus stabilizes the fill of an earthen embankment initially and in some cases optimally. Reinforcing function of JGT facilitates soil consolidation in the embankment fill.

Woven JGT inserted in soil layers within an embankment segregates the layer above and under it. The fabric also helps in soil reinforcement during its effective life and acts against the probable planes of slides.

The following points should be kept in mind while designing an embankment with JGT:

- It is necessary that both grain size distribution and coefficient of permeability of fill and of base soil are determined for choice of an appropriate JGT.
- Before construction of any new embankment, JGT is to be treated with a suitable additive to enhance the fabric durability.
- JGT may be laid as basal reinforcement at the embankment base. Apart from acting as a segregating layer, it improves the bearing capacity of the base soil as explained under Chapter VI and prevents intermixing of overlying and underlying soil layers.
- The interval between layers will depend on the height and width of the embankment, composition, and geotechnical characteristics of the soil material and the type, frequency, and extent of dynamic loading.
- There should be provisions for side restraint if the soil material has low internal friction.
- When hydraulic conductivity of soil is low (say less than 10^{-5} m/s), a combination of both woven and nonwoven JGT is recommended.
- Slope stability may be ensured as per guidelines described under Chap. 4.

The following checks are advised to ensure stability of an earthen embankment.

(a) Bearing capacity

The following relation may be used to arrive at the safe allowable height of the embankment.

$$\boldsymbol{q_{\text{allow}} = C_u N_c / \text{FS} = \gamma^* h_{\text{allow}}}$$

where

q_{allow} stands for allowable bearing capacity.
C_u for undrained shear strength of the foundation soil.
N_c for bearing capacity factor.
FS for factor of safety.
γ for unit weight of soil.
h_{allow} for allowable height of the embankment.

(b) Global stability

The purpose is to check the slope stability by assessing the principal stresses cutting across the geotextile plane. Check may be carried out by any suitable software or by direct structural analysis.

Overall stability of the embankment may be ensured by assessing the factor of safety (FS) using the following relation.

$$\text{FS} = \frac{M_R + M_{R1}}{M_D}$$

where M_R stands for resisting moment of soil, M_D for driving moment of soil, and M_{R1} for reactive moment of JGT (all in kNm/m units). FS should be between 1.2 and 1.3.

(c) Elastic deformation

The purpose is to determine the required modulus and failure strain along the principal and other secondary stress directions in the geotextile. The following relation may be used.

$$E = T_{reqd}/\varepsilon_f$$

where E denotes modulus of elasticity, T_{reqd} tension, and ε_f strain in the geotextile, respectively.

(d) Pullout

It is to be ensured that the soil surrounding the slip zone resists pullout for which sufficient distance for holding back is kept to mobilize the requisite strength to counter pullout. Frictional coefficient of geotextile should be sufficient.

For stability against slip failure, the following relation may be used.

$$\text{FS} = P_R/P_A$$

where P_R stands for active earth pressure in kN/m and P_A for interfacial friction between JGT and soil (kN/m).

(e) Lateral dispersion
In this check also, frictional coefficient of geotextile is critical.

As already indicated JGT has high roughness coefficient and can thus better induce a confining force to counteract destabilizing forces in general. Mehndiratta et al. (2003) observed an increase of 60.27 % in modulus of sub-grade "*k*" over the unreinforced sub-grade by using JGT.

8.5 Properties of JGT to Be Used in Embankments

The following properties of JGT are to be kept in view and ascertained before use inside embankments either as basal reinforcement or as intermediary strengthening in successive layers over the base.

(a) Frictional coefficient between JGT and soil should be adequate (of the order of at least 0.8).
(b) Tensile strength of JGT should be ≥25 kN/m.
(c) Creep behavior of JGT. If the deformation of JGT continues without increase in vertical load, the fabric is said to be experiencing creep. In other words, creep is the increase in strain at constant stress and temperature. A suitable factor of safety may be assigned for the purpose.
(d) Prevention of damage during installation.
(e) Chemical and biological resistance. This necessitates smearing the fabric with a suitable eco-friendly additive such as alkali and rubber latex.

8.6 Installation Procedure for JGT in Embankments

The following recommended sequence (a, b, c, d, e, f, and g in that order) shown in Fig. 8.1 should be followed in building up an earth-filled embankment and laying of JGT.

The following guidelines may be followed in building an earthen embankment.

- Surface of base should be leveled and cleared from foreign materials.
- Treated JGT should be placed at the interface of base soil and bottom of the proposed embankment with its ends folded up to one eight of base width of proposed embankment and filled with the fill material (see portions of a+b+c of the above figure).
- More fill materials should be at the edges (portion d).

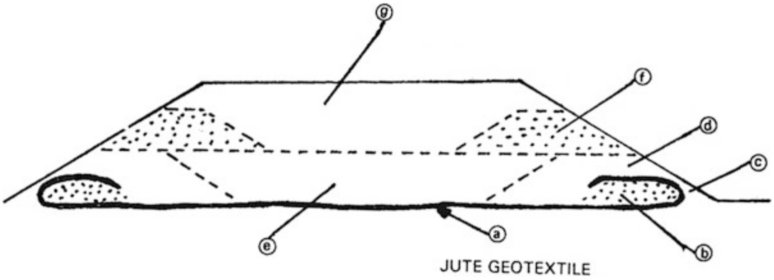

Fig. 8.1 Sequence of embankment construction

- The central portion is to be filled next (portion e).
- The height of the embankments is to be raised (portion f).
- Complete filling of the central portion in stages (portion g).

It is important to take note of the following in addition.

(i) The fill material should not be organic soil or with plasticity index (PI) more than 20 and liquid limit more than 40 when tested according to the relevant ASTM standards.

(ii) The process of filling behind abutments and wing walls of all structures should conform to the guidelines given in the available Standards, e.g., Appendix 6 of IRC:78 (Standard Specifications and Code of Practice for Road Bridges—Section VII published by the Indian Roads Congress in India), in respect of the type of material, the extent of backfill, its laying and compaction, etc.

(iii) The fill materials should be laid in horizontal layers and compacted at the optimum moisture content (OMC).

(iv) Backfilling should not be done in water or over muddy surface. Water and mud should be bailed out and JGT placed on the prepared surface. It is recommended that the granular material of maximum particle size of 75 mm and uniformity coefficient (d_{60}/d_{10}) should at least be 10 in such cases.

(v) Sufficient settlement period should be allowed to the new embankment before any construction is undertaken on it.

(vi) In case of higher embankments, treated JGT may be interposed at appropriate layers within the embankment body.

(vii) In case of high embankment, it may be necessary to use a double-layered woven JGT filled with granular materials as basal reinforcement as shown in Fig. 8.2.

Figure 8.3 shows an arrangement of folding and placement of woven JGT at the sides of an embankment with intermediary sandbag support. The figure above shows an arrangement where woven JGT is placed at 1.25 m vertical intervals after ensuring that earth shall be compacted to a depth of 0.25 m which is usually the thickness of sand-filled bags.

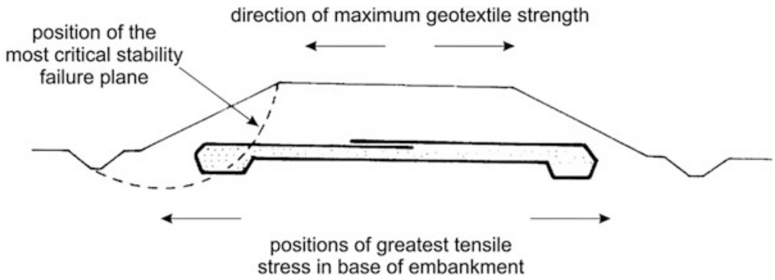

Fig. 8.2 Basal reinforcement consisting of granular fill encapsulated with JGT

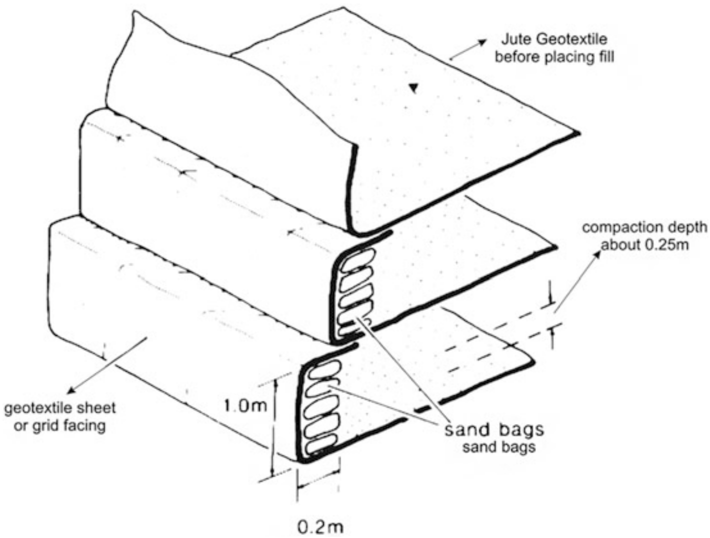

Fig. 8.3 JGT-sandbag intermediary support system in embankment

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Chapter 9
Management of Settlement of Railway Tracks

Abstract Railway tracks built on unstable formation or on poor sub-grade often undergo differential settlement endangering the safety of trains running over it. Before deciding on the remedial approach, the cause for settlement has to be identified. The chapter elaborates the probable causes behind track settlement and reasons out a package of measures with Jute Geotextiles (JGT) as a plausible solution. Sequential steps have been recommended for the purpose along with the guidelines for selection of the appropriate JGT with installation procedures.

Keywords Erosion pumping • Rotational slide • Pore water pressure • Concealed drain • Toe wall

Railway tracks similar to pavements may undergo settlement and in severe cases subside due to the following reasons:

(i) Inability of sub-grade to withstand repeated heavy vibratory loads of moving trains.
(ii) Insufficient bearing capacity of sub-grade.
(iii) Rotational slides.
(iv) Ingress of rainwater into the embankment and entrapment of water within the embankment if the soil is clayey, developing unacceptably high pore water pressure within it if the drainage is deficient causing pushing up of soil slurry into ballast layer called *erosion pumping*.
(v) Intermixing of ballast into sub-grade.
(vi) Erosion of cess due to anthropogenic causes and rain cuts.

Any or a combination of the causes above could lead to track settlement. Railway tracks are built on earthen embankments usually. Settlement of railway track may manifest in heaving up of the two sides of it as in the case of failure due to punching shear. Settlement is seldom uniform leading to unequal settlements in view of unequal distribution of stress through the ballast layer. Interfacial contact stresses (at the interface of the sub-grade and the ballast layer) could be quite high.

Open textured ballast layer allows penetration of rainwater into the sub-grade. Embankment fill in many cases is built on soil with clay dominance leading to entrapment of water and consequent volume change of the sub-grade. It is for this

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reason that an efficient drainage system at the sub-grade level is called for. Due to absence of any separating medium in between, the sub-grade and the overlying ballast base sub-grade soil may get mixed up with the overlying ballast layer and inhibit drainage, besides reducing the design ballast layer thickness due to its interpenetration into the underlying sub-grade.

When the embankment fill is weak in shear strength, it becomes susceptible to slips or rotational slides. Pore water if entrapped within soil develops high pressure and could result in erosion pumping in some cases.

Railway tracks behave almost in the same way as roads. It is the sub-grade that requires special attention. The necessity of drainage of water is far more in case of railway sub-grade as the chances of intrusion of water principally from the top through the free draining ballast layer are greater than that in roads.

9.1 Remedial Approach

The basic remedial approach is to drain out the entrapped water from the sub-grade and the soil below and prevent migration of soil particles from the sub-grade. The treatment is basically similar as in case of a road with an unstable sub-grade, the only difference being that the dynamic load is distributed over the underlying base course and the sub-grade via the defined alignment of the rails. Usually a combination of woven and nonwoven JGT is recommended for laying on the sub-grade to resist the dynamic stresses and to facilitate drainage.

In new railway embankment constructions, care should be exercised for use of the right type of fill materials and ensuring efficient drainage under the track. Existence of clay in and under the sub-grade creates problems. In existing embankments with compressive fill materials (soft soil), especially in areas with moderate to high rainfall, prefabricated vertical jute drains (PVJD) can provide long-lasting solution (see Chap. 10 for details). The geotechnical properties of sub-grade should be analyzed first followed by assessment of the depth to which PVJD needs to be inserted into the soil. The basic purpose is to ensure attainment of the desired degree of consolidation over a specified time period in relation to subsoil conditions.

Keeping in view of what has been stated above, the following measures are recommended for rehabilitating a settled track. For new railway tracks built on new earthen embankments, the following approach is recommended:

- To expose the sub-grade followed by placement of woven JGT (bituminized) over a thin layer of sand duly compacted by a portable mechanical vibrator.
- To rebuild the base layer under the track as previously specified with stone ballast.
- To provide concealed drains comprising brick ballasts encapsulated in nonwoven JGT on the side of the affected track. In severe cases PVJD (Chap. 10) should be used.
- To provide a dwarf toe wall on the slope to the affected track for prevention.

- To provide open weave JGT on the prepared slope after restoring the eroded cess with earth.

The major hurdle while executing is that the affected track could not be made available free from train movement. The situation required realistic planning for execution. The following schedule was adopted in consultation with the railway authorities in a work of rehabilitation of a long-standing settlement of a busy railway track in Bardhaman-Howrah Chord Line near Kolkata, West Bengal, India, with JGT. Figure 9.1 depicts the remedial arrangement suggested by Sanyal (2000) for restoring the settled track to shape.

- *First step*
  - To support the portion of the track to be restored by placing a rail cluster on either side
  - To scoop out the ballast in the base course and expose the sub-grade
  - To ram the exposed sub-grade with a mechanical vibrator, place sand on it followed by laying of JGT
  - To build up the base course with ballast after placing a thin layer of sand
- *Second step*
  - To excavate small rectangular conduits at 15 m intervals to reach the bottom of the sub-grade
  - To place nonwoven JGT on the conduits and fill it with rubbles and fold JGT to encapsulate rubble
  - To cover the excavated portions with earth
- *Third step*
  - To build up the eroded cess with earth ensuring compaction
  - To restore the profile of the embankment slope with earth after manual compaction
  - To construct a dwarf toe wall preferably with wire-crated boulders
  - To lay open weave JGT on the slope
  - To place grass sods on JGT in the slope

To ensure uninterrupted train services along the affected track, the portion between adjacent sleepers must be completed in a day.

9.2 Installation Procedure

For installation of JGT, the following sequence is recommended:

- The sub-grade is to be excavated, cleared from foreign materials, and compacted to the optimum moisture content (OMC) of soil.
- A thin layer of local sand (about 100 mm thick) must be spread over sub-grade.

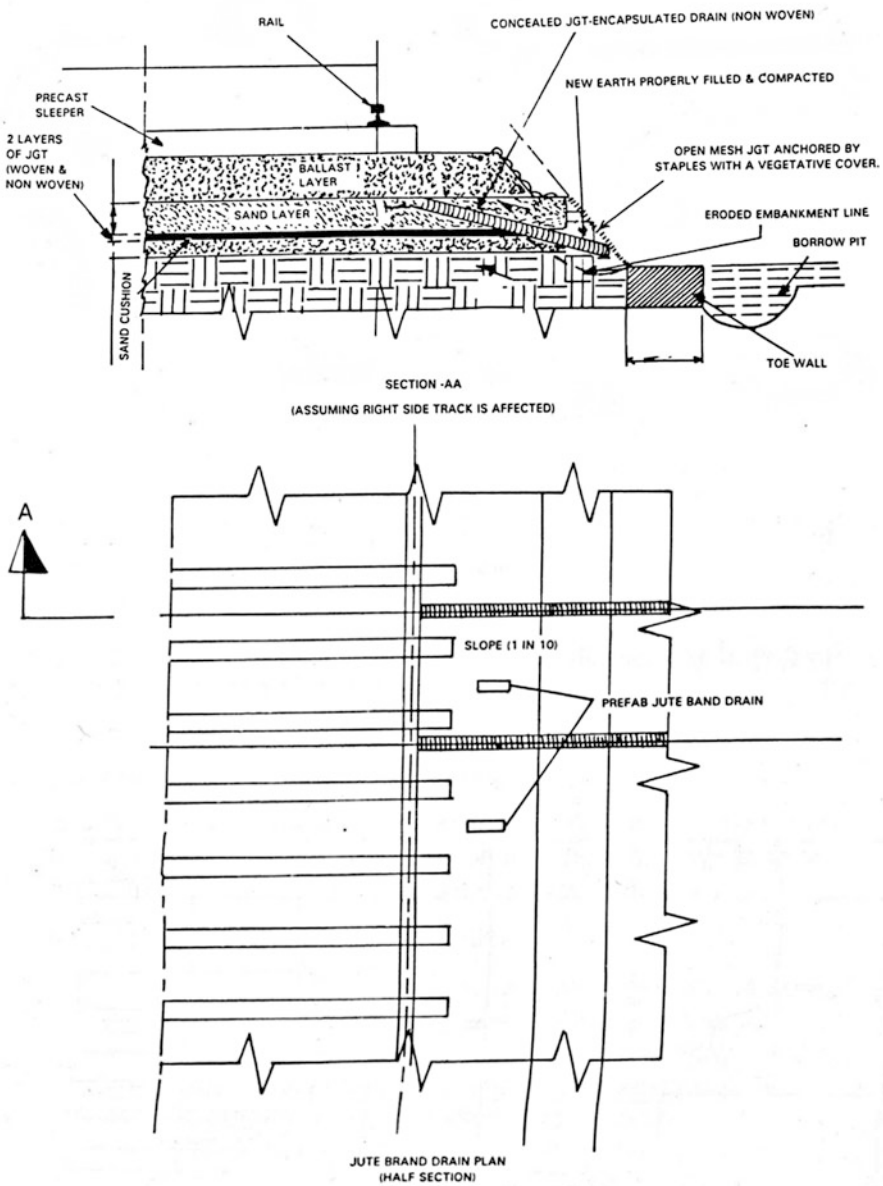

Fig. 9.1 Typical remedial measures for track settlement in railway embankments (After Sanyal 2000)

- Woven JGT must be laid by unrolling, ensuring proper drapability, and stapled at an interval of 300 mm with overlaps of 150 mm. Staples should be preferably U-shaped nails (11 gauge). Suitable wooden staples may also be used. Overlaps must be avoided to the extent as possible.
- After completion of laying of woven JGT, nonwoven JGT must be laid over it.
- Again a cushion of local sand (about 300 mm thick) may be spread over JGT to prevent puncture/damage due to rolling of ballast layer.
- For application in curves, JGT should be folded and overlapped in the direction of turn. Folds in JGT should be stapled at an interval of 300 mm.
- Before laying JGT, the torn and damaged portions of the fabric, if there be any, shall be patched up by small pieces of JGT cut from an approved roll.
- In the case of the existing railway tracks, ballast layer is to be scooped out completely supporting the rails on wooden blocks, leveling the sub-grade, spreading a thin layer of sand on it, placing JGT overlain by a cushion of sand, and replacing the ballasts after cleaning them.
- Constructing JGT-encapsulated rubble drains, placed laterally, to drain out entrapped water.
- Inserting PVJD if there are signs of erosion pumping.
- Reshaping the embankment as per the design profile given below in the figure.
- Protecting the exposed slopes with open mesh JGT and with grass growing on it.

9.3 Type of JGT to Be Used

Woven JGT with minimum 25 kN/m tensile strength or higher (attainment of 35 kN/m tensile strength is possible for JGT) in both warp and weft directions and nonwoven 500 gsm JGT with coefficient of permeability of 2.9×10^{-3} m/s (both for sub-grade with the woven type and for concealed drains) are usually recommended for use. Woven JGT treated with eco-friendly additives is preferred. In case there are signs of erosion pumping, use of prefabricated vertical jute drains (PVJD) under the sub-grade level is recommended. Specifications of PVJD and their spacing are to be decided on the basis of subsoil conditions.

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Chapter 10
Consolidation of Soft Soil with Prefabricated Vertical Jute Drain

Abstract Soft soils with high clay content pose problems for any construction. Such soils have a tendency to entrap water and take a long time to settle. The remedy lies in quick dissipation of pore water held back within pores through a guided straight path. This was earlier used to be done through vertical sand drains. Prefabricated vertical drain (PVD) made of contiguous polymeric micro-channels under a sheath provides vertical drainage paths accelerating pore water dissipation.

Prefabricated vertical jute drain (PVJD) is a new development that functions through its coir wicks and jute sheath for draining out water vertically and also in radial direction. Initial laboratory findings conducted on PVJD are very encouraging and are comparable to PVDs. PVJD is a worth trying option for consolidating soft soils.

This chapter discusses in depth the construction of PVJD and presents a short comparative analysis of PVD and PVJD. Specifications for PVJD and preliminary laboratory findings on performance of PVJD conducted by the University of Wollongong, Australia, have also been indicated in this chapter.

Keywords Soft soil • Prefabricated vertical jute drain (PVJD) • Sand drain • Prefabricated vertical drain (PVD) • Smear effects

Soils with high clay content, loosely termed soft soils, pose problems for any type of construction built on it due to volume variation with change in its water content. Consolidation of such soil is difficult as it holds back water. Soft clay soil in view of its low hydraulic conductivity takes a long time to settle. The only way to consolidate such soil is to rid it of water. Prefabricated vertical jute drains (PVJD) can shorten the time of settlement by creating straight drainage paths which, when inserted into the soil, extracts water by capillary action along these drainage paths and effecting radial drainage through its sheath (the outer cover of the drain proper). It is worth noting that lateral hydraulic conductivity of soft soils is more than its vertical component. PVJD is virtually an improved version of conventional sand drain.

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10.1 Advantages of Using PVJD in Soft Soil Consolidation

- Prefabricated vertical jute drain (PVJD) is an effective draining medium.
- It is a better substitute for sand drains.
- It drains out water by capillary action and also by simultaneous radial drainage through its sheath.
- Standard prefabricated vertical jute drains with jute/coir wicks are available from selected jute mills and are competitively priced.

It may be noted that the conventional prefabricated drain made of man-made materials (synthetic) functions through a series of contiguous channels unlike PVJD which drains off subsoil water principally through wicks in the vertical direction as well as radially.

10.2 Design Approach

As already indicated vertical drains (VD) are essentially artificially created straight vertical drainage paths that accelerate soil consolidation by removing pore water present in the substrata up to a level, after which the imposed load on soil is dispersed over a wide area beyond the zone of influence. Interestingly soft soils contain a high percentage of clay having higher hydraulic conductivity in the horizontal direction than in the vertical. VD reduce the length of the drainage path of water which otherwise would have moved following a circuitous route. Kjellman first introduced the prototype of PVD in the 1930s. Man-made PVD comprises a plastic core with longitudinal channels covered usually with a nonwoven sheath.

Initially PVD of circular shape was conceived along with rectangular cross section. It has been substantiated subsequently that round and rectangular PVDs do not affect the consolidation rate if their circumferences are kept identical (Hansbo 1979). The essential function of any PVD is to dissipate pore water pressure within soil mainly as upward discharge. Discharge in radial directions also takes place (see Fig. 10.1). Efficiency of any PVD thus depends on the discharge capacity of the drain which may get affected due to several reasons such as lateral earth pressure, large settlement, clogging of drain, biological and chemical activities in soil, and hydraulic gradient (Bergado et al. 1997). Kinking of vertical drain may also affect its discharge capacity.

Apart from the aforesaid factors that influence the discharge capacity of vertical drains, there is another determining factor. The clay layer surrounding the drain gets disturbed while driving the drains into soil. The phenomenon is termed "smear effect" which reduces the horizontal hydraulic conductivity (radial drainage) of the soft soil (Fig. 10.2). Studies on smear effects have been carried out by Barron (1948) who derived analytical expressions to take this factor into account. The problem was also considered by Cassagrande and Poulos (1969) and later by

Fig. 10.1 Typical PVJD with coir wicks

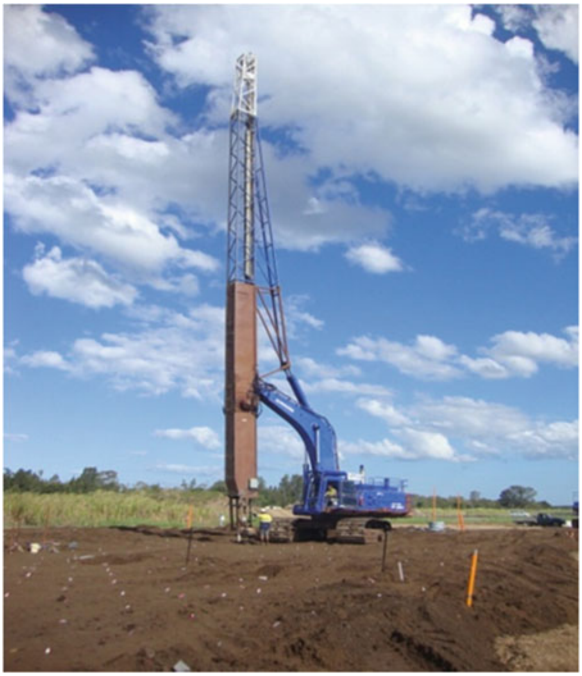

Fig. 10.2 Installation of PVJD in progress in Ballina, Australia

Rujikiatkamjorn and Indraratna (2010). Cassagrande and Poulos were of the view that a thick smear zone could affect soil consolidation adversely. The combined effect of smear zone and the zone in between smear and undisturbed zones has also been studied by Abuel-Naga et al. (2012) and other researchers.

But the most critical factor to ensure the desired discharge capacity of vertical drains is their spacing. Barron (1948) and Kjellman (1948) investigated the matter and developed relations for determining equivalent drain diameter (d_e) and equivalent zone of influence of vertical drains (Z_e) which was confirmed by an exercise on finite element analysis by Runesson et al. (1985). The relation is

$$d_e = \frac{2(B + T)}{\pi}$$

where B stands for the width of the band drain and t is its thickness.

Equivalent influence zone is a controlled variable. If L is the drain spacing, then for a triangular grid of vertical drains the equivalent zone of influence could be between 0.525 and 1.05 L. For a square grid, the value of Z_e lies between 0.546 and 1.13 L.

10.3 Prefabricated Vertical Jute Drain (PVJD)

Conventional PVJD has two parts—an outer sheath and an inner core comprising coir/jute wicks (see Fig. 10.3). Usually the sheath of PVJD is made of woven JGT with specified trapezoidal tear strength, elongation at break, grab tensile strength, bursting strength, puncture strength, permittivity, and apparent opening size (AOS). The core consisting of usually coir wicks should possess the desired discharge capacity both under straight and twisted (kink) conditions, apart from fulfilling the tensile strength requirements. The wicks are placed in compartments of the sheath

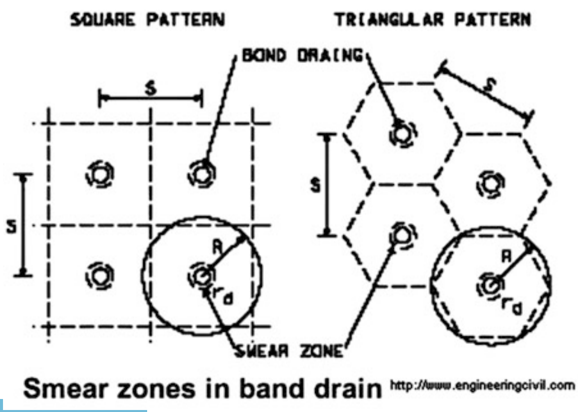

Fig. 10.3 Indicative smear zones around PVJD

Table 10.1 Indicative technical specifications of PVJD

Sl. no.	Properties	Unit	Standard	Specifications
A. For drain (wick)				
1	Width	mm	–	≥100
2	Thickness	mm	ASTM D5199	3–4
3	Elongation at break	%	ASTM D1682	≤10
4	Tensile strength (wide width)	kN	ASTM D4595	≥2.5
5	Discharge capacity (straight)	m^3/s	ASTM D4716	$>80 \times 10^{-6}$
	$i = 1$ at 200–300 kPa pressure			
6	Discharge capacity (buckled)	m^3/s	ASTM D4716	$>25 \times 10^{-6}$
	$i = 1$ at 250 kPa pressure			
B. For filter (sheath)				
1	Material		–	Woven
2	Elongation at break (MD × CD)	%	ASTM D4595	10 × 10
3	Trapezoidal tear strength	N	ASTM D4533	≥100
4	Tensile strength (grab)	kN	ASTM D4632	>0.5
5	Bursting strength	kPa	ASTM D3786	≥1,000
6	Puncture resistance/strength	N	ASTM D4833	400–500
7	Permittivity at 50 mm constant head	Sec^{-1}	ASTM D4491	>1
8	Apparent opening size (AOS)	μm	ASTM D4751	150–200
9	Mass per unit area	gsm	ASTM D5261	120–150

made by stitching in longitudinal direction, i.e., along the length of the drain. Indicative technical specifications of PVJD in common use may be seen in Table 10.1.

IIT Delhi also developed a variety of PVJD with a flattened "braided" sheath of jute wrapped around four coir strands (wicks) held by three continuous longitudinal stitches named "fiber drain." Braiding incidentally is a process of fabric formation in which threads cross the fabric diagonally from side to side and also pass over and under each other in such a way that no adjacent threads make complete turns about each other. Rao (2003) commented that swelling of the braided sheath could prevent clogging of PVJD. The discharge capacity of braided drains was however found to be lower than that of the conventional synthetic PVD. Fiber drain has not been tried in the field.

The width of conventional PVJD is usually 100 mm. Variations of PVJD to ensure quicker productivity are under development. Ludlow Jute Mill, Howrah, West Bengal, has manufactured several variants of PVJD which have been sent to the University of Wollongong, Australia, for tests.

The major difference in functioning between PVD and PVJD lies in the fact that PVJD has the ability to retain water effecting both immediate and sustained release. Dissipation of water is mostly through the wicks upward and partly along the sheath mostly in the radial direction. On the other hand, discharge propagation of PVD is direct through built-in U-shaped channels in its core. It is important to investigate time-related discharges of the two types and make a comparison. Indian Jute

Industries' Research Association (IJIRA) in a study has shown that capillary rise through PVJD wicks is of the order of 11.5 cm. This requires validation. PVJD also swells with absorption of water unlike its polymeric counterpart, though swell is not significant above 150 kPa. Clogging of the sheath of PVJD understandably may impede expulsion of subsoil water and retard the rate of consolidation.

Another factor is worth mentioning in this connection. Discharge capacity of PVJD is affected by confining pressure unlike PVD (Asha and Mandal 2012). Anyway, such behavioral features of PVJD do not adversely affect the discharge capacity of PVJD (Rao 2003). Degradation of PVJD vis-à-vis its discharge capacity is also a matter warranting an in-depth study.

Suitable spacing of band drains is the most critical part of design after ascertaining the geotechnical features of the subsoil and deciding on the depth of vertical drains. According to Kjellman's observation, effectiveness of a drain depends more on its circumference than on its cross section. He determined the equivalent drain diameter (d_e) and equivalent zone of influence (Z_e). It is worth mentioning here that band-shaped and circular drains possess the same radial drainage capacity.

A drainage blanket (usually of sand) should be laid to cover the PVJDs to facilitate discharge of water drawn from the subsoil through drains usually laid along the periphery of the construction area. If necessary, nonwoven JGT may be laid underneath the drainage blanket for more efficient drainage and quicker consolidation.

It is relevant to mention in this context that the aspect of functioning of PVJD after its degradation remains to be studied. The recent study on PVJD in progress under the control of Australian Research Council (ARC) through the University of Wollongong and other industry partners would throw light on this aspect. National Jute Board, Ministry of Textiles, Government of India, is a partner in this project (see the relevant paragraph on the study below for more details).

10.4 Installation of Vertical Drains

Installation is done by means of a rig fitted with a mandrel with a metal shoe at its tip that can grip the drain and keep it in position. At the tip of the mandrel is a detachable metal shoe. Its main purpose is to keep the drain at the desired depth, while the mandrel is withdrawn. Vertical drains are driven usually to a depth of 15–20 m usually depending on the depth of the water-soaked stratum of the soil. Water that comes out on surface is drained off by suitable measures such as through a basal blanket covering the "proud" portions of PVDs. (See Fig. 10.2.) It hardly takes 20 odd seconds to drive a vertical drain into soil up to a depth of 15–20 m usually.

As PVJD is thicker than PVD, the shoe has to be suitably adjusted/modified to ensure grip. The other aspect with PVJD that deserves attention is to ensure continuity of coir wicks after each roll so that vertical transmission of water is not hindered. The adjustment at site to do so needs extra time which, in turn, delays the installation to some extent.

Production of PVJD in a mill may get delayed due to manual longitudinal stitching of the sheath to "compartmentalize" the wicks. No systematic study has been done so far as to the effect on discharge of PVJD if the wicks are bundled together instead of compartmentalizing each wick.

10.5 Study on Performance of PVJD by the University of Wollongong, Australia

At the initiative of Prof. Buddhima Indraratna of the University of Wollongong, Australia (UoW), the National Jute Board (NJB) funded and partnered a comprehensive project on PVJD with primary emphasis on standardizing both the product and the installation technique for PVJD. NJB has sent to the University both conventional and several variations in construction of PVJD manufactured by two jute mills of standing for study. Already 40,000 m of PVJD have been installed at a site (Ballina) in New South Wales, Australia, with underlying marine clay. Installation has been completed under the supervision of the University (Fig. 10.4). Preliminary findings are encouraging which confirm that PVJD is as good as the man-made vertical drains. The aspect of degradability of PVJD compared to the long-term behavior of man-made PVD will also be studied. In fact this is a critical area that can affect the discharge capacity of PVJD after it gets degraded. Degradability of PVJD incidentally is a continuing process resulting from wear and tear of jute fiber, changes in elemental composition of jute fiber, and loss in strength and weight. A number of tests with sophisticated instruments are being carried out by UoW (Fig. 10.5).

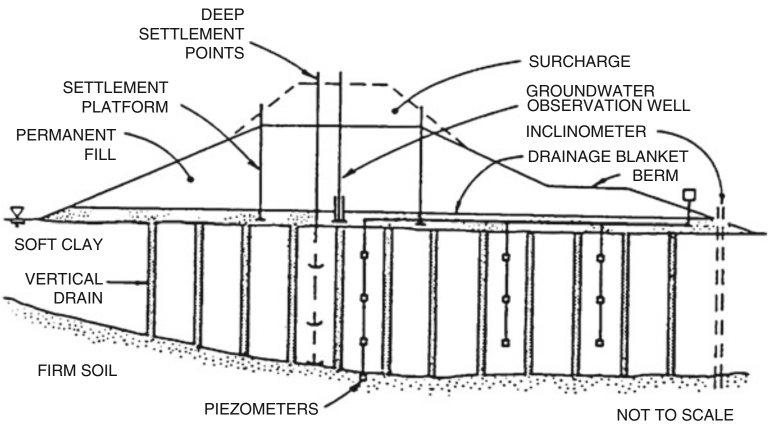

Fig. 10.4 PVJD installation set-up

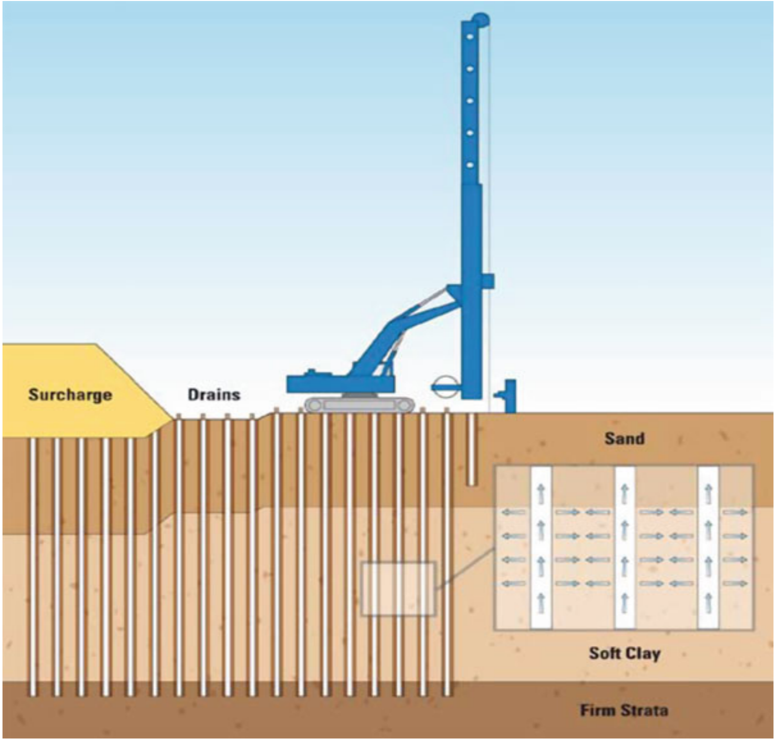

Fig. 10.5 Conceptual functioning of vertical drains (Courtesy: Balfour Beatty)

UoW is using a large scale consolidometer cell (diameter 650 mm) to evaluate the consolidation behavior of Ballina clay. UoW is planning to install an array of pore pressure transducers at various points along the radius of the drain to measure pore water pressure dissipation. The study aims at developing a numerical model for PVJD application.

This is a 3-year project which took off in July 2013 since extended by a year. Recently the project has been linked with Australian Research Council (ARC). The basic purpose of the proposed collaborative effort is to standardize the product and PVJD-specific installation technology; ascertain its effectiveness in consolidating soft soil, particularly marine soil; carry out corroborative laboratory simulation tests; and compare its effectiveness vis-à-vis man-made PVD. Pending the outcome of the joint research project on PVJD in Australia, specifications of PVJD indicated in Table 10.1 may be adopted for further in situ trials/experiments.

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Chapter 11
Jute Geotextile Standards, Properties, and Test Methods

Abstract Standardization of any engineering material is essential for ensuring its wide-scale use. Based on more than 260 field applications with Jute Geotextiles (JGT) in India in different areas, several Indian standards on JGT have come out. This is a step toward securing global accreditation of the product for different successful applications with JGT. For securing any standard, what is needed is replication of success in the field under a set of conditions and corroboration of findings in the laboratory with field results.

The chapter deals with all the relevant aspects of standardization of JGT including standards that have been published so far in India, tests methods followed in the laboratory—physical, hydraulic, mechanical, and endurance properties of JGT to be tested with passing reference to European and International Standards for man-made geotextiles.

Keywords ASTM test methods • Property parameters of JGT • Drapability test • Tensile strength test • Trapezoidal tear strength test • Puncture/bursting strength test • Dynamic penetration test • Interfacial friction test • Permittivity test • Transmissivity test • Gradient ratio and hydraulic conductivity ratio test

Proper testing of technical textiles for geotechnical uses is critical to ensure their effective performance. The standards evolved for this purpose relate to man-made geotextiles only. The standards are not uniform and vary from country to country, the reason being the design methodology is based on empirical exercise carried out individually in each country. Standard methods of testing have been evolved in the case of man-made geotextiles. In the absence of test standards for JGT, standards for testing man-made geotextiles—mostly ASTM test standards—are adopted for JGT also for the present. In view of the growing demand of JGT, it is felt necessary to have exclusive application-wise standards for JGT.

The selection of JGT for a particular application in geotechnical engineering areas basically depends on the texture and nature of soil and the type and extent and nature of imposed load. Two critical factors for the choice of JGT are the fabric tensile strength and its porometric features that can address the specific functional characteristics of end-use requirements. If these properties are found short of the

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specified value of a particular test for a particular application, distress/failure of the construction cannot obviously be ruled out. On the other hand, if the fabric properties more than meet the desired specifications, then the selection of the fabric demands optimization of its properties. As the physical features and mechanical properties of natural and man-made fibers distinctly differ, we need to decide specifications of JGT carefully keeping in view, among other technical aspects, the inherent lack of uniformity of features of jute fiber and its durability.

11.1 European Standards for Man-Made Geotextiles

Most of the countries of Western Europe (e.g., Belgium, France, Germany, Italy, the Netherlands, Switzerland, and the United Kingdom) have national standards on the construction, testing, and use of various types of geotextiles. The European Economic Community (EEC) has a number of European Committees for Standardization (CEN) for various disciplines and product groups. The committee for geotextiles and geotextile-related products is CEN/TC 189, of which the Belgian Institute for Standardization (Institut Belge de Normalization) acts as the secretariat. CEN/TC 189 has been functioning through five working groups (W.G.) that cover all areas in which standards need to be set. W.G.1 deals with general and specific requirements and performance criteria for geotextiles in various applications. W.G.2 deals with identification processes for geotextiles on-site, the sampling and preparation of test specimens, the determination of thickness at specified pressures, the determination of mass per unit area, and the vocabulary to be used in connection with geotextiles. It also deals with classification schemes for geotextiles based on characteristics determined from index tests.

The terms of reference of W.G.3 cover a large number of standards relating to determination of properties and performance tests for geotextiles. W.G.4 deals with the determination of properties of, and test procedures for, geotextiles and related products, such as geogrids and geonets. The terms of reference of W.G.5 relate to measurement of the aging of geotextiles in wet and dry air, resistance to chemicals and microbiological degradation, etc.

11.2 International Standards for Man-Made Geotextiles

There are reportedly as many as 293 different standards for the manufacture, testing, etc. of various types of geotextiles all over the world. The International Organization for Standardization (ISO) has been working on the harmonization of these standards for several years and has succeeded in reducing their numbers, in some instances, basically by identifying identical standards carrying different names.

Table 11.1 Standard test methods of ASTM adopted for JGT

Sl. no.	Test parameters	ASTM no.
1	Mass per unit area	D-5261-92 (1966)
2	Nominal thickness of JGT	D-5199-01
3	Tensile strength and elongation test, wide-width strip method	D-4595-86
4	Bursting strength test, hydraulic	D-3886
5	California bearing ratio (CBR) puncture resistance	D-6241
6	Index puncture resistance	D-4833 (96)
7	Trapezoid tear strength	D-4533
8	Pore size determination, dry (apparent opening size)	D-4751-99a
9	Water permeability and permittivity	D-4491
10	Soil vs. fabric friction test and soil retentivity test	D-5321
11	Abrasion resistance test and fatigue resistance test	D-4886 and D-6243
12	Rot resistance, soil-burial determination test, etc.	D-5819

Mention has not been made about the ASTM Standard on ultraviolet resistance as the short effective life of JGT, and its catalytic function are not significantly affected by its exposure in the open for ultraviolet exposure

Usually test methods on man-made geotextiles based on guidelines of ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM) which is a globally acknowledged Standards organization that develops and publishes consensual technical standards for a wide range of materials, products, systems, and services that are accepted globally. In the absence of international standards on JGT, ASTM testing guidelines and protocol are followed.

In the United States, the ASTM has a Standard Committee specially constituted for geosynthetics (D-35) testing methodology, which is useful and convenient as well as accepted globally for different geotextile applications. As the standard testing methods of man-made geotextiles are not uniform, ASTM standard testing methods for testing of different types of man-made geotextiles as well as JGT in most of the cases are being followed for the sake of uniformity. In India, BIS standards are followed where such standards exist for testing of JGT.

ASTM standards for testing relevant property parameters related to geotextiles may be seen in the table below. These guidelines are adopted for JGT in the absence of specific test protocol for the natural product (see Table 11.1).

11.3 Published Indian Standards

Several standards and normative references are available on JGT. As many as 260 field applications have been carried out in India so far with reported success. The references are stated below.

(i) Publications of the **Bureau of Indian Standards** (**BIS**)

- Guidelines for application of Jute Geotextiles for rainwater erosion control in road and railway embankment and hillslopes (**IS 14986**:**2001**)
- Jute Geotextiles: Strengthening of sub-grade in roads—Specifications (**IS 14715**: **part I**: **2016-2nd revision**)
- Jute Geotextiles: Control of bank erosion in rivers and waterways—Specifications (**IS 14715**: **part II**: **2016-2nd revision**)

(ii) The document prepared by CRRI with inputs from the National Jute Board on "*State-of-the-art Report on Use of Jute Geotextiles in Road Construction & Prevention of Soil Erosion & Landslides*" has been published by the Indian Roads Congress (IRC)—**Special Report 21**.

(iii) The Union Ministry of Railways has published *Guidelines for application of JUTE GEO-TEXTILE in railway embankment and hill slope* (No RDSO/2007/GE:G-0008 of February 2007).

National Jute Board (NJB), Ministry of Textiles, Government of India, has published a manual on JGT (under revision). An anthology of authentic research papers on JGT has also been published by NJB (Sept, 2011).

11.4 Property Parameters of JGT and Tests

Standards are prepared on the basis of performance of particular types of JGT for specific applications for which close monitoring of works and reliable test results are essential. The contents hereunder give an insight into various properties of JGT and test methods in common use in accordance with ASTM standards. This section is subdivided into four categories:

- Physical properties
- Mechanical properties
- Hydraulic properties
- Endurance properties

11.5 Testing of Physical Properties

The important physical properties are: mass per unit area, thickness, porometry/AOS, width and length, and drapability. Procedures adopted for assessment of the parameters are briefly indicated below.

11.5.1 Mass Per Unit Area

This parameter is measured in a calibrated balance with an accuracy of 0.01 g. The specimen should be placed without stretching. The test for this property shall be as per ASTM D5261-1996 or IS 14716-1990. Measurable values usually from 250 to 1500 gsm (g/m^2) for different types of JGT.

Mass per unit area is calculated by weighing small square or circular specimens of JGT of known dimension. The minimum number of test specimens is five and should be of identical dimension (minimum 10,000 mm^2).

11.5.2 Thickness

Thickness of JGT is measured between the upper and lower surfaces of JGT at specified pressure. ASTM D5199–1999 stipulates that the thickness is to be measured to an accuracy of at least 0.02 mm under a pressure of 2 kPa. Thickness of JGT ranges from 0.25 to 10 mm. There is also an Indian Standard for the test (IS 13162: Part 3:1992).

11.5.3 Porometry/Apparent Opening Size

The apparent opening size (AOS) or the equivalent opening size (EOS) is a measure of the largest effective opening in JGT. It is a property which indicates the diameter of the approximate largest particle that would effectively pass through a geotextile. It is a critical property influencing retention and filtration function of JGT.

Open weave JGT is like nets with varying opening (pore) size as per end-use requirement. Woven JGT presents a texture with fine apertures ranging usually between 200 μm (μ) and above. The test for this property is conducted as per ASTM D 4751-1999/IS 14294-1995 (when measured by dry sieve test). The test method comprises shaking glass beads of different sizes ranging from 0.075 to 1.70 mm separately on a JGT specimen in a sieve frame. As per ASTM, O_{95} is considered as the AOS ensuring retention of 95 % of the chosen bead size after sieving. For each size of beads tested with each JGT specimen, the nearest percentage of passing may be calculated from the following relation

$$B = 100P/T$$

where B is the number of beads passing through the specimen in %, P represents the mass of glass beads in the pan in grams, and T is the total mass of glass beads used.

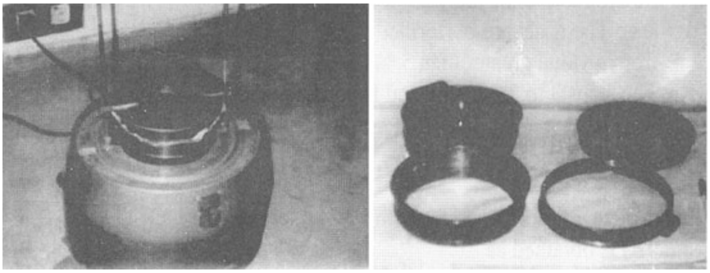


Fig. 11.1 AOS-measuring apparatus with frames to hold JGT

The test needs a mechanical sieve-shaker, sieves of different pore sizes, a pan, a cover, a measuring balance, and, of course, spherical glass beads of different sizes (Fig. 11.1).

There is also a wet test method for determining opening size of JGT (ISO 12956-1999). This is important as JGT swells when in contact with water unlike its man-made counterpart. The specimen is kept saturated in water for 12 h to ascertain the extent of swelling.

11.5.4 Width and Length

The standard width available is from 1 to 2 m. Some jute mills manufacture wider JGT up to about 5 m. The roll length may be in the range of 100–200 m.

11.5.5 Drapability

JGT can shape itself to soil contours ensuring full contact with soil. The extent of drapability is assessed by measuring the sag (Δ) in mm of JGT in between two points (S) in mm, and a graph is drawn with values so obtained. It is a measure of JGT, i.e., bending of JGT under its own weight between two points (test method ASTM D 1388) (Fig. 11.2).

N.B. Drapability of jute is more when wet, and JGT possesses a better drapability than man-made and Coir Geotextiles.

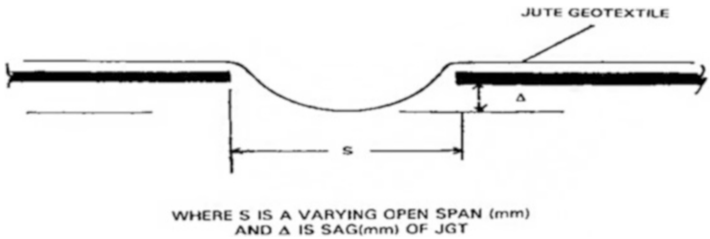


Fig. 11.2 Drapability test for JGT

11.6 Testing of Mechanical Properties

The properties to be discussed here indicate JGT's resistance to mechanical stresses developed due to applied loads and installation conditions. The parameters that require to be tested are: tensile strength, tear strength, puncture strength, burst strength, and interfacial friction. The test methods adopted usually are indicated below.

11.6.1 Tensile Strength

The most important property of a geotextile is its tensile strength (grab strength). The JGT specimen is stretched till its failure. While extending the sample, both load and deformation are to be noted. Usually wide-width tensile tests are done in a tensile-testing machine (CRE type) with an interfaced computer to determine the fabric tensile strength following ASTM D 4595-1994/IS 13162 (Part 5)-1992, measured in kN/m (Fig. 11.3).

A JGT specimen of sufficient width is gripped under the clamps of the instrument at the prescribed rate of extension ($10 \pm 3\,\%$ per min) and is subjected to a longitudinal force till it breaks. Tensile strength, elongation, and initial and secant modulus can be read from the interfaced computer.

Another test known as narrow strip test is also performed as per ASTM D 5035-2006 for the same purpose. Wide-width tensile test is however preferred.

11.6.2 Trapezoidal Tear Strength

During installation, JGT is often subjected to tearing stresses. Resistance of JGT to such stresses is determined by a test—trapezoidal tear strength test—which is carried out as per ASTM D 4533-1996/IS 14293-1995 measured in kN.

In this test, JGT is inserted into a tensile-testing machine with an initial 15 mm cut. The load stretches the individual fabric gripped in the clamp before it tears.

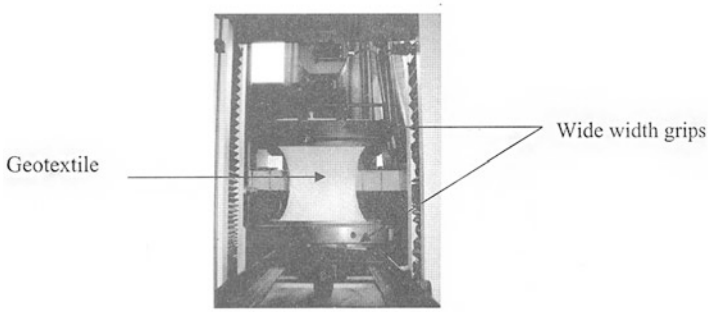
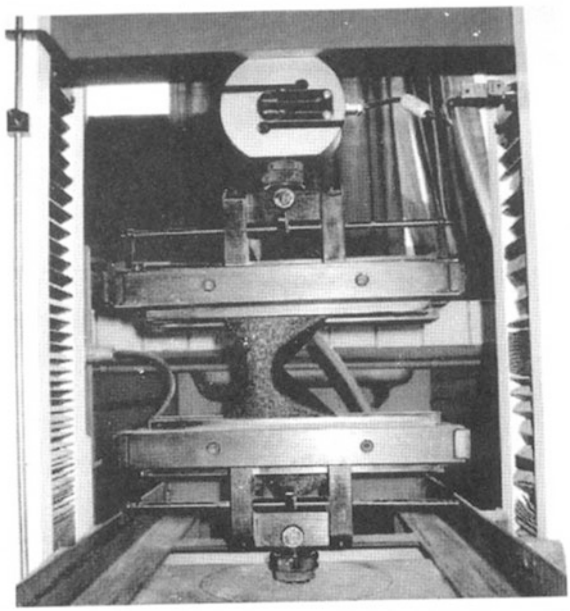


Fig. 11.3 Wide-width tensile strength measuring apparatus

Fig. 11.4 Trapezoidal tear strength instrument



Force-extension curve is shown in the interfacing computer. A typical view of the instrument may be seen in Fig. 11.4.

11.6.3 *Puncture Strength*

The test specimen is held with clamps in un-taut condition between circular plates of a ring clamp attachment of a tensile-testing machine. A solid steel rod attached to the load indicator is forced through the unsupported portion of the specimen till its

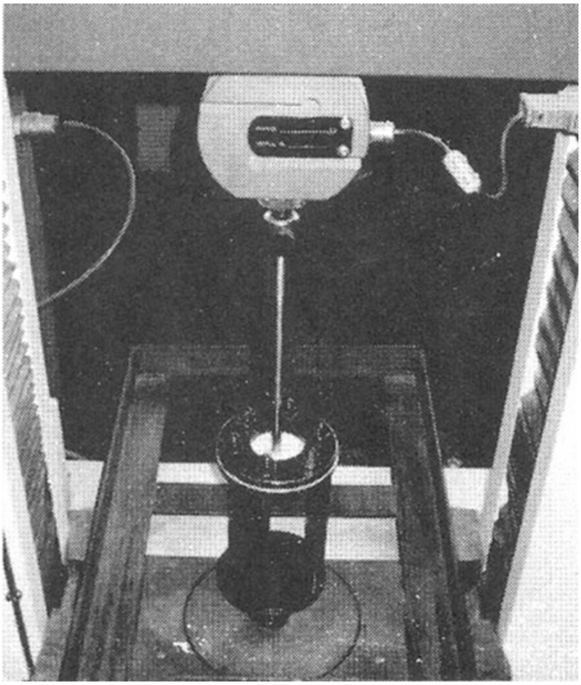


Fig. 11.5 Apparatus for measuring puncture resistance with rod

rupture (Fig. 11.5). The maximum force exerted is the measure of the puncture resistance of the JGT specimen as displayed in the interfaced computer.

The test is conducted as per ASTM D 4833-2000 Resistance to puncture is measured in N or kN. There is an alternative method (static puncture test) using 50 mm probe carried out as per ASTM D 6241-19999. Dynamic penetration test is also conducted for the same purpose by dropping a steel cone from a specified height following IS 13162 (Part 4)-1992.

11.6.4 Mullen Burst Strength

It is a measure of JGT resistance to rupture from load and the test is described in ASTM D 3786. JGT is given a shape of hemisphere by inflating a rubber diaphragm (membrane) properly clamped. Bursting of JGT sample occurs when no further deformation is possible and reported as kilo Pascal (kPa). This is an index test and is widely used for quality control. The phenomenon is depicted in Fig. 11.6.

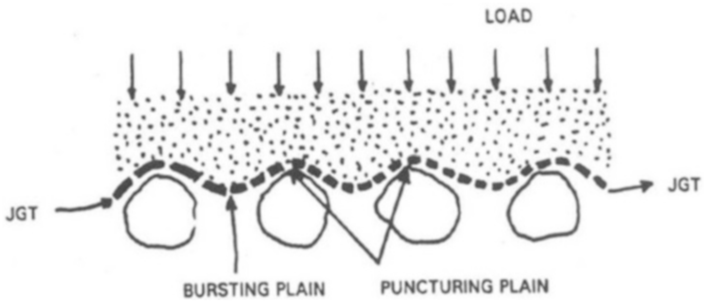


Fig. 11.6 Puncturing and bursting of JGT

11.6.5 Interfacial Frictional Resistance

This property is evaluated for JGT-soil friction (shear resistance) and can be determined either by direct shear test or by pullout test.

In direct shear test, the JGT sample is placed between two parts of shear box with its lower half fixed and JGT clamped over a dummy at the plane of shear. The upper half filled with soil placed over JGT is moved horizontally relative to the lower half at constant rate of displacement (Fig. 11.7). Thereafter, a test similar to conventional direct shear test in a direct shear box apparatus can be conducted at different (at least 3) normal stresses. The maximum shear stresses are then plotted against the applied compressive stresses. From the best-fit line “c” and “φ” are determined. The slope of the line is the coefficient of interfacial friction. ASTM D5321-2002 states the guidelines for the test.

In the pullout test, JGT sample sandwiched between two halves of the box fitted with soil is pulled by the jaws at a constant rate of displacement. The force required to pull out the JGT is obtained. By determining the pullout stresses at different normal stresses, the angle of interface friction can be obtained.

N.B. It may be noted that the determination of values of different tests indicated above mainly depends on strict compliance of testing procedures like the method of gripping the sample, slippage of sample, rate of deformation, sample size, etc.

The stress-strain curve of JGT sample indicates the following:

- Maximum tensile stress (ultimate strength)
- Strain at failure (elongation at break)
- Modulus of deformation (slope of initial portion of stress-strain curve)
- Toughness (area under stress-strain curve)

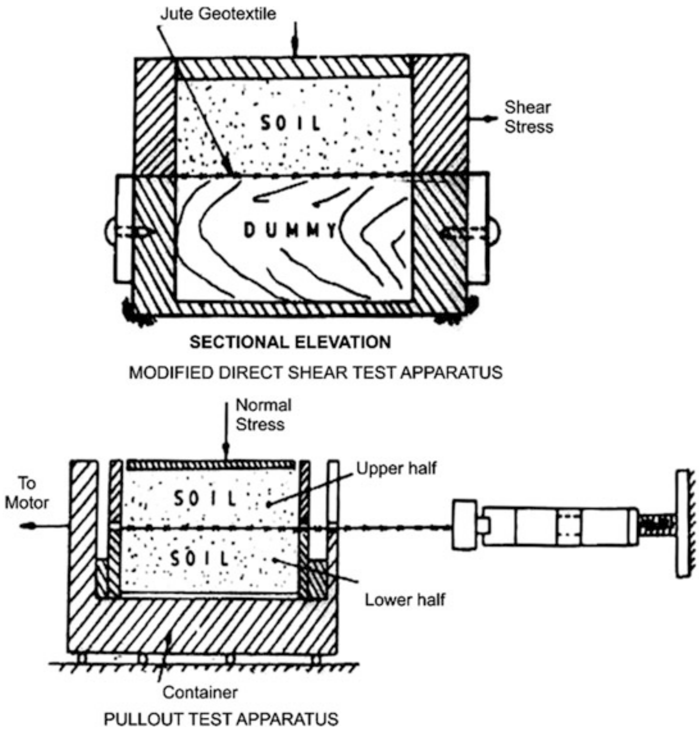


Fig. 11.7 Interfacial frictional resistance test

11.7 Testing of Hydraulic Properties

The purpose of JGT for filtration requirement is to permit the free flow of water while retaining soil particles. JGT helps develop “filter cake” zone in soil which is in fact the “soil filter” zone, and the two together control the ultimate flow capacity of the system. Properties of both soil and JGT influence the hydraulic characteristics of the system. Assessment of permittivity and transmissivity is extremely important for filtration function of JGT. Determination of clogging potential is also important in the sense that the result of this test (hydraulic conductivity ratio test or gradient ratio test) can predict the vulnerability of the candidate JGT to clogging. JGT with clogging potential may require larger AOS than initially designed. This is essentially a matter of experience. Anyway, indicated below are the test procedures of the three parameters in brief.

11.7.1 Permittivity of JGT (Ψ)

Permittivity (Ψ) is a measure of hydraulic conductivity of JGT *across* its plane in relation to fabric thickness. It is a characteristic that defines JGT flow capacity. Its unit is /second or s^{-1}.

Permittivity of JGT can be measured either under a constant head or a falling head of a column of water. Under constant head ASTM recommends the following relation for determining permittivity of a JGT sample.

$$\Psi = Q\,R_T/h\,A\,t$$

where Ψ is permittivity in s^{-1}

R_T—temperature correction factor
h—head of water in mm
A—cross-sectional area of test specimen in mm^2
Q—quantity of flow in mm^3
t—time in sec for flow

The temperature correction factor ranges from 0.90 for 25 °C of water to 1.30 for 10 °C of water temperature as per ISO 12958-1999. R_T (as ordinate) versus test water temperature curve may be constructed with these two limits by making a grid of R_T and temperature with 0.02 and 1° difference, respectively. It is almost a straight line.

In the falling head method, a head difference has to be maintained by adjusting the flow keeping a difference of 50 ± 1 mm. The test ends when the head loss and the flow reach zero.

Usually the constant head method is adopted when the flow rate of water through JGT is so high that it becomes difficult to keep track of the readings of the head change versus time in the falling head test. It may be borne in mind that the flow capacity of JGT should be such as to ensure higher hydraulic conductivity than that of the soil.

There are however reservations about precision in results. Even carefully conducted soil permeability tests could vary widely. Anyway the results of this test give an overall idea of the hydraulic conductivity of soil and permittivity of JGT.

The cross section of a typical permittivity-measuring apparatus is shown in Fig. 11.8.

11.7.2 Transmissivity of JGT (θ)

It is a property of JGT to transmit flow *along* its plane and is a function of its thickness and fabric construction. It measures volume of flow per unit width of specimen per unit gradient. This test requires a special instrument having facility to

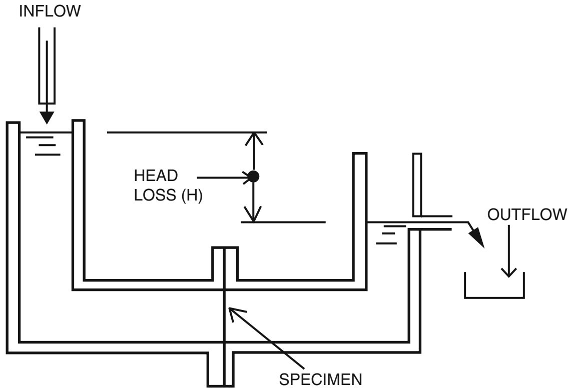
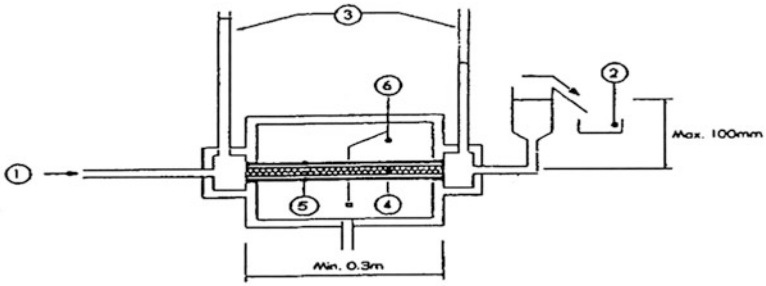


Fig. 11.8 Cross section of a typical permittivity-measuring apparatus



1 water supply	2 water collection
3 manometer	4 specimen
5 membrane	6 pressure cell
7 foam	8 load
9 loading platen	10 overflow weirs at hydraulic gradients 0,1 and 1,0

Fig. 11.9 Cross section of a typical transmissivity measuring apparatus

maintain constant head loss at different water levels under a constant normal compressive test.

Transmissivity of JGT may be ascertained by following the relation below.

$$\theta = R_T Q_t L / WH$$

where θ is transmissivity

R_T—temperature correction factor
Q_t—quantity of water discharged in unit time in m^3/s
L—length of JGT specimen under normal compressive stress in m
W—width of specimen in m
H—difference of head across the specimen in m

Transmissivity measuring instrument may have to be customized for precision. Cross section of a typical transmissivity measuring apparatus is shown in Fig. 11.9.

11.7.3 Clogging Potential of JGT

The test methods ensure long-term flow compatibility between soil and JGT. Clogging potential of JGT is low when flow rate decreases with time and then attains a stable value over time, whereas clogging potential is high when flow rate continues to decrease with time and does not stabilize. The test methods to evaluate clogging potential of JGT are:

- Gradient ratio test (ASTM D 5101)
- Hydraulic conductivity ratio (HCR) test (ASTM D 5567)

Gradient ratio test evaluates permeability and clogging potential of soil-JGT system without considering the influence of compaction and confinement. In this method water is allowed to flow through soil placed over JGT in a vertical column and then hydraulic gradient is measured at two locations above JGT. If the ratio of flow exceeds the acceptable standard limit, then it indicates clogging potential of JGT is high.

Hydraulic conductivity ratio (HCR) test method is intended to evaluate the performance of specific on-site soils and geotextiles at the design stage of a project and to provide qualitative data that may help identify causes of failure (i.e., clogging, particle loss).

There are several endurance tests such as assessment of damages during installation, determination of creep (elongation of JGT under a constant load), resistance to chemicals, temperature, UV radiation, thermo-oxidation, etc. There are ASTM standards for all the endurance tests as indicated. However in the case of JGT, endurance tests are not considered important in view of its comparatively short durability during which endurance tests are not usually called for. It is reiterated that all geotextiles—natural and man-made—act as change agent to the soil to be improved, and therefore long-term durability of geotextiles according to our field experience is not required in majority of cases. Endurance properties of jute depend largely on the selected jute batch. There being no defined standard methods of testing endurance properties of JGT, we have not included the topic in this book.

Acknowledgment *NABL-accredited Geotextile Laboratory of the Department of Jute and Fiber Technology, the University of Calcutta*

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Chapter 12
Environmental Aspects

Abstract Environmental concordance of Jute Geotextiles (JGT) is a major advantage over other geotextiles. Eco-compatibility of jute, and for that matter of JGT, has been substantiated by studies undertaken so far including its life cycle analysis (LCA) from cradle-to-grave carried out by Pricewaterhouse Coopers Ltd. The chapter presents the findings of the studies in a nut shell. A reference has also been made to erosion control benefit matrix (ECBM) introduced by Harding. A comparison of environmental effects between jute and polypropylene has been also been presented in a tabular form in the chapter.

Keywords Carbon sequestration • Life cycle analysis (LCA) • Life cycle inventory analysis (LCIA) • Greenhouse effects • Eutrophication • Erosion control benefit matrix (ECBM) • Carbon footprint • CO_2 emission

Jute and allied fibers are fully organic, eco-friendly, soil-friendly, biodegradable, and annually renewable in nature as well as cost competitive as compared to synthetic fibers and some other bast and leaf fibers for producing cost-effective geotextiles.

12.1 Life Cycle of Jute

Processes which jute undergoes in the various stages of its life and its effects on environment are broadly shown in the diagram (Fig. 12.1).

12.2 Environmental Assessment

The following points are relevant in the context of eco-concordance and socioeconomic value of jute:

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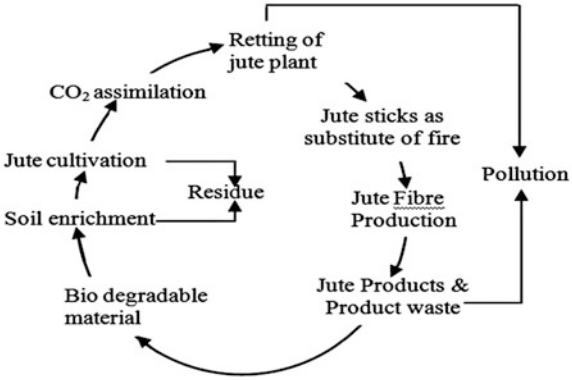
Fig. 12.1 Life cycle processes of jute



(a) *Jute plant purifies air*
During the 100 days of jute growing period, 1 ha of jute plant can absorb about 15 MT of CO_2 from the atmosphere and liberate about 11 MT of O_2, the life-supporting agent. Studies reveal that CO_2 assimilation rate of jute is several times higher than that of trees (Inagaki 2000; IJSG 2003). In fact jute helps in carbon sequestration.

(b) *Jute cultivation*
Environmental impacts of jute production are much less harmful as compared to synthetic fibers. Jute cropping system enhances soil organic matter through shedding of its leaf thus improves nutrient availability in the soil. Jute cultivation facilitates *multiple cropping pattern* enabling farmers to increase their field outputs.

(c) *Agricultural practices*
Quantities of fertilizers and pesticides/fungicides necessary for jute cultivation are far less than those required for cotton cultivation. The leaves of jute left out after harvesting are rich in nitrogen (N), phosphorous (P), and potassium (K), and therefore fertilizers are not required for jute cultivation.

(d) *Jute retting and wastes*
Jute fibers are extracted from jute plants by retting. Water in retting tanks does not affect natural drainage nor does it pollute groundwater usually. Retted water can be used for irrigation for watering crop fields.

Jute stick is the major by-product after extraction of jute fibers. The main use of jute sticks is as fuel in jute-growing countries. About 80 % of sticks are used as firewood for household cooking. The yield of jute sticks is 2.5 times the fibers by weight. Jute sticks annually save 5.06 million tons of forest wood (in India and Bangladesh) and help in preserving ecological balance.

(e) *Disposal*
JGT pose no environmental threat. Being biodegradable, JGT ultimately coalesces with soil on which it is laid, adding nutrients to it and retaining water for quicker growth of vegetation. JGT poses no disposal hazards.

12.3 Eco-compatibility of JGT

A study related to life cycle assessment (LCA) of jute was conducted by Pricewaterhouse Coopers Ltd. (PwC) in an assignment awarded to the firm by the National Jute Board (erstwhile Jute Manufactures Development Council) in 2006 for developing an eco-label protocol for jute. Before indicating the findings of the study, it is relevant to mention the following:

1. Jute is an annually renewable agricultural resource.
2. Jute cultivation facilitates multiple cropping pattern and precedes paddy and pulse cultivation in that sequence.
3. Leaves of jute plants act as green manure and enrich soil fertility.

The LCA referred to aim at identifying the extent of environmental impacts associated with cultivation of jute, manufacture of jute products including JGT, and their use from the stage of extraction of raw materials till their final disposal ("cradle-to-grave" approach). The entire life cycle of jute was divided into three phases, viz., phase I, cultivation, production of fiber, and transportation from the farm to mill ("cradle-to-gate" phase); phase II, processing of fiber and manufacture of finished jute products ("gate-to-gate" phase); and phase III, transportation of finished jute products from the mill to consumer, use, and disposal ("gate-to-grave" phase).

The LCA study by PwC was preceded by life cycle inventory analysis (LCIA) which is an account of all mass and energy inputs and outputs to the life cycle systems. It presents a detailed outline of the production system, system boundaries, data collection, data allocation, and preparation of an inventory table. PwC used a software titled "Tools for Environmental Analysis and Management" (TEAM TM 4.0) procured from Ecobilan, France. The software is claimed to possess a high degree of flexibility and modularity and high potential of evolution and is reportedly one of the best in the market.

For phase I, i.e., the cradle-to-gate phase which is essentially the agricultural phase, a secondary data from national and international sources for Indian jute were used. This phase has two distinct divisions, viz., cultivation and retting (the process of softening by soaking the plant with mildly flowing water to facilitate fiber extraction). Emissions to the soil due to pesticide activity were assumed to have no environmental significance as the chemicals are supposed to end up as run-off in the extreme case. The half-life of the product is incidentally 4.8 days.

For phase II, i.e., the gate-to-gate phase which is essentially the manufacturing phase, data were collected from different jute mills and units engaged in treatment of the manufactured fabric. PwC also used inputs from DREAM database regarding road transportation of jute products including JGT. Values recommended by the Intergovernmental Panel on Climate Change on emission for ship transportation of jute goods were used. In this phase it was assumed that the electricity would be sourced from a grid with 80 % thermal component and that the power contribution from DG sets during power failure would be negligible.

12.4 Findings of the Study by PwC

Life cycle analysis of jute products (version 3, May 2006) made by PwC has focused the following:

(a) The most significant impact on the jute life cycle is carbon sequestration by green jute plants in the agricultural stage. Approximately 4.88 t of CO_2 get sequestered per ton of raw jute fiber production. Jute plantation acts as a sink for carbon.
(b) The CO_2 emission from jute is carbon neutral in nature since the product is from the plant source and can be considered as a biomass (ref: www.greenfloors.com/HP/Linoleum.index.htm).

GHG emissions from jute are *negative* on the account of large carbon sequestration in phase I. All man-made geotextile substitutes exhibit positive GHG emissions. Air acidification of jute and JGT is also far lower when compared to other man-made alternatives.

The LCA referred to aimed at identifying the extent of environmental impact in three distinct phases in the life cycle of jute viz. cultivation phase, processing & manufacturing phase and transportation and installation phase ('cradle-to-grave' approach).

The LCA study by PwC was preceded by Life Cycle Inventory analysis (LCIA) which is an account of all mass and energy inputs and outputs to the life cycle systems. It presents a detailed outline of the production system, system boundaries, data collection, data allocation and preparation of an inventory table. PwC used a software titled 'Tools for Environmental Analysis and Management' (TEAM TM 4.0) procured from Ecobilan, France. The software is claimed to possess a high degree of flexibility, modularity and high potential of evolution and is reportedly one of the best in the market.

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For Phase II i.e. the gate-to-gate phase which is essentially the manufacturing phase, data were collected from different jute mills and units engaged in treatment of the manufactured fabric. PwC also used inputs from DREAM data-base regarding road transportation of jute products including JGT. Values recommended by Intergovernmental Panel on Climate Change on emission for ship transportation of jute goods were used. In this phase it was assumed that the electricity would be sourced from a grid with 80 % thermal component and that the power contribution from DG sets during power failure would be negligible.

PwC in its report also quantified the effects of greenhouse, eutrophication, and air acidification. The findings are summarized in Table 12.1.

The Environmental Protection Encouragement Agency (EPEA), Hamburg, in association with the FAO secretariat, made a comparative study of jute and polypropylene in respect to waste generation, energy consumption, and CO_2 emission in 1992. Table 12.2 reveals.

Boyce (1995) has reported that the environmental impact of jute is modest, whereas PP generates numerous air pollutants, toxins, and CO_2. He laments that environmental cost is being ignored as a result of which "green" (jute) has been replaced by brown (PP). The total estimated quantum of GHG emission for PP is 127 kg per ton of PP. The US Biomass R&D Technical Advisory Committee and the US Department of Agriculture have targeted that 25 % of the US chemical production be bio-based by 2030. The decision will necessitate invention of new polymerization chemistry and increased the use of renewable resources.

There are other environmental advantages as well. Jute and allied natural fibers are fully organic, eco-friendly, soil-friendly, biodegradable, and annually renewable in nature as well as cost competitive as compared to synthetic fiber and some other bast and leaf fibers for producing cost-effective geotextiles.

The following points are relevant in the context of eco-concordance of jute:

(a) During the 100 days of jute growing period, 1 ha of jute plant can absorb about 15 MT of CO_2 from atmosphere and liberate about 11 MT of O_2. Studies reveal that CO_2 assimilation rate of jute is several times higher than that of trees (Inagaki 2000; IJSG 2003).
(b) The main use of jute sticks (a retting output) is as fuel apart from other household uses. The yield of jute sticks is 2.5 times the fiber by weight. Taking the overall production of raw jute/mesta fiber at 2.7 million tons (in India and Bangladesh), the total output of jute sticks comes to 6.75 million tons. Considering the other household use at 25 % level, jute sticks annually save 5.06 million tons of forest wood and bamboo in these two countries and help in preserving ecological balance.
(c) Leaves which are left in the field are good manures and increase the fertility of land.
(d) Jute cultivation creates a large direct employment to the farmers and industrial workers and indirect employment to workers associated with ancillary industries.

Harding (1994) proposed an erosion control benefit matrix (ECBM) to determine the best management practice in erosion control. He considered six basic parameters, viz., effectiveness, acceptability, cost competitiveness, installation ease, vegetation establishment, and maintenance. He also included several sub-parameters under each of the aforesaid parameters. JGT according to the ECBM as proposed stands out against all other geotextiles.

Eco-concordance and technical suitability of JGT make it a material not only best suited for surficial soil erosion control in hill slopes and slopes of earthen embankments but also it has environmental benefits in other types of constructions

Table 12.1 Analysis of environmental effects of JGT (After PwC)

Sl. no.	Impact	Specification	Unit	Value			
				Cultivation phase	Woven JGT	Nonwoven JGT	Soil saver (open weave)
1	IPCC greenhouse effect (direct 100 years)	CO_2, CO_2 equivalent CH_4	g. eq. CO_2	−4502370	120.72	612.14	14.823
2	CML eutrophication	Phosphate (PO_4 3−, HPO_4−, H_3PO_4, AS P) (W)	g. eq. PO_4	NA	NA	NA	NA
3	CML air acidification	Sulfur dioxide and nitrogen oxides (as SO_2 and NO_2)	g. eq. H +	NA	NA	NA	0.00013

Table 12.2 Comparison of environmental effects of jute and PP fiber (per ton basis)

Parameter	Jute	Polypropylene	Ratio (PP/jute)
Waste (MT/MT)	0.9	5.5	6.1
Water (m^3)	54–81	1.3	0.016–0.02
Energy (GJ/t)	5.4–14.35	84.3	5.9–15.6
CO_2 emission ()	1.2–0	3.7–7.5	–

built on soil as well. In road applications reinforcing effects of JGT enable construction of roads with lesser thickness that is necessary for conventional construction. Reduced thickness of pavements will help diminish the consumption of fossil fuel and natural resources used in road construction and curb the carbon footprint as a result. In riverbank erosion control, the use of JGT enables elimination of the granular filter conventionally used. If sustainable vegetation with deep roots can be grown on the bank as cover over JGT, then the need for mining of boulders may be at least partly eliminated. This aspect has been covered in a separate chapter. What is needed is quantification of reduction of carbon footprint by modeling and data collection and compilation. A separate study on this aspect is warranted to quantify the exact environmental benefits accruing out of use of JGT.

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Chapter 13
Potentially Important Jute Geotextiles

Abstract Jute like all other natural fibers lacks uniformity in texture and properties. Jute Geotextiles (JGT) thus vary in quality calling for identification of the precise fabric types for different applications. As there could be a range of JGT for a particular application, it is necessary to zero in on potentially important JGT for each application type for facilitating large-scale use. This will result in ease of manufacture and economization of cost of the fabric.

The chapter contains logical exposition of the optimization exercise in identifying the potentially important JGT out of several for specific application. It also contains comparison of properties of JGT and its man-made counterpart in a tabular form.

Keywords D/W plain weave • Open weave • Woven and nonwoven JGT • Tolerance limit • Average weighted ranking procedure • Hairiness of jute • Standard deviation • Population size • Stochastic variable

It has already been indicated that unlike man-made fibers, jute fiber has limitations in regard to uniformity. Varying patterns of fiber arrangement, nonuniform drafting, and other extraneous factors contribute to the lack of uniformity of jute yarns. Hairiness of jute fiber influences permittivity of JGT as also its swelling when wet. Inherent features of jute as well as application-specific technical requirements should therefore be taken into account for precise fabric design. Design of JGT is thus apt to be different from its synthetic (man-made) counterpart.

In the initial stages of application of JGT for sub-grade strengthening and erosion control of riverbanks, usually 760 gsm D/W twill woven JGT was put to use. Coating woven JGT with industrial bitumen was the usual practice earlier for riverbank erosion control to ensure water repellance as persistent contact with water hastens the degradation of jute. On top of this, hot bitumen-coating affects porometry of the fabric and hence its permittivity. Bitumen coating makes the fabric rigid with reduced drapability. Recently eco-friendly additives have been developed (notably by IIT, Kharagpur, Indian Jute Industries' Research Association) which are supposed to be free from limitations posed by industrial bitumen as well as eco-friendly. The newly developed additives have been put to field tests. Jute loses its durability due mainly to moisture content and bacterial and fungal attacks. Organic content in soil and temperature (especially in the range of

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30–37 °C) has also a role. The performance results are awaited. It has been observed that sandy ambience ensures longer durability of JGT.

Besides ensuring retention of essential features of JGT during its operative period, the other important aspect is to optimize JGT fabric design. Optimization implies designing JGT by minimizing fabric weight (i.e., gsm) without compromising with the critical parameters, especially tensile strength and porometric features. The cost of JGT can be decreased as a result. It is for this reason woven JGT to be used for sub-grade strengthening, and control of riverbank erosion have been recently optimized with D/W plain weave (instead of D/W twill) JGT of lower critical weight. Since the critical functions of JGT in the majority of its application are separation, filtration, drainage, and initial reinforcement, the fabric designer needs to consider these functions vis-à-vis fabric properties appropriate for performing the related functions in a particular application.

It should be appreciated that a wide range of any variety of JGT could pose problems in choice for both manufacturers and end-users. For commercial uptake it is advisable to restrict varieties of JGT to the minimum so that a specific type of woven JGT can cater to a wide range of applications or, at least, meet most of the technical requirements for a particular application. We may name such JGT as "potentially important."

As already indicated two important parameters which any geotextile should conform to for a particular application are (a) tensile strength and (b) porometry. It is concurrently important to know the conditions of the particular site where JGT is proposed to be laid. Tensile strength of JGT should have cushion to cater to the maximum expected stress JGT could be subjected to. It has been found that in the majority of roads, fabric tensile strength of 25 kN/m is supposed to serve the purpose. In the case of riverbank application, the fabric tensile strength of 20 kN/m is considered adequate.

Pore size of fabric will however vary as average grain size distribution of soil is seldom similar. The manufacturer has to take the trouble of producing woven JGT of the appropriate porometry. It needs mention that many of the European specifications do not mention pore size and permittivity in the design of synthetic geotextiles used in roads mainly as separators. But it is felt that the function of filtration is also important in strengthening of sub-grades. It is important to ascertain the design pore size of JGT for effective concurrent functioning of separation and filtration in a particular construction for a specific application keeping in view the fabric swelling and hairiness factors. A section of researchers is of the view that the prevailing porometric considerations for man-made geotextiles are conservative especially for filtration functions and should be relaxed (Ogink 1975; Heerten 1982; Knaap et al. 1986). They argue that total retention of soil particles is neither feasible nor desirable. According to Ogink, the resistance to migration of soil particles depends on (i) uniformity of fabric porometry, (ii) total open area in the fabric per unit area, and (iii) thickness and structure of the fabric. He suggests that O_{98} should be the maximum aperture of woven SGT. O_{98} of a geotextile, according to him, is a stochastic variable assuming different values with varying probabilities.

The determination of tolerance limit of JGT is also critical. The exercise requires comparison of machine and process parameters by the method of average weighted ranking procedure. The Department of Jute and Fibre Technology, Calcutta University, has undertaken rigorous exercises in this area and come up with recommendations. Standard error vis-à-vis population size have been considered to determine the standard deviation for ascertaining the allowable tolerance limits on the basis of ten samples of woven JGT collected from different jute mills in respect of “gsm” value (weight of JGT), bursting strength, and apparent opening size (AOS) of the samples.

Incidentally, there are reportedly around 293 different standards for the manufacture, testing, etc. of various types of geotextiles—natural and man-made—all over the world. The International Organization for Standardization (ISO) has been working on the harmonization of these standards for several years and has succeeded in reducing their numbers. Most of the countries of Western Europe (e.g., Belgium, France, Germany, Italy, the Netherlands, Switzerland, and the United Kingdom) have their own national standards on the construction, testing, and use of various types of synthetic geotextiles.

Filtration function may get modified due to hygroscopic nature of jute. Pore water pressure dissipation may be influenced due to absorption of water by JGT causing swelling of jute strands. The extent of swelling of JGT under different water contents deserves consideration. JGT is often flattened by a process known as calendaring which understandably reduces the pore sizes of the fabric.

An all-purpose JGT for a particular application is understandably based on the performance of such fabric under varying conditions of soil and loading. In the initial phase of the use of JGT, the fabric design was based on an overall theoretical knowledge of functional mechanism, practical experience, and specification adopted for its man-made counterpart. The Common Fund for Commodities (CFC), a financial institution under the UN, has recently sponsored a project on JGT in which development and application of potentially important JGT are among the objectives. A total of 26 trials in the sectors of low volume road, control of erosion in the riverbank, and management of hillslope have been carried out in India (16 projects) and Bangladesh (10 projects) successfully. Performance in each case has been monitored for a period of 18 months after completion at quarterly intervals. The optimized woven JGT and open weave (OW) JGT have been applied in these trials.

Before commencement of the exercise on optimization, it is necessary to know the technical requirements of a particular application so that the optimized JGT can meet the requirements economically. The tables below show the relationship between types of JGT vis-à-vis the functions it is required to perform in a specific application.

Tables 13.1, 13.2, and 13.3 indicate application-function relationship for selecting a particular type of JGT—woven, open weave, and nonwoven for a specific application.

Table 13.1 Relationship between functions, properties, and applications of woven JGT

JGT functions and properties → / JGT application ↓	Function				Structure			Hydraulic	Mechanical						
	Separation	Filtration	Drainage	Initial reinforcement	Thickness	Pore size	Friction	Permittivity	Tensile strength	Elongation (%)	Drapability	Tearing	Burst	Puncture	Abrasion
Rural roads (low volume road)	Δ	Δ	Δ	Δ	•	Δ	□	Δ	Δ	Δ	•	Δ	□	Δ	•
Riverbank protection	Δ	Δ	Δ	□	•	Δ	□	Δ	Δ	Δ	□	□	□	Δ	•
Assessment grade															
	Δ 1 (decisive for selection)							□ 2 (important for selection)			• 3 (less important for selection)				

Table 13.2 Relationship between functions, properties, and application of open weave JGT

JGT functions / properties →	Function						Structure		Hydraulic	Mechanical		
JGT application ↓	Run-off velocity reduction	Control of soil migration	Conservation of soil moisture and temperature	Overland storage	Biodegradability	Vegetation growth	Thickness	Aperture size	Water-holding capacity	Tensile strength	Elongation (%)	Drapability
Hillslope management	Δ	Δ	Δ	□	Δ	Δ	□	□	Δ	□	□	Δ
Assessment grade	Δ 1 (Decisive for selection)				□ 2 (Important for selection)				• 3 (Less important for selection)			

Table 13.3 Relationship between functions, properties, and applications of nonwoven JGT

JGT functions/ properties	Function		Structure		Hydraulic		Mechanical				
JGT application	Filtration	Drainage	Thickness	Pore size	Permittivity	Transmissivity	Tensile strength 5 %	Elongation at break (%)	Drapability	Tearing	Puncture
Control in settlement of railway track	Δ	Δ	□	□	Δ	Δ	□	□	□	□	□
Assessment grade	Δ 1 (decisive for selection)				□ 2 (important for selection)				• 3 (less important for selection)		

13.1 Specification of Different Types of JGT Vis-à-Vis Application

It is relevant to know the area of application of a particular type of JGT before finalizing its specification. Specification of JGT also depends on the severity of a particular application. In the recently concluded international project funded by the CFC, several types of JGT—open weave, woven and non-woven—were applied at site and their performance was monitored.

For open weave JGT used to control surficial soil erosion, the prime determinants are aerial coverage and thickness reflected by its weight. For woven JGT tensile strength and porometry of JGT are of prime importance. Non-woven JGT being weak in tensile strength, but high in permeability is sometimes used in combination with the woven type to meet both hydraulic conductivity and tensile strength requirements. Non-woven JGT is mainly used encapsulating rubble in concealed drains used mostly in hill roads.

13.2 Type 1: Open Weave Jute Geotextile

Areas of application for open weave JGT

- Slope of embankments
- Overburden dumps in coal mines and pulverized fly ash heaps
- Denuded lands
- Control of topsoil erosion

N.B. Plantation of vegetation on open weave JGT is a necessity to sustain the functions of open weave JGT after its biodegradation.

Open weave JGT is the most preferred option in case of control of topsoil erosion caused by precipitation, for its thickness helps in overland storage and can pose successive micro-barriers to reduce the velocity of surface run-off. Open weave JGT is the most economical of the three types followed by the nonwoven type. Table 13.4 indicates the different types of open weave JGT which have been applied with success depending on the severity of site conditions.

13.3 Type 2: Nonwoven Jute Geotextile

Areas of application for nonwoven JGT

- As a cushion over woven JGT on railway sub-grades
- In conjunction with woven JGT where better permittivity is necessary with strength

Table 13.4 Specifications of different types of OW JGT

Properties	Type 1	Type 2	Type 3	Type 4
Weight (g/m^2) at 20 % M.R.≥	292 ± (10 %)	500 ± (10 %)	600 ± (10 %)	700 ± (10 %)
Threads/dm (MD × CD)≥	11 × 12	6.5 × 4.5	8 × 7	8 × 8
Thickness (mm)	3	4.5 ± 10 %	5.25 ± 10 %	5.5 ± 10 %
Width (cm)≥	122	122	122	122
Open area (%)		55–50	45–50	40–45
Strength (kN/m) [MD × CD]≥	10 × 10	6.5 × 6	12 × 6	14 × 7
Water holding capacity (%) on dry weight		450–500	450–500	550–600

Table 13.5 Specifications of different types of nonwoven JGT

Properties	Type 1	Type 2
Weight (g/m^2) at 20 % M.R	500 ± 10 %	1000 ± 10 %
Thickness (mm)	4 ± 10 %	8 ± 10 %
Width (cm)	150 ± 5 %	150 ± 5 %
Strength (kN/m) [MD × CD]	4 ± 10 × 5 ± 10 %	6 ± 10 × 7 ± 10 %
Elongation at break (%) (MD × CD)	20 ± 10 × 25 ± 10 %	20 ± 10 × 25 ± 10 %
Permittivity at 50 mm constant head in 'per second' −1.94 (minimum)	3.4×10^{-3}	3.4×10^{-4}

- As an outer permeable cover of encapsulated rubble drains in road sides, within embankments, etc.
- In areas where drainage is the main criterion

Table 13.5 indicates specifications of two main types of nonwoven JGT in common use in civil engineering.

13.4 Type 3: Woven JGT

Areas of application for woven JGT

- On sub-grades of roads and railways
- As basal reinforcement of embankments
- For bank protection of rivers and waterways

N.B.

- Type of weave, ends/dm and picks/dm are for general guidance only.
- AOS (O_{95}) is decided on the basis of average particle size distribution of soil and its hydraulic conductivity. AOS shown in the table is therefore indicative.

Table 13.6 Specifications of woven JGT for different areas of applications

Properties	Woven JGT 20 kN/m (for riverbank protection)	Woven JGT 25 kN/m (for rural road construction)
Construction	1/1 DW plain weave	1/1 DW plain weave
Weight (gsm) at 20 % MR ≥	627	724
Width (cm) ≥	200	200
Ends × picks/dm ≥	85 × 32	94 × 39
Thickness (mm at 2 kPa)	1.7 ± 10 %	1.85 ± 10 %
Tensile strength (kN/m) MD × CD ≥	20 × 20	25 × 25
Elongation at break (%) MD × CD	8 ± 10 × 8 ± 10 %	10 ± 10 × 10 ± 10 %
Puncture resistance (kN)	0.400 ± 10 %	0.500 ± 10 %
Burst strength (KPa)	3100 ± 10 %	3500 ± 10 %
Permittivity at 50 mm constant head in 'per second' (min)	$350 \times 10^{-3} \pm 10\,\%$	$350 \times 10^{-3} \pm 10\,\%$
AOS (micron) O_{95}	150–400	150–400

Interested readers may peruse the BI Standards viz IS 14715(Part I): 2016 & IS 14715(Part II): 2016 for details regarding the specifications

- Due to nonuniformity in diameter and length of jute yarns, no acceptable correlation between AOS and permittivity of woven JGT with a specified tensile strength could be established. The table indicates the minimum admissible value for permittivity against AOS of 150 μm.
- For riverbank protection purpose, the 627 gsm fabric is to be treated with suitable additives.
  **Width of the fabric may be fixed as agreed between buyer and seller, subject to a lower limit of 100 cm.
- Width of the fabric may be fixed as agreed between buyer and seller, subject to a lower limit of 100 cm.

Typical specifications of two principal types of woven JGT widely used in road, river, and embankment-related applications are shown in Table 13.6. The specifications shown have been optimized keeping in view the essential technical parameters necessary for the aforesaid applications. Fabric optimization results in price economy without sacrificing fabric quality.

13.5 Comparative Assessment of JGT with Man-Made Geotextiles

Durability and tensile strength are the only criteria in which man-made geotextiles outscore JGT. In so far as other properties such as grab strength, tear strength, puncture resistance, and burst strength, JGT is comparable to its man-made counterpart. With ultimate strain (elongation at break) <50 %, grab strength of JGT is usually 1200 N as against 1100 N for man-made geotextiles; tear strength of JGT is 500 N compared to 400 N for its man-made counterpart; and puncture resistance of JGT is 450 N corresponding to 400 N for polymeric geotextiles.

Table 13.7 shows comparative evaluation of basic properties of the two types of geotextiles.

- Woven geotextile fail at elongation (strain) <50 %, while nonwovens fail at elongation (strain) >50 %. The required minimum average roll value (MARV) test strength for woven filament geotextile is 250 N
- Data in the parentheses represent corresponding property parameter of Jute Geotextiles (JGT)

Table 13.8 indicates the comparative properties of jute and polymeric fibers. Class 1, 2, and 3 categorizes survivability as well as severity conditions.

13.6 Property-Wise Advantages of JGT Over Other Geotextiles

There are other features of JGT that are critical for any geotextile. JGT possesses high along-plane drainage capability (i.e., transmissivity) and high roughness coefficient which ensures better load transference and exercises better confining action on soil than its synthetic counterpart. Low elongation at break of woven JGT calls into play its membrane effect better than man-made geotextiles.

Superiority of JGT over other geotextiles in case of erosion control of exposed soil is well established. The reasons are reiterated below:

(i) JGT has far greater water absorbency than all other GTs—a quality which enables sustained release of the absorbed water, thus creating a congenial microclimate for better growth of vegetation.
(ii) Its thickness, unlike polymeric geotextiles, helps reduce the velocity of overland flow and entrap detached soil particles, thus facilitating control over surface soil erosion.
(iii) Drapability of JGT is the best among all geotextiles – touches soil contours at all points and ensures intimate contact with it.
(iv) JGT help increase hydraulic conductivity of soil & add micro-nutrients to it on bio-degradation.
(v) It attenuates extremes of temperature, acts as mulch, and ensures quick vegetation growth.

Table 13.7 Comparative properties of JGT and SGT

Property	Test method	Unit	Geotextile classification					
			Class 1		Class 2		Class 3	
			Strain <50 % (JGT)	Strain >50 %	Strain <50 % (JGT)	Strain >50 %	Strain <50 % (JGT)	Strain >50 %
Grab tensile strength	ASTM D4632	N	1400 (1300)	900	1100 (1200)	700	800 (900)	500
Tear	ASTM D4533	N	500 (500)	350	400 (500)	250	300 (400)	180
Puncture strength	ASTM D4833	N	500 (500)	350	400 (450)	250	300 (400)	180
Burst strength	ASTM D3786	kPa	3500 (3500)	1700	2700 (3200)	1300	2100 (2300)	950
Permittivity	ASTM D4991	s^{-1}	Minimum property requirements for permittivity, AOS, and UV stability are based on usual geotextile application					
AOS	ASTM D4751	μ						
UV Stability	ASTM D4355	%						

Source: DJFT, Calcutta University

Table 13.8 Comparative properties of jute and polymeric fiber

Properties	Polyester	Polypropylene	Jute
Specific gravity	1.38	0.91	1.48
Tenacity, g/day	2–9.2	2.5–5.5	3–5
Breaking elongation, %	10–145	14–100	0.8–2.0
Elastic recovery, %	57–99	75–95	75–85
Moisture regain, %	0.4	0.01	12.5–13.8
Effect of heat	Sticks at 440 °F and melts at 485–500 °F	Softens at 290–310 °F, melts at 320 °F, and decomposes at 550 °F	Does not melt up to 356 °F, no major weight and tenacity loss Hemicellulose melts at around 559 °F
Effect of acid/alkalis	Excellent resistance to acids and disintegrates in concentrated hot alkali	Excellent resistance to concentrated acids and alkalis	Good resistance to dilute acids but degrades in concentrated acids and affected by hot alkalis
Resistance to mildew, sunlight, and abrasion	Excellent resistance to mildew and sunlight	Immune to attack by mildew	Relatively poor resistant to mildew attack under moist conditions (>75 %)
	Good abrasion resistance	Good resistance to abrasion	Possess high roughness coefficient
	Prolonged exposure to sunlight may cause loss in strength	Stabilizers provide good resistance to sunlight fading	UV resistance of jute under investigation

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Chapter 14
Transportation, Storage, and Handling of JGT

Abstract Jute Geotextiles (JGT) require special care in transportation, handling, and storage to avoid damage. In this chapter users of JGT have been advised to follow a set of guidelines in respect to its transport, storage, and handling along with checks to be exercised regarding its acceptance at the site before installation.

Keywords Transportation of JGT • Acceptance at the site • Unloading • Storage • Testing of JGT consignment • Protective wrapping • Rolls • Bulk cargo

JGT should be transported and handled with care. Transportation of JGT is usually done in trucks either in bales or rolls. Overseas transportation is done in containers as a bulk or break-bulk cargo. The following precautions are advised in transportation of JGT:

- Care should be taken to keep it insulated from moisture and fire. JGT rolls should be provided with a protective wrapping.
- JGT may be conveniently carried by inserting a bamboo or similar pole into the central hole of the roll or as considered convenient at the site.
- Should not be dragged on the ground.
- Check that fabric does not get damaged due to wrong handling before laying.

14.1 Acceptance of JGT at the Site

After transportation of JGT to the destination, the following checks should be exercised:

- Check the name of the supplier-mill, brand name if any, type of JGT supplied vis-à-vis specification stated in contract document, test certificate* (whether by the mill or by any independent testing outfit), certificate of the competent authority recommending the use of the consignment, and the quantity of the consignment.

  (**One set of tests for each consignment of 16000 m^2 of JGT or as specified should normally be carried out*.)

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- Any apparent shortcoming in JGT- construction (quality, quantity, etc.) should be brought to the notice of the engineer.

14.2 Storage

Proper storage of JGT is extremely important. JGT if exposed in the open will degrade fast and are apt to lose its strength and other properties. The following is advised regarding storage of JGT:

- Prolonged storage is discouraged, i.e., must not be stored normally beyond 1 month. Retesting of the fabric should be done if lying unutilized for long.
- Must not be kept directly on the ground/floor.
- Must be kept in a covered shed without removing the protective poly-sheet.

14.3 Unloading at the Site

The following procedures may be adopted for unloading of JGT supplied in bulk at the site:

- A fork lift/front-end loader is recommended for machine-aided unloading.
- A broad wooden plank must be kept inclined toward the end of the truck for easy manual unloading of JGT.
- A sheet of plastic should be placed on the ground at the time of unloading.

Usually, JGT rolls are protected by wrapping with plastic sheets. When wrapping is damaged, the rolls should be covered again with waterproof sheet. If the outer layer of JGT itself is damaged, it should be cut off and thrown away. The outer wrap should also be replaced.

If JGT rolls get wet due to any reason before use, its waterproof cover should be removed and JGT should either be dried in the open or by a blower.

It is critical to ensure that JGT does not get damaged during installation at the site. It is likely that JGT is punctured or otherwise damaged due to sharp edges of aggregates or by contact with uneven sub-grade or soil surface. It is recommended to spread a thin cushion of sand over it to prevent such damage. In riverbank erosion control works, JGT may get damaged due to careless placement of boulders used as armor over JGT.

The supplier, the transporter, and the engineer at the site should exercise their common sense to ensure careful handling of JGT during loading, unloading, transportation, storage, and handling as there could be situations not thought of earlier. It should be noted that JGT should be transported and handled with more carefully than its synthetic counterpart as all natural products are susceptible to rough handling and are more prone to damage. Interested readers may look up ISO

10320:1999 and ASTM D 4872: 1988 for overall guidance on transportation, handling, and storage for man-made geotextiles. The guidelines broadly apply to JGT also, though JGT demands more intensive surveillance given its susceptibility to rough handling.

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Chapter 15
Prospective Applications of JGT and Its Variants

Abstract Apart from its conventional use for strengthening sub-grade, control of erosion of riverbank, and slope management, Jute Geotextiles (JGT) may be gainfully used in geo-environmental sector. It may be used for watershed management, stabilization of PFA (pulverized fly ash) heaps and OB (overburden) dumps in opencast mines, management of MSW (municipal solid waste) in urban conglomerates, etc. In fact the use of JGT in the geo-environmental sector has so far been overlooked.

Besides the aforesaid applications, innovative variants of JGT have also been developed for several useful applications. Mention may be made of Bituminized Jute Paving Fabric (BJPF) for use as overlay on road-top, jute fiber-reinforced concrete (JFRC), jute agrotextiles (JAT), jute fabriform, turf-reinforced jute mats, and specially designed open weave JGT for controlling wind-induced erosion in deserts. Successful field trials for BJPF, JAT, and specially designed open weave JGT for wind erosion control in the sands have been conducted, while other variants await field trials. The variants have been developed after careful laboratory studies.

Keywords Turf-reinforced jute mats • Watershed management • PFA heaps • MSW • OB dumps • Geo-environmental application • Fabriform • Bituminized Jute Paving Fabric (BJPF) • Jute fiber-reinforced concrete • Jute agrotextiles • Wind-induced erosion control in deserts

In the preceding chapters conventional uses of JGT have been presented because of successful field applications with JGT in those areas supported by corroborative laboratory studies. It has been mentioned in the preceding chapters that over 260 field applications have been carried out with JGT so far. Field trials with JGT have also been undertaken overseas, for the control of soil erosion, rehabilitation of mine dumps, and restoration of high-altitude slopes (refer to the report of Rod Smith on jute geotextiles in ENACT, an environmental magazine). A study by Grenoble University a few years ago reveals that over a full range of rainfall intensities and slopes, JGT outshines all other types of geotextiles. It is however felt that the potential of this innovative natural material still remains to be fully and properly exploited. It is relevant to indicate the untried promising areas where JGT can be applied with both economical and environmental advantage.

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JGT can be used with advantage in geo-environmental sector. Not much work has been done in the following areas:

– Watershed management
– Management of fly ash heaps in the power generation sector
– Management of MSW (municipal solid wastes)
– Stabilization of mine spoils and OB (overburden) dumps

Watershed management is a neglected sector in developing countries. Denudation of forests is common in these countries which ultimately lead to detachment and transportation of topsoil. This in turn often adds to the sediment load of waterways reducing their carrying capacity. If top soil erosion goes on unabated, this could lead to floods.

Opencast mines are saddled with the problem of managing huge OB dumps and mine spoils can be stabilized by conjunctive use of JGT and vegetation. JGT has been applied successfully at the two opencast mines of northern and western coalfields (Singrauli and Nagpur, respectively) in India.

Unutilized pulverized fly ash (PFA) heaps in thermal power plants are potential environmental hazards. Accidents often take place in thermal power plants for destabilization of such heaps. Fly ash heaps can be stabilized with JGT and vegetation and converted into greeneries.

Management of MSW is utterly neglected in developing countries with high population density. Daily cover over MSW is seldom provided. Covering JGT with low-cost JGT—may be the nonwoven variety—can keep air pollution in check. JGT may be the ideal solid waste cover for engineered landfills. On biodegradation it will coalesce with soil and can even prevent infestation of rats and vermin and facilitate formation of biomass. When creation of greenery on top of a closed landfill is desired, JGT should be the preferred facilitating material. Nonwoven JGT when appropriately used may be used as traps to bacteria (not viruses) that may move with groundwater. Effective life of JGT is certainly longer than the life expectancy of bacteria.

Besides the geo-environmental sector, a couple of JGT-based products hold good potential if developed.

(a) Turf-Reinforced Mat (TRM)
It is one such ready-to-use product which can be directly laid on eroded soil and denuded ground. It appears possible that pruned tufts of the chosen grass species can be tied up/bonded with JGT as basal support and the finished product may be supplied in rolls. However manufacturing process of the product has not yet been standardized.
(b) Fabriform
It is essentially a three-dimensional woven JGT that can give any concrete desired shape and is also in demand. Once the concrete hardens, JGT becomes redundant and degrades on its own. The concrete made in fabriforms may be used as revetment and armors on eroded riverbanks and for other purposes. Fabriforms of JGT may be put to use for making revetment mattresses and

remedial works for concrete structure. The function of JGT is to give and retain the desired shape of the concrete and its function ceases once the concrete hardens. Biodegradability and high water absorbency of JGT are advantage in such cases. The product has not however been tried.

Research and development for variants of JGT for specialized applications have led to the development of the following JGT variants with good potential:

15.1 Bituminized Jute Paving Fabric (BJPF)

Bituminized Jute Paving Fabric (BJPF) has recently been developed for use as top wearing course in roads and highways as an improved substitute for bitumen mastic asphalt used extensively as paving course in heavy duty roads. The new product has been developed by the Department of Jute and Fiber Technology, Calcutta University, in association with the Central Road Research Institute (CRRI), Delhi, with funding from the National Jute Board under Jute Technology Mission.

The paving course in a flexible pavement has to withstand the moving vehicular load directly. It constitutes the riding surface of the pavement requiring adequate strength and resilience to resist abrasion and shear of moving loads. Its vulnerability affects the durability of pavement.

Bitumen mastic, a combination of straight run or industrial bitumen of suitable penetration and viscosity, binder, and aggregates, is now being used extensively on flexible pavements as it provides a dense and impermeable sheet which does not disintegrate during its lifetime. The Indian Roads Congress has specified the mix design of bitumen mastic indicating the desired hardness number, binder content, preparation of the mix, and its laying.

High initial strength, low extensibility, and high roughness coefficient are some of the properties of jute that can help make a strong and resilient wearing surface. On top of it, the thermal compatibility of jute with hot bitumen is a feature that no other fiber perhaps can match. Moreover, large-scale availability of jute and the expertise acquired in manufacturing over the years are distinct advantages. Readers are reminded of "tar-felts"—a combination of tar and jute felt—that were and are still being used extensively for roof treatment as waterproof course in the Indian subcontinent. The service life of tar-felts is usually 8 years.

The other factor that weighs in favor of JGT is that nonwoven JGT is an excellent receptor of bitumen. The use of a suitable combination of woven and nonwoven varieties of JGT may provide an excellent reinforcement to the bitumen sheet to be developed as wearing course. Though weak in tensile strength, a combination of nonwoven JGT and woven JGT can ensure the desired level of tensile strength and bitumen receptivity. In fact different combinations of JGT were tried to select the optimum combination.

Table 15.1 Specifications of BJPF

1.	GSM (weight in gm/sqm)	3500
2.	Thickness (mm)	8.0
3.	Strength (KN/m) [MD X CD]	40.0 × 40.0
4.	Elongation% [MD X CD]	9 × 10
5.	Bursting strength (kg/cm^2)	41.0

Source: DJFT, Calcutta University

The other aspect that is important is the choice of bitumen type. After rigorous trials PMB (polymer-modified bitumen) 40 was chosen by CRRI because it possesses high elastic modulus, excellent resilience, and fatigue resistance.

BJPF was finally developed with combination of five layers of JGT in its core. Five layers of JGT comprise three layers of woven and two layers of nonwoven JGT bonded together. It can also be used to arrest reflection cracks that emanate from sub-grade and move up to the wearing course on roads. Its finished thickness measures 8.5 mm while it weighs 4505 gsm. Table 15.1 shows the salient specifications of the developed BJPF.

BJPF was subjected to 20,000 cycles (wheel tracking test) and a temperature of $50\,^\circ\mathrm{C} \pm 2\,\%$ was maintained during the test in an insulated closed chamber in CRRI laboratory. Tests confirmed that BJPF can provide a good resilient overlay to cater to varying traffic-induced stresses on the road. An important aspect of the developed product is that requirement of bitumen is less than in the case of the conventional bitumen mastic designed for the same application. The rationale of using nonwoven JGT is that nonwoven JGT is a better receptor of bitumen than the woven type. CRRI selected PMB 40 as the binding material after rigorous tests and laboratory trials.

One point deserves mention in this context. If only BJPF is used as wearing course, it will be subjected to abrasive stresses due to moving loads. It is therefore recommended to have a thin layer of bitumen mastic of thickness 15–20 mm over BJPF as cushion. The total cost of the product is close to the conventional bitumen mastic.

The product has already been tried in a busy road at Kolkata, India (Uday Shankar Sarani), nearly a year back and is performing satisfactorily. A stretch of a state highway in West Bengal (Contai-Belda road) has also received BJPF treatment some time back and is also reportedly in good shape:

A sectional view of the optimized and standardized BJPF may be seen in Fig. 15.1.
B: Bitumen layer (PMB 40).
W1, W2, W3: Woven fabric components.
NW1, NW2: Nonwoven fabric components.

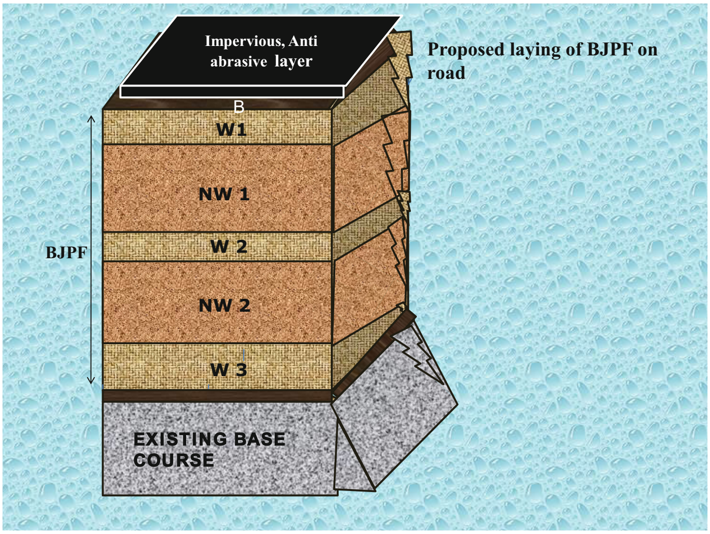

Fig. 15.1 Sectional view of the standardized BJPF

15.2 Jute Fiber-Reinforced Concrete

Jute fiber can be used to strengthen concrete as secondary reinforcement. IIT Kharagpur has completed a study on the subject with funding from the National Jute Board. It has been found that jute fiber-reinforced concrete possesses higher compressive strength and has also reinforcing properties. It has been tried in manufacturing of concrete hume pipes with satisfactory results.

Small jute fiber is used for the purpose (around 1 % of the concrete volume). It can be used in the making of pre-stressed railway sleepers and concrete pole also. The production process however has to be improved.

In several studies conducted recently notably by Md Akhtar Hussain et al. (2015), D Kumar et al. (2015) significant improvement in soil characteristics has been observed. Improvement including improvement in CBR% of the sub-grade and other characteristics such as maximum dry density, OMC (optimum moisture content). Percentage of jute fiber and the length of fiber are critical determinants. It is advisable to undertake field trials to ensure if the laboratory results corroborate the laboratory findings.

JGT may also be used to increase the bearing capacity of soil supporting light to medium structures. Som (1988) has shown that for that purpose sufficient deformation of the footing is to be allowed for mobilizing the strength of the geotextile. The reinforcing effect of the fabric is supposed to increase the rigidity of the soil enabling better load dispersion. However such applications have not yet been tried with JGT. But this could be a possibility.

15.3 Jute Agrotextiles (JAT)

In this context it may be mentioned that jute agrotextiles (JAT) though functionally different from JGT may be treated as a variant of JGT. Application of JAT is confined to agriculture but the fabric construction of the two does not differ in essence. In JAT tensile strength, AOS, and other features such as permittivity and transmissivity are of less importance. For instance, in application such as weed suppression, a dense variety of nonwoven JAT is necessary to ensure inhibition of light through the fabric. Specification of JAT is decided considering the application and its objective. Jute sleeves used for holding soil bulbs with saplings can be manufactured to any shape and size and has distinct advantages over man-made polythene sleeves. Jute sleeves can be directly planted without any need to remove it as in the case of ploy sleeves. The growth rate of plants is higher with jute sleeves which excel all other soil sleeves in performance. Its flexibility, soil-friendliness, and hassle-free use are other advantages.

JAT was used with success in two tea gardens in Assam (Rosekandy and Arcuttipore) for weed suppression in which Indian Jute Industries Research Association (IJIRA) and Tea Research Association, Guwahati, were involved. JAT was also tried in an arid zone near Kharagpur in West Bengal jointly by IJIRA and the state forest department for a comparative prototype study in regard to plant growth. The study established the usefulness of JAT in fostering plant habitation in lateritic soil. A recent research project on JAT with focus on weed suppression and growth of various fruit-growing plants under the sponsorship of the National Jute Board (NJB) is now in progress in an agricultural university (Bidhan Chandra Krishi Viswavidyalaya, Kalyani) in West Bengal. Initial results are encouraging. In view of the reported success in all its applications so far carried out, JAT holds very good commercial prospects if properly marketed.

15.4 Open Weave JGT for Wind-Induced Erosion Control in Deserts

Shifting sand dunes in the sands is a big problem in de-desertification. The shift is due to high winds. As a result seeds of vegetation are carried away and do not get the ambience conducive to growth. Added to this extreme climate in deserts and high rate of evaporation are impediments. Subsoil moisture gets dried up and sapling roots wither.

The usual practice in India (Thar Desert in Rajasthan) is to uproot dried vegetation from nearby areas and plant them in the windward side in a chequer board fashion. The practice has been partly successful warranting an alternative methodology to replace it.

The National Jute Board and Rajasthan Forest Department recently embarked upon a new endeavor by using open weave JGT to control the shift of sand due to

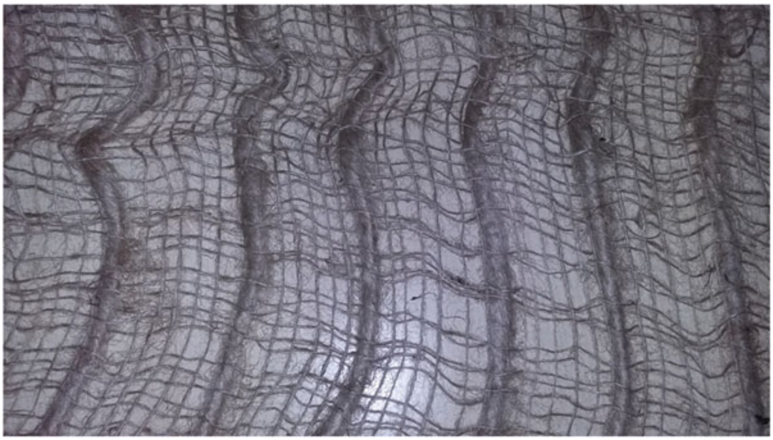

Fig. 15.2 Specially designed open weave JGT for wind erosion control in deserts

high wind at Jaisalmer, Rajasthan. The high water-absorbing capacity of jute coupled with the advantage of thick yarns of open weave JGT was considered to be of advantage. It has been observed that the sand shift is confined to about ten times the thickness of the yarn placed against the prevailing wind direction. Accordingly open weave was specially designed and manufactured. The experiment was highly successful. Sewan grass (*Lasiurus sindicus*) and phog (*Calligonum polygonoies*) were used. Sewan is a major fodder species in the desert, while phog is a multipurpose vegetation. Given the indications open weave—specially designed—may be given a try in other sands of the world with similar problems.

In the instant experiment, warp yarn was made of 7.5 mm dia and supporting weft yarns to make the fabric dimensionally stable (Fig. 15.2). Warp yarns were placed at 75 mm/125 mm/200 mm apart.

This innovative use of specially designed open weave JGT holds high promise in continents with tracts of deserts afflicted by wind-induced erosion where greenery development poses tough problems.

Apart from the above innovative variants, JGT can also be used with economical and environmental advantage in temporary and haul roads especially in construction sites, mining areas, and areas under development eliminating the cost and hazard of taking out man-made geotextiles usually resorted to. In such applications specification of JGT could be less stringent than what is indicated in the relevant chapters of this book.

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Chapter 16
Economical and Environmental Advantages of JGT

Abstract The contents of the chapter analyze objectively the environmental and economical advantages of Jute Geotextiles (JGT) in its three major applications, viz., low-volume road construction, riverbank erosion control, and slope management. The process of evaluating the advantages has been indicated in the chapter.

Keywords Transport costs • Environmental benefits • Savings in natural resources consumption • Reduction in carbon emission • Lower fuel consumption

Jute Geotextiles (JGT) may be used with environmental and economical advantages for the purposes stated above in technically appropriate cases. For instance, its efficacy has not been tested in high-volume roads. It is left to the judgment of the designer to recommend use of JGT considering the nature and severity of site conditions. Its technical suitability stands proven in various types of field applications in India numbering more than 260 as of now. Its effectiveness has also been corroborated in laboratory studies conducted by research institutes of repute.

16.1 Economical Advantages of JGT in Different Applications

16.1.1 Economical Aspects of Using JGT in Low-Volume Road Construction

It has been found from laboratory studies corroborated by approximately 50 field trials that with JGT application, CBR value enhances by at least 1.5 times over the control value of sub-grade in all cases and even more in few field trials in relation to elapsed time since consolidation is a long drawn process and continues for years. The economical advantage accrues due to the enhanced CBR% of the sub-grade in roads as a result of the use of JGT justifying consequent reduction of the base course thickness. The total cost thus gets reduced.

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Cost savings vary from site to site and with time as well as depend on various factors like different CBR, ESAL range, etc. In a simplified way, cost savings in % can be summarized below.

Design with conventional method	Design with Jute Geotextiles
Length of pavement and width of different constituents of pavement will be similar in both cases	
Thickness of pavement as per conventional design is T_1. Considering the total cost of the pavement per unit thickness as R_1, the total cost of pavement stands at $R_1 \times T_1$	Thickness of pavement as per recommended design with JGT is T_2. Considering the total cost of the pavement per unit thickness as R_2, the total cost of pavement stands at $R_2 \times T_2$.. Add cost of JGT "J"
Total labor charges required for constructing the pavement as per conventional design are taken as L_1	Total labor charges required for constructing the pavement as per design with JGT are taken as L_2
Transportation charges required for carrying different constituents of pavement symbolized as Tr_1	Transportation charges required for carrying different constituents of pavement designed with JGT symbolized as Tr_2
Total cost of a section of a road with conventional design $C_1 = (R_1 \times T_1) + L_1 + \mathrm{Tr}_1$	Total cost of a section of a road design with JGT $C_2 = (R_2 \times T_2) + J + L_2 + \mathrm{Tr}_2$
According to the recommended design method, thickness $\mathrm{T}_1 > \mathrm{T}_2$	
The cost savings in % may be represented as $(C_1 - C_2)/C_1 \times 100$	

It has been observed from case studies that approximately 10–11 % savings can be made by using JGT in low-volume road construction by replacing the conventional design according to the prevailing cost of construction in West Bengal.

16.1.2 Environmental Aspects of Using JGT in Low-Volume Road Construction

This study indicates indirect savings caused in the construction phase only comprising site-delivered cost of materials required for construction of a road. The fuel consumed in transportation has a direct bearing on emission of carbon in the environment. Understandably persistent high consumption of nonrenewable resource like diesel and granite could ultimately lead to depletion of the natural resources, besides adding to the increase in carbon footprint. Reduction in base course thickness using JGT goes to reduce the eco-discordance partially. The aspect of carbon sequestration in the agricultural phase of jute has not been considered as its quantified impact has not been standardized.

In fine the impact of JGT in reducing adversity in environment when a road is constructed with it may be summarized as under.

Design with conventional method	Design with Jute Geotextiles
Quantity of materials carried by a truck symbolized as Q_{tr} will be same in both cases	
Quantity of different materials (GSB, WBM) constituting total thickness of pavement with conventional design symbolized as Q_1	Quantity of different materials (GSB, WBM) constituting total thickness of pavement designed with JGT symbolized as Q_2
Transportation (number of trips) by a truck of quantity Q_{tr} required for carrying Q_1 quantity of materials of pavement as per conventional design symbolized as N_1	Transportation (number of trips) by a truck of quantity Q_{tr} required for carrying Q_2 quantity of materials of pavement designed with JGT symbolized as N_2
Due to reduced thickness of pavement for design with JGT $Q_1 > Q_2$	

The environmental benefits will accrue in terms of

(i) savings in natural resources consumption (%) i.e., $Q_1 - Q_2/Q_1 \times 100$ and
(ii) savings in hauling/quarrying of materials from the source to the work site will depend on the quantum of resource reduction and the distance.

Reduction in carbon emissions due to lower fuel consumption for less extraction of natural resource such as stone/brick ballast and lower transport operations of material carriage from source to site will add to the environmental benefit. Translation of carbon emission due to quarrying and transportation into monetary terms is a matter of specialized study.

16.1.3 Economical Aspects of Using JGT in Riverbank Protection

Riverbank erosion could take place as a result of one or a combination of factors, viz., erodibility of bank soil, extent of drawdown, eddies at the bank toe, high flow hugging the bank, etc. The phenomenon has been explained in Chapter VII. Granular filters are commonly used to resist and control riverbank erosion. In certain cases flow regulatory structural measures are required to be adopted additionally.

JGT provides an effective and technically precise alternative to inverted granular filters as already explained in the relevant chapter of this book. Replacing conventional inverted filter with JGT will conserve natural sources of stone, time, and money. Boulders (riprap) are placed over JGT to avoid direct exposure of JGT to sunlight and flowing water as well as to dissipate the thrust of wave actions and are common to both conventional and JGT design. Besides environmental advantage, JGT treated with durability-enhancing eco-friendly additive will also significantly affect the overall economical benefit.

Cost savings is apt to vary from site to site. The transport of materials from the source to the site and the distance between the two destinations are important factors influencing the cost of construction. The process of calculation of economical benefit due to the use of JGT for riverbank erosion control works is indicated below.

Design with conventional method	Design with Jute Geotextiles
Length and width of riverbank to be different constituents of pavement will be similar in both cases	
Cost of inverted granular filter (different grades) constituting total thickness T_1 and cost/unit thickness R_1 is symbolized as $R_1 \times T_1$	Cost of riprap is symbolized as $R_2 \times T_2$ with R_2 representing the cost/unit thickness of the riprap and T_2 thickness of riprap + J (cost of JGT)
Labor charges required for preparing riverbank symbolized as L_1	Labor charges required for preparing riverbank with JGT symbolized as L_2
Transportation charges required for carrying riprap and different grades of granular materials symbolized as Tr_1	Transportation charges required for carrying riprap and JGT symbolized as Tr_2
Total cost of a section of riverbank with conventional design $C_1 = (R_1 \times T_1) + L_1 + \mathrm{Tr}_1$	Total cost of a section of a riverbank design with JGT $C_2 = (R_2 \times T_2) + J + L_2 + \mathrm{Tr}_2$
As JGT fully replaces the costly thick granular filter at a much lower cost and the cost of riprap in both cases being identical, $T_1 > T_2$	
The cost savings in % may be represented as $(C_1 - C_2)/C_1 \times 100$	

It has been observed from case studies that an approximate of 15 % savings may be effected by using JGT in riverbank construction from conventional method when prevalent rates in India are considered.

For ascertaining environmental advantages in monetary terms, the same principle as indicated in the case of low-volume road construction may be followed. It is however difficult to quantify the environmental advantages of using JGT as replacement of granular filter conventionally used in monetary term.

16.1.4 Economical and Environmental Aspects of Using JGT in Slope Management

There will be no direct cost savings using JGT compared to the conventional method of slope management as conventional method focuses on slope correction methods like toe protection, retaining walls, etc., which may have to be undertaken, if conditions warrant in the case of JGT also. Environmental advantages for adoption of bioengineering measures with JGT are obvious as it uses nature to protect the distresses caused by nature itself. It has already been indicated in Chapter V that JGT attenuates extremes of temperature, increases hydraulic conductivity of soil, acts as mulch after degradation, and creates a congenial microclimate ensuring quick growth of dense vegetation. Finally the root system of vegetation ensures soil retention and also provides sustainable solution to the problems of erosion. JGT, a natural product, fosters vegetation growth and paves a way for providing bioengineering solutions to soil erosion problems. It may be noted that structural corrections where absolutely needed should not be avoided.

Eco-concordance, cost-competitiveness, and technical suitability of JGT make it a material worth trying in low-volume road construction, riverbank protection, and hillslope management. The principle of economical and environmental cost comparisons as enunciated may be followed in all cases where JGT is used as a replacement of the conventional construction. While it is easy to make constructional cost comparison, environmental cost evaluation demands in-depth in situ specialized study and cannot therefore be generalized.

Reference

Ramachandra TV, Shwetmala (2009) Emissions from India's transport sector: state-wise synthesis. Published in Atmospheric Environment, 2009

Chapter 17
Application of JGT and a Few Case Studies

Abstract The chapter presents applications of Jute Geotextiles (JGT) in the areas of low-volume road construction, riverbank erosion control, management of slide-prone hill slope, rehabilitation of settled railway track, and stabilization of mine-spoil heaps with the attendant case studies. All the case studies are pioneering applications with JGT corroborating efficacy of JGT in the applications. The case studies conducted in India have been published in technical journals of repute.

Keywords PMGSY • Soaked CBR • Void ratio reduction • Dry density • Treatment on JGT • Shrinkable soil • Vegetation establishment • Moisture improvement • Erosion control

Though JGT is now being increasingly applied in many places within and outside India, precise data on the applications carried out are not available for analysis. JGT is reportedly being sold mostly as “hessian” in the overseas which covers a wide range of jute products besides JGT. Open weave JGT is being exported under the style of “Soil Saver.” Information gathered from different sources reveals that so far a little above 260 field applications with JGT have been successfully carried out in India out of which 28 % of the applications have been in road construction, 32 % in riverbank protection, and 33 % in slope management, while the share of application in railways is 7 %.

It may be noted in this connection that prior to 2006, JGT was used sporadically in India mostly at the personal initiative of a section of engineers looking for an alternative environment-friendly engineering material for mitigating difficult soil-related problems. Even man-made geotextiles had a belated beginning in India. The general tendency of engineers in India is to wait, watch, and then use.

Applications of JGT gained some momentum from the late 1990s. A pilot project with JGT was taken up in 2006 in nine rural roads under Pradhan Mantri Gram Sadak Yojana (PMGSY), a massive project initiated by the Government of India for rural area connectivity in India. The pilot project was taken up in five states, viz., Assam, Chhattisgarh, Madhya Pradesh, Orissa, and West Bengal with the support of the Ministry of Rural Development (MoRD) and the Ministry of Textiles (MoT). The Central Road Research Institute (CRRI) prepared the DPRs and monitored performance of five of the nine roads put to trial application. The project covering a total stretch of 47.84 kms was executed by the respective state

T. Sanyal, *Jute Geotextiles and their Applications in Civil Engineering*,
Developments in Geotechnical Engineering, DOI 10.1007/978-981-10-1932-6_17

governments. The report on satisfactory performance of the JGT-treated roads was submitted by CRRI to the National Rural Roads Development Agency (NRRDA), the nodal organization under MoRD for PMGSY project, which recommended that the product (JGT) be applied in rural roads under PMGSY as an R&D initiative. This marked the beginning of concerted efforts to promote JGT by the National Jute Board (NJB) (erstwhile the Jute Manufacturers Development Council), a national promotional body for jute and jute products directly under the Ministry of Textiles, Government of India, prior to which promotional responsibilities of JGT were shouldered by the Indian Jute Industries' Research Association (IJIRA), Kolkata.

Prior to the pilot project referred, Eastern Railways used JGT in four problem-ridden railway formations in Howrah-Bardhaman section, in 2004 based on a paper presented by the present author in the Annual Indian Geotechnical Conference (IGC) at IIT, Bombay, in 2000. The package of solutions provided was successful in solving a long-standing settlement problem in these stretches. Recently a stretch of weak formation in Baltikuri-Dankuni-Ballyghat section under the same railway network is being improved with JGT. In fact the Ministry of Railways has accepted JGT as a potent engineering material for use in unstable formations (vide the budget speech of the Honorable Railway Minister in 2010–2011 and 2011–2012) watching the performance of JGT.

The National Hydroelectric Power Corporation and Border Roads Organization (BRO) in India are using JGT for slope stabilization. JGT has been recently used to stabilize a slope at Leh at a very high altitude. The place experiences temperature extremes with mercury hovering between −42 °C and 33 °C at some places in the Himalayan district. JGT has been applied in a number of low-volume roads under PMGSY project in West Bengal, Tripura, and especially in Karnataka. The Irrigation Department, Government of West Bengal, executed a number of bank protection works in several rivers of West Bengal. Mention may be made of bank protection works undertaken recently in rivers Kaljani and Dharala in Cooch Behar district, rivers Phulahar and Punarbhava in Malda district, river Bhagirathi at Santipur in Nadia district, and river Jagaddal in South 24 Parganas. In Orissa bank protective work was taken up in river Balukhai. JGT was proposed for strengthening "AILA"-affected stretches of the embankments in Sundarban area of West Bengal where work has recently commenced. The National Highway Authority of India have also applied open weave JGT for slope erosion control in embankments.

17.1 Potential Areas of Application of JGT

It has been indicated that JGT can be used with advantage in the following areas:

- Protection of slopes in earthen embankments, hill slopes, OB dumps, and heaps of granular materials like fly ash in thermal power plants
- Stabilization of embankments

- Control of erosion in banks of rivers, waterways, and canals
- Construction of roads and haul roads
- Control of settlement of railway tracks
- Construction of concealed drains especially in hill roads
- Consolidation of any type of soft soil by prefabricated vertical jute drain
- Management of watersheds and prevention of denudation of arid and semiarid lands

The potential of JGT in geo-environmental applications still remains to be seriously explored in India. Solid municipal waste (MSW) cover with nonwoven variety of JGT is one such area in urban settlements. There are reports about the use of jute fabric over MSW in some of the countries overseas, e.g., Brazil. JGT holds an edge over its man-made counterpart in geo-environmental applications because of its biodegradability and other eco-concordant properties.

17.2 International Projects on JGT

(a) An international project on JGT is under way in which NJB is the PEA. The project which is spread over India and Bangladesh is funded and sponsored by the Common Fund for Commodities (CFC), a financial wing of the UN, with the direct support of the two governments. As many as 26 field trials have been conducted under the project—16 in India (7 in low-volume roads, 6 for riverbank erosion control, and 3 for hill slope management) and 10 in Bangladesh (5 in low-volume roads, 3 for riverbank erosion control, and 2 for hill slope management). Additional sites have also been included to generate more data for credible conclusions regarding performance of JGT. The sites have been selected with an eye to geological and geotechnical distinctiveness. Works have been completed and their performance is being monitored.

One of the objectives of the project is to identify potentially important JGT for each of the three specified applications and to develop test standards for JGT. Two varieties of JGT have been identified—724 gsm with tensile strength of 25 kN/m and 627 gsm with tensile strength of 20 kN/m. The first variety is recommended for use in low-volume roads, while the latter for river-related applications. Three varieties of open weave JGT have been designed for slope management, viz., 500, 600, and 700 gsm. Choice of open weave JGT will depend on the gradient of slope, type of slope topsoil, and intensity of rainfall as indicated in the relevant chapter of this book.

The basic aim of the project is to secure global accreditation of JGT and to evolve JGT-specific design methodology for application in low-volume roads, riverbank erosion control, and hill slope management. The project took off in January 2010 and is supposed to end in June 2016. The project has been sponsored by the CFC with the aim of achieving higher uptake of jute as the ingredient of JGT which in turn could help alleviate poverty in the two major jute-producing countries in the world.

(b) National Jute Board has tied up with the University of Wollongong, Australia, for conducting extensive laboratory experiments on different varieties of prefabricated vertical jute drains (PVJD) along with field studies for corroboration of the results. Already 40,000 m of PVJD manufactured by two jute mills in West Bengal were supplied by National Jute Board. The supplied PVJD have been successfully installed at Ballina, a site with marine clay deposit in Australia. In this case also the basic objective is to substantiate the effectiveness of PVJD in soft soil consolidation and to secure global accreditation of the product. The project commenced in July 2013 and will continue till 2017. Meanwhile the project has been linked with the Australian Research Council. The preliminary results of PVJD are reportedly comparable to its synthetic counterpart (PVD) in performance. The point to watch is about performance of PVJD after jute degrades with time.

17.3 Case Studies

More than 260 field applications have been conducted so far for sub-grade strengthening in low-volume roads, for riverbank erosion control, and for slope management. As already indicated precise and comprehensive data for all the applications are not available. In this chapter five case studies in five different areas of application, viz., low-volume road reinforcement, riverbank erosion control, settled railway track rehabilitation, mine-spoil stabilization, and hill slope management—each warranting distinctly different remedial approach—are presented in brief. Interested readers may look up the original papers for further details.

17.3.1 Case Study 1

Application Area: **Restoration of a severely damaged unpaved road**[1]
Location: Kakinada Port Area, Andhra Pradesh, India

Status of the Road:

The road in question is an unpaved pavement built over a new embankment and is a part of the road communication network near a new port facility under construction at Kakinada, Andhra Pradesh, India. The road was devastated by floodwaters. The

[1] *The work was carried out by the Central Road Research Institute, New Delhi, under a UNDP project on JGT. The evaluation and the case study were done by Prof. A Sreerama Rao of JNTU College of Engineering, Kakinada, Andhra Pradesh.*

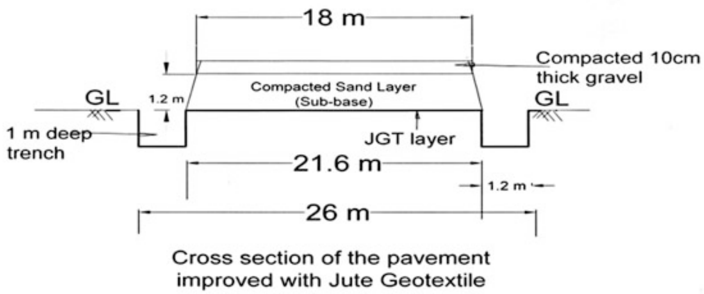


Fig. 17.1 Cross section of the road after restoration

Fig. 17.2 Condition of the damaged road

sub-grade comprised soft clay with sporadic distribution of silty sand within the clayey zone existing up to about 4 m of depth from the ground. The phreatic zone was 0.5 m below the ground level. The area often gets overtopped due to tidal influx. The formation was unstable and was susceptible to settlement under vehicular load. It was observed that as much as 30 % of the fill would sink into the subsoil necessitating the use of costly granular fill materials. The nature of the ravaged road may be seen in Figs. 17.1 and 17.2.

Objective:

Reinforcement of the embankment with the help of JGT for controlling post-construction settlement and sub-grade improvement, apart from ensuring stability of the slope and embankment and allowing controlled construction over it.

Remedial Concept:

As self-weight of the fill of an embankment generates outward shear stresses ultimately, the primary role of the reinforcing material would thus be to resist the outward shear stresses and thus relieve the foundation of the resultant effects. Woven JGT chosen as the reinforcing fabric placed as basal reinforcement under the embankment fill and over the sub-grade was supposed to counter the outward shear stresses. Additionally JGT would also act as a separating medium to prevent interpenetration of the underlying soil and overlying fill. Sand cushion was also provided to supplement drainage function.

Salient Design Aspects:

The height of the fill was 1.5 m with 30° as its angle of internal friction. Undrained cohesion was 6 kN/sqm. Factor of safety of the unreinforced embankment was calculated as 0.75—an unacceptable low value. For the woven JGT possessing tensile strength of 20 kN/m, the available factor of safety was calculated to be 3.2. The time required for 90 % consolidation was calculated as 205 days or about 7 months. Settlement was estimated to be of the order of 175–200 mm by using standard relations. Factor of safety was checked at the end of 90 % consolidation phase and was found to be 1.26 which was acceptable.

The point to note that the desired level of factor of safety reached after about 7 months implying adequate gain in the strength of sub-grade within that period after which the role of the reinforcing fabric ceased.

Year of Construction: 1997

Properties of Subsoil:

Mainly clay up to a depth of 4 m with occasional mixture of silt or sand (Table 17.1).

Installation Sequence:

The damaged sub-grade was first restored by filling the settled portions after removing water from the depressed sections followed by proper compaction with rollers to OMC and to the desired superelevation. The selected woven JGT was laid on the prepared sub-grade duly secured by stapling at suitable intervals. The base course and the unpaved riding layer were laid over JGT with a cushion of sand (Fig. 17.3).

Properties of Jute Geotextile Used (Table 17.2)

17.3.1.1 Results and Discussion

1. At the end of 7 months, the shear strength of the subsoil ensured the required factor of safety. The strength of fabric thereafter ceased to be of prime concern (Study by P J Rao).

Table 17.1 Sub-soil properties

Moisture content	70–80 %
Liquid limit	60 %
Plastic limit	28 %
Bulk density	1.3 mg/cum
Undrained shear strength (in situ vane shear test)	6.0 kN/sqm
Compression index (C_c):	0.225
Coefficient of consolidation	2.0×10^{-7} sqm s
Soaked CBR%	1.61
Un-soaked CBR%-	2.1

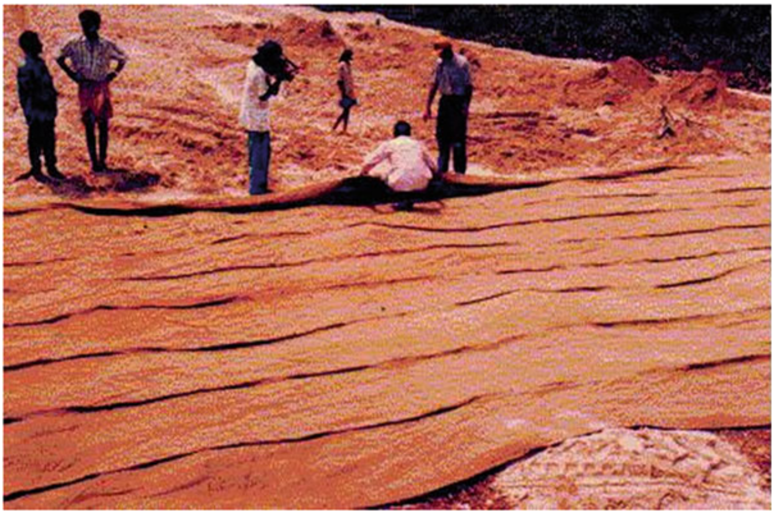


Fig. 17.3 JGT installation in progress

Table 17.2 Specification of JGT used

Type of JGT	Woven treated with cupra-ammonium sulfate
Thickness	3 mm
Weight	750 gsm
Tensile strength	20 kN/m
Elongation at break	3 %
Puncture resistance	350 N

2. Following are the findings by Prof. S Rama Rao from JNTU College of Engineering, Kakinada in which soil samples were collected at elapsed times of 3, 7, 21, and 30 months after laying of JGT. The cross section of the restored road may be seen in Fig. 17.1.

   (a) *Water content of soil before and after laying JGT* (Table 17.3)
   (b) *Dry Density of Soil Before and After Laying of JGT* (Table 17.4)

Table 17.3 Water content in soil (pre-work/post-work)

Water content %					
		Following laying at elapsed months of			
Location	Before laying JGT	3	7	21	30
1	97.4	76.3	68.7	55	50.0
2	72.7	69.1	56.3	45.4	35.3
3	76.4	69.1	68.7	59	53.4

Table 17.4 Dry density of soil (pre-work/post-work)

Dry density (mg/cum)					
		Following laying at elapsed months of			
Location	Before laying JGT	3	7	21	30
1	0.7	0.85	0.89	0.95	1.05
2	0.82	0.87	1.01	1.25	1.35
3	0.84	0.92	0.89	0.94	1.07

(c) *Time-related change in values of void ratio and compression index of soil* (Table 17.5)

(d) *CBR values of sub-grade soil before and after laying of JGT* (Table 17.6)
The test was performed 30 months after laying JGT and the following results were obtained. The increase in CBR% was almost three times for un-soaked soil and more than three times for the soaked one.

(e) It may be mentioned that the stabilized road section was unaffected by the severe cyclone of 6th Nov 1996 in which Kakinada was devastated, and the roads in other areas of port were badly damaged.
Findings of post-work assessment done by an independent expert showed that the use of the appropriate woven JGT could reduce water content, void ratio and compression index of the sub-grade, and cause increment in its dry density and CBR values.

3. Visual Observations
The unpaved road is in satisfactory condition with no noticeable distress on surface even after 17 years of construction (Fig. 17.4)!

17.3.2 Case Study 2

Application Area: **Control of riverbank erosion**[2]

[2] *The work and the case study were carried out under guidance of the author by the Special River Training Cell, Haldia Dock Complex, and later by the Hydraulic Study Department, Calcutta Port Trust, India.*

Table 17.5 Void ratio & compression index of soil (pre-work/post-work)

	Void ratio					Compression index				
		Following laying at elapsed months of					Following laying at elapsed months of			
Location	Before laying	3	7	21	30	Before laying	3	7	21	30
1	2.63	2.1	2	1.7	1.6	0.65	0.52	0.5	0.5	0.45
2	2.1	1.8	2	1.3	1.1	0.61	0.56	0.5	0.4	0.38
3	2.1	1.9	2	1.6	1.4	0.61	0.60	0.5	0.4	0.40

Table 17.6 CBR values of sub-grade (pre-work/post-work)

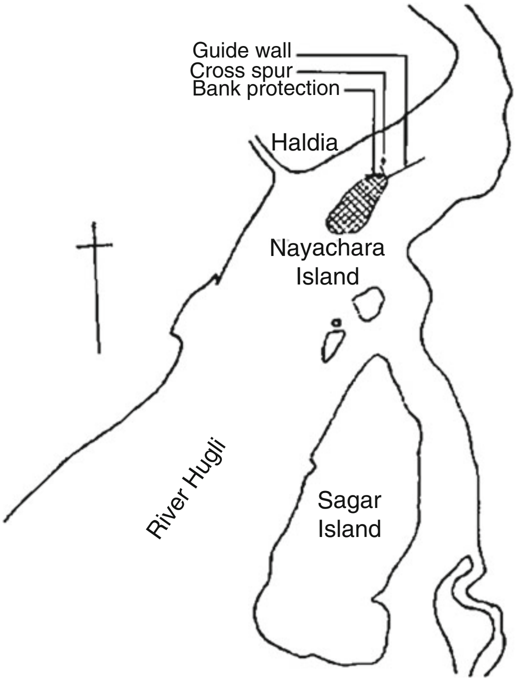
Natural soil (before laying JGT)		Improved soil (after laying JGT)	
Un-soaked CBR (%)	Soaked CBR (%)	Un-soaked CBR (%)	Soaked CBR (%)
2.1	1.61	6.03	4.78

Fig. 17.4 Finished road after 17 years

Location:

Western bank of Nayachar island, 21 nautical miles away from the face of the Bay of Bengal, in the estuary of the river Hugli opposite Haldia Docks, West Bengal, India (Fig. 17.5). The estuarine reach of the mighty river Hugli, the name of the holy river Ganga in its tidal reach given by the foreign settlers in Bengal, is fraught with a number of sandbars and sharp meanders experiencing varying degrees of tidal fluctuation and unpredictable geomorphologoical changes. The river-reach is plagued with eroding banks and small unstable islands that have come up within the vast expanse of the river estuary. One such island—Nayachar island—which raised its head in 1947 and divides the river flow into two was subjected to severe erosion in its western face close to a massive guide wall being built to divert a major share of the flow along Haldia channel on which Haldia Docks are located.

Fig. 17.5 Location of the site in the Hugli estuary



Nature of Erosion:

The island is built on alluvial deposition spread over the last several decades and is understandably unstable. There was no habitation in the island at that point of time. The primary reason of erosion could be due to waves generated by ship movements along the 3 km wide Haldia channel and high current close to the bank along with vortices near its toe. The affected stretch was near the northern tip of the island where a massive guidewall with an adjoining cross spur was under construction for flow diversion along Haldia channel. It was observed that the rate of erosion was maximum immediately after the monsoon when the discharge from upland was the highest. Erodibility of bank soil and erosivity of flow hugging the bank combined to contribute to the bank erosion (Figs. 17.6 and 17.7).

Objective:

The objective was to protect the eroded western bank of the island from erosion.

Remedial Measure:

The conventional remedial approach against bank erosion is to provide a layer of inverted granular filter overlain with a riprap. Tidal rise as well as rise in water level due to high upland discharge causes water to penetrate into the bank soil. The intruded water tries to force its way back into the river during drawdown, i.e., when the water level goes down and destabilizes bank soil in the process. Filtration

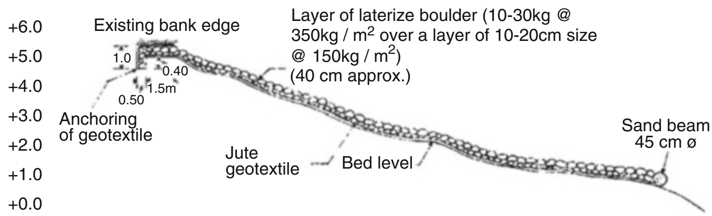


Fig. 17.6 Cross section of the restored bank with details

Fig. 17.7 Eroded river bank at Nayachar island

function has therefore to be ensured in such cases for control of migration of bank soil and for facilitating passage of pore water. It was decided to use woven JGT coated with hot industrial bitumen (as no other water-repellent additive was known at that point of time and considering the fact that jute has excellent thermal compatibility up to about 170 °C) armored with a stone riprap on top of the fabric. This was an experiment never tried before with JGT.

Year of Construction: 1988–1989

Geohydrological Data:

Nayachar island is a land outcrop in this reach bifurcating the river flow. The channel to its east, Rangaphala Channel, is wider—about 9 kms in width—while the channel to its west, Haldia Channel, is about 3 kms wide. Haldia Docks are located on Haldia channel. Notably the two channels experience variation in tidal rate of flow. Geohydrogical data of the river Hugli in its estuarine reach is given in the table (Table 17.7).

General Composition of Bank Soil

The composition of the eroded bank soil is given in Tables 17.8 and 17.9.

Table 17.7 Geo-hydrological data of the river

Tides	Semidiurnal with periodicity of 12.42 h
	Average flood period, 5 h
	Average ebb period, 7.42 h
Tidal range	Minimum neap, 0.71 m
	Maximum spring, 6.25 m
Current	Peak velocity in spring, 3.0 m/s
Wind	Mid-April to mid-September, strong southwesterly winds
	March to May, Norwesters reaching up to 9 in Beaufort scale
Wave	Wind generated waves, 1.6 m high.
	Periodicity, 6 to 8 s
Salinity	Varied from 6 ppt. during freshets to 18 ppt. in the post freshet season

Table 17.8 General composition of bank soil at different depths

	Sand (%)		Silt (%)	Clay (%)
Depth (m)	Med. 2.0–0.425 mm	Fine 0.425–0.075 mm	0.075–0.002 mm	<0.002 mm
3		0.50	65.50	34.0
6		0.30	61.70	38.0
9	0.32	50.80	48.88	–

Table 17.9 Specification of JGT used

Type of JGT	D. W. Twill
Thickness (mm at 100 g/csqm)	2.83
Weight, gray/bituminized (gsm)	850 gsm (gray)/1538 (bituminized)
Tensile strength-gray (kN/m)	20
Elongation at break (%)	11.8 (warp)
	13.5 (weft)
Puncture resistance (Kgf/csqm)	37.9
Air permeability (cum/sqm/min)	16.2
Water permeability at 10 cm water head (l/sqm/s)	20.4
Pore size (microns)	150

Evidently the topsoil of the bank up to 6.0 m is clayey silt. With depth, the proportion of clay gets reduced and at 9.0 m and under the soil becomes far more erodible with no clay in its content. (Also refer to Tables 17.10a, b.)

Properties of Jute Geotextile Used

Physical characteristics of JGT used is shown in Table 17.9.

Installation:

The damaged bank was cut to a stable profile in keeping with the angle of internal friction of the bank soil and dressed evenly removing all muddy elements. Bitumen-

Table 17.10 Bank soil properties

A

Sample no.	N. M.C. (%)	M.C. (saturated) (%)	Bulk density	Saturated Density	Permeability (cm/s)
1	54.20	57.15	1.67	1.72	3.60×10^{-4}
2	47.07	53.91	1.64	1.70	0.89×10^{-4}
3	46.72	55.0	1.63	1.71	6.7×10^{-5}
4	51.83	57.92	1.67	1.76	–
5	46.71	54.88	1.65	1.74	1.266×10^{-4}

B

Sample no.	L. L. (%)	P. L. (%)	P.I. (%)	Sand (%)	Silt (%)	Clay (%)
1	54	20	34	–	51	49
2	51	24	27	–	51.5	48.5
3	50	26	24	8.5	58.5	33
4	51	25	26	14	49	37
5	49	26	23	–	60.5	39.5

treated woven JGT as specified was laid over the prepared bank (Fig. 17.8) duly anchored at the bank top edge in a trench duly secured by stapling (Fig. 17.10) and with a toe beam improvised by folding the end of the JGT roll (45 cm dia) and filling the hollow of the folded portion of JGT with the available sand. Riprap was placed over JGT in two layers (Fig. 17.9. First smaller-sized laterite ballasts (10–20 cm size) were placed at 150 kg/sqm followed by laterite boulders (10–30 kg weight) spread at 350 kg/sqm (Fig. 17.5).

Conclusion:

There were no signs of any subsidence or distress of the protected stretch after a period of 25 years (Fig. 17.11)! Though the stability cannot be attributed to JGT alone as measures to reduce the effects of vortices at the bank-toe (by constructing short submerged spurs) was concurrently taken; JGT certainly helped grow salt-tolerant vegetation on the bank soil and played a major role in protection of the severely eroded embankment. Samples of jute were also tested. Strength in both directions was found to have reduced by about 70 % after about 18 months. The study is a pointer to catalytic functioning of JGT. The average siltation over this period was estimated to be around 50 cm over the riprap after 1.5 years.

Inspection was again carried out in November 2001. No subsidence and disturbance of the armor layer were observed. Jute Geotextile samples were exhumed from the site. The samples taken out showed that they had not lost their porometric features retaining distinct signs of bituminous treatment. There certainly has been considerable degradation in their strength, but the samples were neither torn nor punctured. The fabric perfectly draped the bank soil.

The undisturbed bank after more than two decades implies that JGT performed its expected functions and helped in natural consolidation of the bank soil.

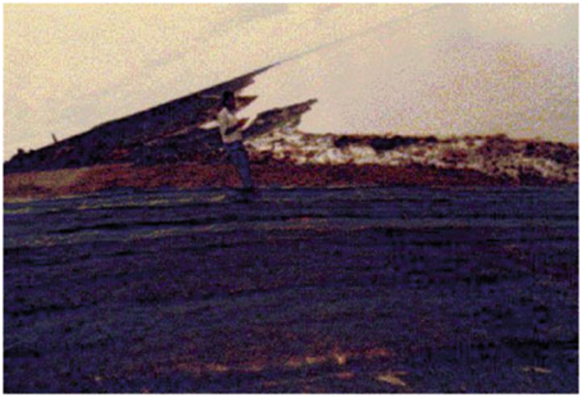


Fig. 17.8 Bituminized JGT laid on prepared slope of the eroded bank

Fig. 17.9 Riprap laying in progress

Durability of JGT beyond 1.5 years, even under continuing adverse conditions, proved to be redundant due to catalytic function of JGT in the initial phase of application by which time the process of consolidation of the bank soil started which continued even after (Fig. 17.6).

Soil samples collected from under JGT were tested in the laboratory of Jadavpur University. The test results are presented below.

17.3.2.1 Note on Treatment of JGT

Admittedly the most suitable additive to act as water-repellent apart from its environmental limitations should be used in river-related applications of this nature. As there was no such alternative additive with proven water-repellence property at that time, industrial bitumen was used. JGT was heavily coated with bitumen.

Fig. 17.10 Anchoring of JGT in a trench

Fig. 17.11 Bank condition after 20 years

17.3.3 Case Study 3

Application Area: **Restoration of settled railway track**[3]

[3] *The work and the case study were carried out by Eastern Railway*, *Howrah division of Indian Railways. The remedial concept was based on the paper presented by the author in the Indian Geotechnical Conference held at IIT*, *Bombay, in 2000* (“*Track subsidence in railway embankments – A case for Jute Geotextiles as solution*”).

Location:

Gurap section of Howrah-Bardhaman Chord line, 36 km west of Howrah Station in the Eastern Railway, India

Nature of the Problem:

The railway embankment in question was built long back with fills of cohesive nature having varying compositions—silty clay to silty loam. Out of the three tracks laid on the embankment, the central track did not undergo any settlement, while the two outer tracks settled (Fig. 17.11). The track to the south was more affected than the northern track. The nature of the problem was several. The track alignment was not in shape, cross level of the outer tracks was disturbed, and cess was eroded. The slope of the embankment was steeper than the angle of internal friction of the fill, and there were palpable signs of surface soil erosion on the slope. The section is extremely busy on which important express trains such as Rajdhani Express and Poorva Express run, besides heavy goods traffic. The problem of persistent track settlement in the section prompted the Railway authority to conduct studies to find out the root cause of distress. The first study was conducted in 1968 followed by two others—one in 1977 and the other in 1987.

The study in 1968 confirmed existence of shrinkable soil but not black cotton soil. Shear strength of the fill ranged between 1.47 and 1.96 T/sqm. Dry density was found to be in the range between 70 and 80 %. Driving *sal* (*Shorea robusta*, a large gregarious tree) *bullahs* (spike-like poles) as palisades was recommended. In the second study, it was advised to provide sand drains and lime-filled columns at critical locations with slopes flattened to 1:2.5. In the third study, installation of sand drains with a sand blanket was advised. The Railways reportedly implemented all the recommendations, but the settlement could not be controlled. The Railway's design wing (RD&SO) recommended provisions of sub-bank and wooden piling at the distressed locations. Railway engineers were concerned more about the disturbed track alignment and cross gradient of the tracks for reasons of safety in train movements.

Objective:

The aim was to restore the settled sub-grade of the track (maximum settlement, 72 mm) and to set the tracks to right alignment and cross level.

Remedial Concept:

Cohesive fills have inherent tendency to hold water. Inadequate drainage coupled with insufficient compaction of the fill at OMC during construction could be the reasons for the settlement under heavy moving traffic. Ballasts were seen to have penetrated into the sub-grade layer. The first trial was done in the southern track which was more severely affected in the stretch between Madhusudanpur and Belmuri stations.

The remedial concept was based on the following measures:

(a) To quickly drain off rainwater before it could reach the track sub-grade

(b) To provide a separator between the sub-grade and the overlying ballast layer
(c) To improve the bearing capacity of the sub-grade by controlling soil migration, optimizing the tension membrane effect of the separator geotextile (in this case JGT)
(d) To prevent lateral dispersion of the embankment toe
(e) To reclaim cess and slope surface

The measures based on the causes of settlement were supposed to stabilize the embankment as a whole and as a result would be able to ensure the alignment and cross level of the track after having been set right. Remedial arrangements may be seen in Fig. 9.1 of Chap. 9.

Year of Construction: 2004

Features of the Site:

- The old railway embankment was built with cohesive fills of varying composition—silty clay to silty loam—and of varying height ranging between 1 and 6 m.
- Side slope of the embankment varied between 1:2 and 1:1.5.
- The cess at the side of the southern track was almost nonexistent due to unabated erosion of the topsoil.
- Water-filled borrow pits almost touched the toe of the embankment at most places.

Properties of Sub-grade Soil:

The fill of the embankment on which the tracks were laid is dominantly of shrinkable type. It is however not black cotton soil. It holds water for which it takes time to consolidate. The table reveals (Table 17.11).

Methodology of Application of JGT:

The methodology was so planned as not to interrupt train movement during the entire period of execution (83 days).

Woven JGT was laid on the sand spread over the sub-grade, and nonwoven JGT was laid over woven JGT after scooping out the base layer and exposing the sub-grade. Nonwoven JGT was placed as shock absorber and as a supplementary drainage medium.

Nonwoven JGT-encapsulated rubble (brick ballast) drains at a suitable gradient were inserted under the sub-grade with their open ends (outlets) ending on the embankment slope.

Table 17.11 Properties of embankment fill

Properties	Value
Type of soil	Shrinkable but not of black cotton type
Shear strength (T/sq m)	1.47–1.96
Natural dry density	70–80%

Open weave JGT was used to guard against erosion caused by precipitation on the slope of the embankment (slope corrected to 1:2.5) for topsoil erosion control. Dwarf toe wall (with boulders encapsulated in wire nets) was also constructed as lateral restraint against possible dispersion of the fill comprising the embankment. Borrow pits filled with water was in existence close to the embankment toe.

Implementation of the measures in different phases was decided as follows:

- **Step 1:** Scooping out the ballast layer, exposing the sub-grade in the space between two sleepers by making the track lines rest on old rail clusters and wooden blocks, cleaning the sub-grade of the penetrated stone ballasts, and spreading sand over the sub-grade (Figs. 17.12 and 17.13). This was followed by placing woven JGT over the sand layer topped by nonwoven JGT (Fig. 17.14). Additional sand layer (22.5 to 30 cm thick) was provided over nonwoven JGT for absorbing a part of the dynamic stresses induced by the moving trains. Sand layer was mechanically vibrated. Ballasts scooped out were put back after washing.
- **Step 2:** Installation of concealed nonwoven JGT-capsulated rubble drains at suitable intervals starting from just under the sub-grade and finishing on the exposed slope following an easy gradient was done by digging earth. After installation of the drain, it was covered up with earth. Saucer-shaped open surface drains were constructed on the embankment slope to guide water coming out of the concealed drains and to prevent rain-gully formation.
- **Step 3**: The eroded cess was rebuilt with earth (cess width at least 900 mm). Berms were made where the height of the embankment exceeded 3 m. Dwarf toe wall at the toe of the embankment was constructed with boulders encapsulated in wire nets.
- **Step 4**: The slope of the embankment was dressed to 1:2.5 gradient or supplemented with borrowed earth to make the desired gradient ensuring proper compaction. Open weave JGT was laid on the corrected slope followed by spreading of seeds of locally thriving vegetation or by grass sods.

The most challenging task was to complete the activities in Step 1 in the space between two sleepers in 1 day which measured 1.30 m (length) × 4.00 m (width) × 0.80 m (depth). Seven labor groups were formed with six men in each group to ensure completion of the activities between two sleeper spaces in 1 day (seven such spaces were covered in each day by seven labor groups deployed for the purpose). The entire work took 83 days to complete and this was achieved without disturbing train movement.

Properties of Jute Geotextiles Used

Physical characteristics of JGT used are shown in Table 17.12.

Conclusion

The settlement which was of the order of 72 mm could be reduced to only 12 mm. The extent of settlement has remained steady even after 11 years (Figs. 17.15 and 17.16)! The remedial package proposed by the author was suggested considering

Fig. 17.12 Prework situation

Fig. 17.13 Exposing sub-grade

the causes of settlement and by the judicious use of JGT in its three main varieties, viz., woven, nonwoven, and open weave.

17.3.4 Case Study 4

Application Area: **Stabilization of mine-spoil heap**[4]

[4] *The case study was carried out by a team of ICAR-Indian Institute of Soil & Water Conservation (erstwhile CSWCRTI), Dehradun, comprising G P Juyal, S K Dhyani, and V N Sharda.*

Fig. 17.14 Laying of JGT (woven and nonwoven)

Table 17.12 Specification of JGT used

Properties	Woven (bitumen treated)	Nonwoven	Open weave
Weight (g/sqm) at 20 % MR	1200	1000	500
Threads/dm (MDXCD)	102 × 39	–	6.5 × 4.5
Thickness (MM)	2	8	4
Width (cm)	76	150	122
Strength (kN/m) [MDXCD]	21 × 21	6 × 7	10 × 7.5
Elongation at break % [MDXCD]	10 × 10	20 × 25–	–
Pore size (O_{90}), micron	150	300	–
Water permeability at 10 cm water head (l/sqm/s)	20	–	–
Puncture resistance	400	–	–
Coefficient of water permittivity (m/s)	–	3.4×10^{-4}	–
Water-holding capacity (% on dry wt.)	–	–	500
Open area (%)	–	–	50

Location: Dhandaula Kharawan limestone quarry, Sahasradhara, 18 km away from Dehradun, Uttarakhand, in the lesser Himalayas in the Doon Valley, India

Nature of the Problem:

Mine spoils and landslides are common in lower Himalayas causing land degradation, resulting in deterioration in quality of water and affecting water resources besides disrupting communication links. Lands degraded due to slides possess poor fertility and thus make their reclamation with vegetation difficult. On top of this, the

Fig. 17.15 Finished railway track

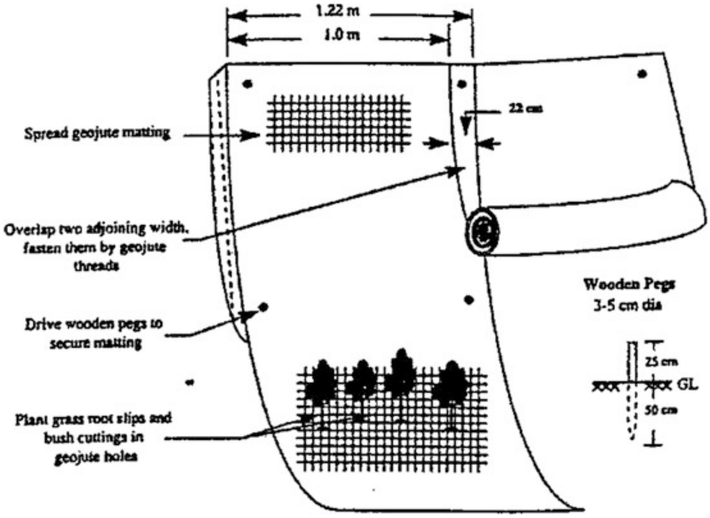


Fig. 17.16 Remedial concept (After Juyal et al. 1994)

ingredients of mine spoils are by nature not conducive to vegetation growth. The site hosts a limestone mine. Mine spoils are inherently erodible.

Mining activities used to disquiet the stability of mine-spoil heaps by shaking and by destroying the cover of vegetation. The type of natural vegetation is of mixed deciduous species of subtropical variety. Steepness of slope aided by high precipitation contribute to heavy debris movement spilling on the road abutting the spoil heaps and ultimately finding passage to the waterway causing reduction to its

Fig. 17.17 Mine-spoil heap at Sahasradhara

carrying capacity which sometimes brings about overflow of the riverbanks (Figs 17.17 and 17.18).

Objective:

Stabilization of the failed slope and protection against along slide of soil, debris, and boulders during heavy rains along with restoration of vegetative cover destroyed due to mining activities and improvement of water quality.

Year of Construction: 1987

Physiography:

The affected area measuring 64 ha having elevation ranging from 842 to 1310 m comprises The site is characterized with weak geology comprising limestone, gypsum, slates, marble, dolomite, etc. Mine spoil has high gravel content (60 % of the spoils is larger than 16 mm size, and is calcareous ($CaCO_3$-55 %) and possesses low fertility (organic carbon 0.13 %, nitrogen 0.02 %, and P_2O_5-5.4 kg/ha). The spoil being essentially non-cohesive does not hold water. The nature of spoil does not conduce to vegetation.

The average slope of the area was about 50 %. The mine spoil flows directly into the river Baldi, a tributary of the Ganga.

Rainfall Pattern:

Rainfall of 3000 mm (average) annually 80 % of which is received during monsoon months (mid-June to mid-September)
Max. 1 day (24 h.) rainfall, 369 mm
Max. rainfall intensity, 240 mm/h (5 min. duration) and 120 mm/h (3 min duration)

Fig. 17.18 Disintegrated mine spoil

Ecology:

Ecologically this area is an example of vegetation of edaphic subclimax, i.e., vegetation changes with modifications in soil composition.

Soil Characteristics:

Soil type—sandy loam (SL)
Sand content—66.6 %
Silt content—19.5%
Clay content—13.9%

Remedial Approach:

Based on the topographical, vegetative, and soil surveys, a corrective plan consisting of a combination of engineering and vegetative measures was devised and implemented (Fig. 17.16). Steep slopes were vegetated with the application of Jute Geotextile as jute on its biodegradation is supposed to coalesce with the soil-spoil mix, adds micronutrients to the mix, acts as mulch, and increases its hydraulic conductivity. The approach was decided with the objective of controlling topsoil erosion by the roots of the vegetation and protecting it against direct impact of raindrops that causes its disintegration. It is a bioengineering approach—more aptly an engineered agronomic intervention. Satisfactory performance in previous applications of similar nature with JGT and other geotextiles weighed in favor of choosing JGT.

Fig. 17.19 JGT laid over the heap

Installation:

Seeds of *Acacia catechu* and *Leucaena* were spread over the treated area and scarified. Locally available grass mulch was also spread at 2–3 tonnes/ha. The selected open weave JGT was then laid over the area to be treated taking care to ensure the fabric draped the contours of the mine-spoil heap. The two adjoining widths of the fabric were overlapped by about 20 cm and fastened with jute threads. Wooden stakes (1.5–2 m long and 5–7 cm diameter) were driven to a depth of about 1 m to secure JGT at specified intervals. The stakes additionally provided mechanical support to the spoil (Figs 17.19 and 17.20).

Rooted slips of grass species (*Saccharum spontaneum*, *Thysanolaena maxima*) along with cuttings of *Ipomea carnea*, *Vitex negundo*, hybrid Napier were planted in openings of open weave JGT at close intervals. At one of the locations, trenches (30 × 30 cm) were dug which were filled with good soil from outside and mixed with Napier grass.

Properties of Geotextile Used

Table 17.13 shows the properties of JGT used in the work.

Results:

(a) Vegetation establishment:
The entire area covered with JGT showed better vegetation establishment compared to control. *Thysanolaena maxima* grass recorded a yield of 3052 kg/ha (oven dry) compared to 640 kg/ha in control after 3 years of plantation. Hybrid Napier when planted in contour trenches filled with good soil mixed with farmyard manure (FYM) recorded an excellent yield of 9850 kg/ha compared to 1960 kg/ha in control. *Saccharum spontaneum* also showed good results. The roots of grass were found to have provided good anchorage to the spoil in the second year of plantation. Tree species planted in

Fig. 17.20 JGT under installation

Table 17.13 Properties of open weave JGT used

Properties	Value
Weight (gsm) at 20 % moisture regain	500
Threads/dm (MD × CD)	6.5 × 4.5
Thickness (mm)	4
Width (cm)	122
Open area (%)	50
Strength (kN/m) [MD × CD]	10 × 7.5
Water-holding capacity on dry weight (%)	500

the affected however did not survive long. JGT biodegraded after about 2 years but by then there was sufficient growth of self-sustaining vegetation.

(b) Moisture improvement:
JGT helped in moisture conservation (10–15 %). It was observed that in the slopes treated with JGT, moisture control reached below wilting point in 7 days compared to 3 days only in control after a rainfall of 20 mm (in the top 15 cm layer). A good amount of moisture below 30 cm depth was observed even after 1 month from the day of 20 mm rainfall.

(c) Erosion control:
Monsoon run-off was reduced from 57 to 37 % due presumably to water-absorbing characteristics of jute. Flood peaks were reportedly delayed by 20 min and attenuated by more than 60 %. Soil erosion was reduced to 8 tons per/ha close to permissible limits within a period of 6 years. Huge quantity of spoils (62,000 cum) could be retained as a result of the measures. The area now wears a green look (Figs. 17.21 and 17.22).

Fig. 17.21 Situation after 9 years

Fig. 17.22 JGT installed over slope

(d) Water resource improvement:
With more infiltration of run-off water into the soil profile by conservation measures, new water sources/springs reportedly regenerated in the watershed. The dry weather flow measured in the months of November and February was 265 and 100 cum per day, respectively, an improvement in water availability for domestic and irrigation purposes.

(e) Soil improvement:

- Organic carbon content increased from 0.13 to 0.26%
- Available P_2O_5 increased from 5.4 to 32 kg/ha
- $CaCo_3$ content decreased from 55 to 34 %
- pH value reduced from 8.1 to 7.7 over a period of 7 years

17.3.5 Case Study 5

Application Area: **Stabilization of slide-prone hillslope**[5]

Location:

Paglajhora on National Highway no 55 (NH-55) off Siliguri, a town in the northern part of West Bengal in India, in the foothills of the Eastern Himalayan range (locally known as “14th Mile hill slide”) covering an area of about 50,000 sqm

Nature of the Problem:

Frequent landslips and erosion of topsoil layers due to rain-induced erosion disrupting the major communication link National Highway 55.

Year of Application: 2011

Site Condition**:**

The area comes under a geologically active slide-prone seismic zone on NH-55 off Siliguri in the northern part of West Bengal close to the foothills of the Eastern Himalayan range. The topsoil contains debris, a conglomeration of dark clayey ingredients mixed with sand which flow down the slope when triggered by either anthropogenic or geological disturbances. Plasticity index of the topsoil was low indicating lack of cohesiveness and high erodibility.

Slopes are steep with an average angle of inclination of about 30–50^0. The hillslope is marked by a large number of small natural falls (known locally as *jhora*). Annual rainfall varies between 2800 and 4200 mm with intensity ranging between 400 and 100 mm/h. Slide zones are located within the upper catchment of *Shivkhola*, a small tributary with substantial celerity. The stream possesses high erosion potential that runs close to the toe of the slide. Slope destabilization as per information from reliable sources started due to the shift of river course toward the toe of the downslope.

Causes of Slide:

The major reason behind slide-proneness is attributed to massive deforestation in the area. Besides a perennial pool of water was located on top of the hill which could be the major source of water penetrating through the slope fill and finding its way out through fissures and crevices destabilizing the core of the slope. Small waterfalls are the outcome of this phenomenon. Fissures and crevices developed as result geological fragility and occasional seismic tremors. Anthropogenic operations like blasting during construction of the highway might have a role in

[5] *The case study no. 5 was published in the proceedings of Indian Geotechnical Conference, December 15–17, 2011, held at Kochi, India (Paper No. Q—381), authored by T Sanyal, P K Choudhury, and N Mondal.*

destabilization. A section of geologists who investigated the cause of geological fragility of the area is of the view that shift of the course of the river Shivakhola might have disquieted the stability.

Remedial Measures Undertaken**:**

Prof. Mamata Desai of the Netaji Institute for Asian Studies conducted a study on the area in November 2010 along with Devashis Chatterjee, former Deputy Director General, Geological Survey of India (GSI), followed by another study by Jaydeep Mukherjee of GSI. Prof. Desai in her report recommended opening up of an alternative alignment for the highway in place of the existing one. But till such time an alternative route is constructed, it was imperative that the existing route would have to be maintained.

The following remedial measures were recommended for immediate implementation. These are:

- A strong toe wall to prevent lateral dispersion
- Cross drainage works for passage of the water of the tributary *Shivakhola*
- Channelizing the discharge of the small waterfalls along stone-faced cascades bounded at the two sides with short sidewalls taking into account the maximum discharge experienced during the monsoon (Fig. 17.23)
- Easing the existing slope to the extent possible by benching
- Installation of Jute Geotextiles of 730 gsm open weave type followed by vegetation establishment (Fig. 17.22)

Installation of JGT

Prior to installation of open weave JGT on the slope, locally available grass seeds were spread directly on the prepared slope. JGT was placed at the top and rolled down to the slope toe. A second dose of seeds was sprayed by hydro-seeding (i.e., spraying a mix of emulsified seeds, fertilizer, growth hormone, enzymes, and soil bacteria) over installed JGT.

Properties of Jute Geotextile Used

Specification of JGT used in the work is shown in Table 17.14.

17.3.5.1 Results and Discussion

- Vegetation establishment: The area treated with JGT was seen to have well stabilized with vegetation growth all over the treated area arresting landslides and erosion of topsoil.
- Open weave JGT was found to be effective to revegetate as a step to stabilizing the highly erodible slopes.
- Even after heavy precipitation in June, 2015, no damage was caused over JGT-treated area though the adjoining slopes experienced destabilizing landslips (Fig. 17.24).

Fig. 17.23 Cascading in progress

Table 17.14 Specification of open weave JGT (soil saver) used

Construction	Open weave Jute Geotextiles (Soil Saver)
Width (cm)	122 cm
Weight (gsm) at 20 % MR	730
Thickness (mm)	7.00
Ends × picks/dm	7 × 7
Wide-width tensile strength (kN/m) {MD × CD}	12 × 12
Elongation at break (%) {MD × CD}	10 × 12

All said and done, it is advisable to search for an alternative route bypassing the distressed zone for the highway. JGT could successfully put on check the topsoil destabilization of the hillslope temporarily, but this was not a permanent solution for overcoming the inherent geological instability of the slope. The experiment is a pointer that engineered agronomic interventions such as the one done in the instant case could be useful for providing palliative solutions to control topsoil erosion.

It may be noted that the case studies 1, 2, 3, and 4 were the *firsts* in the respective applications with JGT undertaken as experimental initiatives. All the experiments met with success and paved way for better understanding of the mechanism of functioning of JGT. It may be admitted that the technology was not perfected when these trials were carried out leaving room for optimizing the specifications of different varieties of JGT and installation methods. The last study, i.e., Case Study 5, although undertaken as a palliative measure, goes to show that JGT if judiciously applied can provide interim stability to a fragile hillslope by appropriate bioengineering interventions. Success of all JGT applications so far also dispels the perception of long-term durability of geotextiles to be effective.

Fig. 17.24 Stabilized slope after reclamation with JGT

Laboratory simulation tests on JGT were first comprehensively conducted by Profs. S D Ramaswamy and M A Aziz of the National University of Singapore in 1989. Since laboratory tests give qualitative indication of the effects of JGT, plate load tests were conducted by them to evaluate in situ behavior of the sub-grade comprising soft to medium silty clay of natural water content of 35 % and in situ vane shear strength of 20 kN.sqm. Plates of 300 mm diameter were loaded directly on the uncompacted sub-grade in the first series and on JGT laid over the sub-grade in the second. The plate load tests confirmed that JGT helped improve the bearing capacity and settlement behavior of the sub-grade. The results were in tune with similar tests carried out with man-made (synthetic) geotextile (Jerret et al. 1977).

The effect of cyclic (repetitive) loading on soft sub-grade of a road was studied by Prof N Som and Dr R B Sahu of Jadavpur University, Kolkata. There was clear indication of increasing strength of the sub-grade made of natural soil with the number of cycles. This could be due to drainage of the upper part of the sub-grade which was facilitated by JGT. At footing pressure of 50 kN/sqm, gain in sub-grade strength was observed to increase from 1.20 with 1000 load repetitions to 1.58 with 16,000 load repetitions. At footing pressure of 75 kN/sqm, the observed increment in sub-grade strength was from 1.38 with 1000 load repetitions to 2.28 with 16,000 load repetitions.

No such laboratory simulation tests however could be conducted in case of riverbank erosion control due to problems in simulating a host of varying influencing parameters in a river. The National Soil Resources Institute under Cranfield University, UK, conducted laboratory simulation tests on slopes in which rainfall was reproduced. Prototype studies on effects of three potential open weave JGT at different inclinations have recently been conducted by ICAR-Indian Institute of Soil and Water Conservation (erstwhile CSWCRTI), Dehradun at its Nilgiri farm in Tamil Nadu, India. Both the studies have been conducted under the ongoing international project on JGT funded by the Common Fund for Commodities (CFC), Amsterdam. The results in both the studies indicate positive role of JGT in reducing soil loss besides other benefits.

A field case study on performance of Bituminized Jute Paving Fabric (BJPF) is in progress. The Department of Jute and Fibre Technology, University of Calcutta, is supposed to be on the job. A case study with prefabricated vertical jute drain (PVJD) is in progress in the University of Wollongong, Australia. Results will be known some time in 1917. Interim results reportedly signify good performance of PVJD compared to synthetic prefabricated vertical drain (PVD) in consolidating soft marine clay.

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Chapter 18
Future of Jute Geotextile

Abstract The last chapter deals with the author's views on the future of Jute Geotextiles (JGT), given its environmental advantages, limitations, availability, present trend of response from end-users, and readiness of manufacturers regarding its large-scale use.

Keywords User-base • Sack-making • Standardization of JGT application • Volatility of raw jute price • Credibility of testing laboratory • New variants

Though this treatise is meant for technical people principally civil engineers, it will however not be out of place if I briefly dwell upon the aspect of future acceptability of the innovative natural product. In a recent report submitted by PricewaterhouseCoopers (PwC) to the National Jute Board, it is predicted that the global demand for geotextiles may reach a figure of 4780 million sq meters by 2018. The estimate is based on the trend of consumption of geotextiles including natural geotextiles of which JGT is one. The major market of geotextiles globally is now under the control of man-made geotextiles with a share of 95 %! Natural geotextiles have a share of the remaining 5 % of which JGT occupies only 1 %. Coir Geotextile (CGT) has a larger share than JGT. This is not unexpected given the fact that availability of coir fiber is widespread, while jute is confined to three countries principally, viz., India, Bangladesh, and China. CGT scores over JGT in respect of durability but has limitations in respect of fineness and spinnability. As has been indicated in the preceding chapters of this book, porometry of a geotextile is of prime importance for a geotextile to function effectively. CGT with its thick and somewhat rigid fiber cannot comply with the fine porometric requirements of a customized geotextile.

Jute needs a favorable climate and soil to grow which is why it cannot be cultivated everywhere. The problem can perhaps be obviated by setting up yarn banks at different places. Careful transportation of yarns and their storage need be ensured for this purpose. Yarn banks may help local entrepreneurs to manufacture customized JGT and broaden the user-base of the product. Manufacture of JGT does not require any special machinery other than the conventional ones used in most textile industry—may be with minor modifications.

But the main issue is to broaden the user-base of JGT. Till date the marketing efforts for JGT have not been as intensive as desired. The jute industry in India looks up to the government for support. Sack-making was and still is the main stay

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of jute mills because of mandatory orders of the Government for the use of jute sacks for food grain storage. The monopoly is in the wane as a result of intrusion of man-made sacks and packaging products. Admittedly all newly developed products need government support in the initial stages till such time such products are accepted by the users. But such dependence on the government cannot go on indefinitely. For this jute industry has to reposition its strategy. Consumers' perception about a product, its special attributes, and effectiveness should get reflected in it. Jute industry has to shift from its overreliance on sack-making and to look beyond sacks. There is global consensus among engineering fraternity to use eco-friendly and effective products wherever technically suitable-for tackling environmental degradation. JGT can claim to be one such product. It will however be too much to expect that the use of JGT would be ubiquitous for addressing all sorts of geotechnical problems like its man-made counterpart and its variants. JGT has inherent limitations. Target segments for JGT therefore need be identified, consumers' demand understood, and its shortcomings located and remedied.

The first step would be to standardize JGT applications. India and Bangladesh have already taken initiatives in this direction. The next step would be to secure global accreditation (see Chapter XI for details). This requires proper documentation of field and laboratory findings. Credibility of the laboratory is also to be ensured. In India accreditation of the National Accreditation Board for Testing and Calibration Laboratories (NABL) is a stamp for such credibility. Only a few geotextile laboratories in India have NABL accreditation to date.

The other issue of concern is the fluctuation of the cost of JGT resulting out of volatility of the price of raw jute. It is to be kept in mind that users of JGT are mainly the engineering departments which draw up work estimates on the basis of costs incorporated in the respective schedule of rates (SoR). The rates of SoR remain in force for at least 1 year. JGT price should remain valid during that period. It is felt that a mechanism should be in place to cater to the escalated price of JGT if escalation takes place within a year. Provision for the rise in the price of JGT should be incorporated in the tenders.

I am not a marketing expert. From my experience spanning over 15 years in this field, I am of the view that there should be full government support initially for a period of 5 years in the shape of mandating its use in areas where technically suitable, especially in jute-rich India and Bangladesh. A commendable step has been taken in the last year by the Government of West Bengal in India by issuance of an order to this effect. In non-jute growing states in India, the government may consider earmarking a fair percentage of low and medium volume roads to be constructed and erosion control measures to be undertaken for using JGT as a matter of policy. The initial focus should on the domestic market which may be subsequently expanded overseas.

One of the difficulties reportedly faced by exporters of JGT is the high freight for transportation. The Government may be approached for considering dilution of the government taxes/duties for export of JGT and other jute goods. Jute being one of the major foreign exchange earners of India and Bangladesh, richly deserves favorable consideration in the matter. The other issue is regarding strict compliance of quality and adherence to delivery schedule agreed upon between the overseas buyer and the domestic seller. There can be no room for relaxation on these two points. The jute industry needs to take the initiative of promoting JGT commercially with support from the Government. It is however left to the decision of the industry if its overreliance on sack-making with government support would go on or it is ready to venture into the new territory of JGT. If the user-base of a new product can be raised to about 15 % from the current level, then its acceptance could be spontaneous thereafter, according to a section of marketing strategists.

The efforts on research and development should not be relented. Development of new variants, improvement in processing and productivity, as well as economization of the cost of production of JGT should be on the focus for JGT to make a dent in the expanding "Geotech" market. Though long durability is not an absolute technical necessity for a geotextile to function as explained in the preceding contents of this book, research on finding out a more effective and competitively priced durability-enhancing additives that can ensure durability of JGT at least for 5 years should be intensified to set at rest the apprehensions about functional effectiveness of JGT. The lack of regular interface between researchers and industry in India and Bangladesh in particular in respect of JGT also leaves a big gap in marketing efforts for the product.

It is easier advocated than implemented. To enable JGT to stand on its own feet, there is perhaps no easier way than to make concerted all out efforts in research, development, and marketing. A target of 5 % of the total global demand of geotextiles for JGT by the next 3 years is achievable if the endeavor is focused and sincere.

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