A Case Study on the Performance Evaluation of Bituminous Pavement Overlay Reinforced with Coir Geotextiles

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Abstract: Pavements are main source of development for any nation progress. Flexible pavements are complex structures consisting of layers of asphalt, soil and granular composites. Non-linear mechanical behaviour of the pavement materials combined with the randomness in traffic and environmental conditions affect the durability and life of pavements. Overlays are provided on an existing damaged pavement to prolong the service life of pavements. Use of Geotextiles is a proved method to modify the mechanical properties of pavements. Coir Geotextiles made from Coir fibre which is a natural materials composed of ligno cellulose cells obtained from coconut husk, nut of the coconut palm (cocoas nucifera), is highly available in the state of Kerala. It is successfully used in ground improvement techniques. Based on exercises in laboratory field investigations were carried out to observe the performance of the pavement overlay reinforced with coir geotextile layer. Geotextile (H2M6) was placed at the interface of the damaged pavement and overlay. The various functional and structural pavement properties like characteristic deflection, roughness index, development of cracking/potholes observed in this test section over many seasons. Performance Analysis showed that introduction of coir geotextile in the flexible overlay reduces the deflection IRI value observed in the test track, compared control section. It is concluded that coir Geotextile is an optimistic environmental friendly natural material that can be effectively utilized for reducing the distress in bituminous pavements.

***IndexTerms* – Bituminous pavement, overlay, rutting, coir-geotextiles, BBD, geo gauge, stiffness.**

I. INTRODUCTION

1 General

Coir is a 100% organic naturally occurring fibre, from a renewable source obtained from coconut [cocos nucifera] husk. Naturally resistant to rot, and moisture, it is not treated with any chemicals during its spinning method for converting it into a yarn. Hard and strongest among all natural fibres, it can be spun and woven into different types of mattings and mats. Geotextiles made out of coir are highly suited for low cost applications because coir is available in abundance. Only 36% of available coconut husks in India are used for extraction of coir. Therefore there is high scope to enhance its application. The ability of coir fibres to absorb water and to degrade with time is its prime properties, which give it an edge over synthetic geotextiles for erosion control purposes. The Investigation was conducted to determine the suitability of coir geotextiles to increase the life of bituminous pavements by conducting field trials using coir geotextile.

Increasing the environmental awareness and sustainability along with high cost of petroleum based geosynthetics have lead the researchers in developing countries to investigate substitute using natural products (Lekha and Kavitha 2006, Rawal and Anadjiwala2007,Sarssby 2007,Chauhan et al 2008). In an agricultural country like India , stringent environmental concern, high energy requirements coupled with high cost and lack of availability of Geosynthetics are major constraining factors make it significant to explore the possibility of alternate natural Environmental friendly material like coir.

1.1 Coir Fibre

Coir is a natural materials which obtained from the husk of coconut, which is considered as waste material, cheaply, abundantly available in India. It is available in different forms like coir fibre, coir mats woven and non-woven coir geotextiles. Coir fibre is strong and degrades slowly compared to any other natural fibre due to high lignin content (Rao and Balan2000).The degradation of coir depends on factors like medium of embedment and climatic conditions and it is found that it retains 80% of its tensile strength even after six months embedment in clay medium (Rao and Balan 2000).

Coir geotextiles is capable to perform the various functions like any geosynthetic material such as separation, filtration, and reinforcement and as drainage barrier. Coir geotextiles were reported to possess good filtration and drainage properties (Ramanathan Ayyar et al 2002, Lekha and Kavitha 2006).The reinforcing mechanism or effect of coir geotextiles depends on factors like type of textiles used, thickness of granular base, location of geotextiles within pavement structure. (Chan et al 1989), and mechanical properties of material (Perkins1999). Nature of interaction between soil and Geosynthetics depends on limiting friction and adhesion and applied load. (Gosh and Madhav 1994). Coir geotextiles develop good interface friction with granular fill and reinforcement (Ajitha and Jayadeep1997). The mobilization of tensile stress in reinforcing material depends on depth of fill also depends on interlocking mechanism and stiffness (Fannin and Sigurdsson 1996).

1.2 Selected Stretch for the case study

A 70 metre stretch of medium volume road at Menamkulam,-Kazhakuttom (vetturoad) at Thiruvananthapuram reinforced with coir geotextile GSM 400 type (trade name H2M6) was selected for the Investigation. Coir geotextile laid at the bottom of overlay for the entire road stretch. Stiffness, Young's Modulus, deflection, and field density values were measured by using Geo-Gauge and Benkelman Beam Deflection unit and Pavement quality indicator (PQI). The results obtained were promising and highlight the beneficial effects of Coir geotextile reinforcement in reducing deflection values and thereby increasing the life of the pavement. Also there were no visual signs of distress on the pavement like potholes, crack formation, ravelling or disintegration compared to control stretch.

1.3. Need for the study

The rutting and fatigue cracking caused by traffic on the bituminous layer is a very common occurrence and must be given a careful consideration in pavement design and selection of materials to prevent premature cracking of bituminous pavements. In this regard different types of additives are added to bitumen to improve its thermo mechanical properties which can offer high resistance to fatigue cracking and permanent deformation in bituminous layers. Therefore there is an addition of coir fibers to evaluate the performance of the bituminous overlay reinforced with coir geosynthetics and to obtain information on the long term benefits over existing pavement.

1.3.1 Specific Objective

The key objective was making use of coir geotextile H2M6 procured from coir board for bituminous overlay in the investigation. It is available in 50 m rolls of 2 m width as shown in fig.1. Generally the geotextile mattings are produced by various local manufactures the properties slightly vary with the type and origin and coir mats generally designated by its density noted as GSM(gram per square metre).In this Investigation geotextile with GSM 400 is used.

Fig.1 H2M6 woven geotextiles

The physical properties of the material used are given in table 1 as below.

Table 1. Physical and engineering properties of coir geotextile

Type of Geotextiles	Designation	GSM	Thickness *(mm)*	Aperture size *(mm x mm)*
Woven	H2M6	400	6.46	21 x 25

1.4. Methodology

Methodology involves the following steps:

1. Field implementation of coir geotextiles on selected road stretch and Investigate/monitor the pavement performance over different seasons.
2. Field monitoring includes;

a. In-situ field measurement of stiffness and Young's Modulus of unreinforced and coir geotextile reinforced pavement section using the NDT instrument Geo Gauge
b. Performing Benkelman Beam Deflection (BBD) studies on both unreinforced and coir geotextile reinforced section using BBD unit for different seasons to compare characteristic deflection.
c. Field density measurement using Pavement Quality Indicator (PQI)
d. Pavement roughness/unevenness measured using merlin instrument to compare IRI value as an index of functional performance.

Results were analyzed and compared with control section for evaluating the beneficial effects of coir geotextiles in improving the pavement performance.

II. EXPERIMENTAL INVESTIGATION

2.1. Field implementation

The data's for the selected stretch was collected with the help of Kerala Public Work Department (P.W.D) on a medium volume road stretch selected for laying coir geotextiles. The details of the road selected as follows

i. The average width of the road was 3.5 m. No side drains for the road was available.
ii. Sub grade was sandy stratum;
iii. Base layer was WBM 15 cm thick over that bituminous layer of premixed macadam 40 mm thick was provided.

The condition of pavement was very bad and there were frequent pothole, ravelling and segregation of materials. The condition of pavement could be rated as poor.

Fig.2 shows the Present condition of the road before resurfacing. The geotextile used was H2M6 (GSM 400) purchased from coir board Kerala .The cost of material was Rs 52.80/m^2. The coir geotextiles spread over the Present damaged road after preparing the surface. It includes cleaning the surface and the pot holes then spraying the tack coat in potholes and filling with aggregates and rolling. Tack coat applied over the surface after that geotextiles spread over this with an overlap of 0.5 m at centre of road. The over lapped portion tied together in staggered manner with coir yarns to keep it in position during construction of overlays. Over that tack coat was applied uniformly using sprayers and premix carpet laid and compacted to a thickness of 20mm. The Figures below shows the various stages of construction.

Fig. 2 Present condition of the road

Fig. 3 Cleaning and preparation of the surface

Fig 4 Placing and tying of geotextiles over the prepared surface.

Fig. 5 Laying and compacted finished surface

2.2. TESTING PARAMETERS

The performance of geotextile modified pavement stretch was monitored and various parameters compared with the performance of unmodified (control) section. NDT testing equipment's like BBD, Geogauge, PQI, merlin used to measure various parameters. Structural and functional performance compared to assess the performance.

2.2.1 Benkelman Beam Deflection BBD Test

Performance of flexible pavements is closely related to the elastic deflection of pavement under the wheel loads. The deformation or elastic deflection under a given load depends upon subgrade soil type, its moisture content and compaction, the thickness and quality of the pavement courses, drainage conditions, pavement surface temperature etc. Pavement deflection is measured by the Benkelman Beam which consists of a slender beam 3.66 in long pivoted at a distance of 2.44 m from the tip as shown in figure 10. By suitably placing the probe between the dual wheels of a loaded truck, it is possible to measure the rebound and residual deflections of the pavement structure.

Using BBD deflections measured as per the standards /procedure stipulated in IRC code SP 81 1997. The readings were taken on left and right wheel paths of the road at chainages of 5 meter interval. The average reading taken for comparison. The readings were taken at 3 seasons and compared with control sample.

Fig. 6 BBD Trial Test

2.2.2 Computation of Characteristic Deflection

From the Benkelman Beam deflection test, it is observed that coir geotextile reinforcement decreased the deflection in pavement by an amount of 21.17 %.During early stage of construction Subsequent observations taken for two more seasons. The results are summarised in table 2 and as shown in fig 7 and the variation shows reduction in deflection for coir geotextile modified section and the percentage variation, decreases with time. The reason may be due to compaction effect due to traffic, densification of layer or aging effect. Hence the results showed that the induction of coir geotextiles reduces pavement deformation**.**

Table 2 characteristic deflection of pavements

Particular	Monsoon 2013	Summer 2014	Monsoon 2014
Reinforced section	1.0745	1.0875	1.298
Unreinforced section	1.363	1.2312	1.352
Percentage reduction	21.17	11.7	3.99

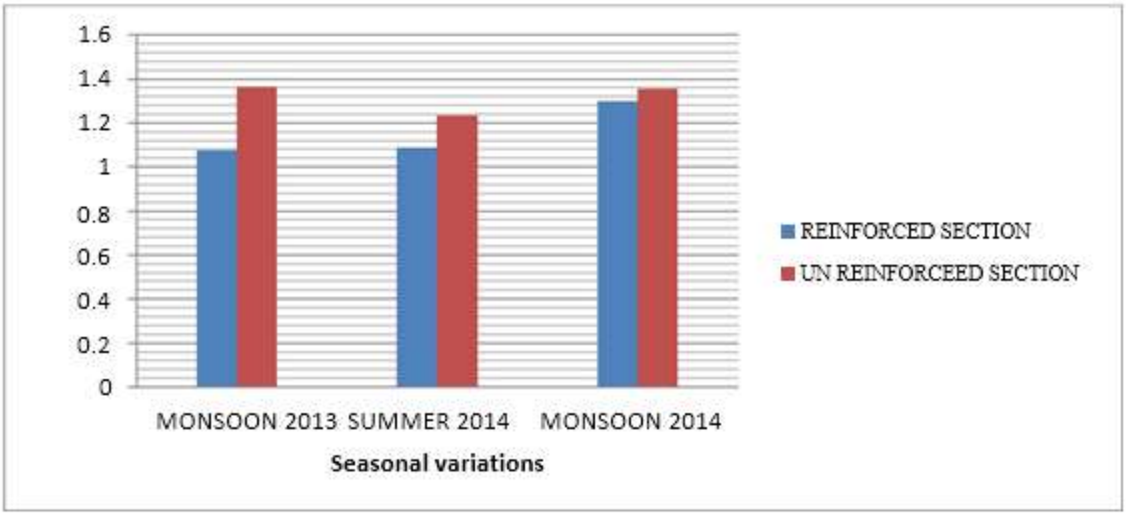

Fig 7 Variation in Characteristic Deflection with time

2.3 Evaluation of Stiffness and Modulus of Pavement Sections

The Humboldt Geo Gauge provides a simple, rapid and precise means of measuring in-place two key engineering and mechanical properties of prepared soil and aggregate, lift stiffness and material modulus. The Geo Gauge measures the material's mechanical impedance at the surface of the ground. In other words, it measures the force imparted to the soil and the resulting surface deflection as a function of frequency. Stiffness, force per deflection, follows directly from the impedance. The Geo Gauge imparts very small displacements to the ground (< 1.27 x 10-6 m) at 25 steady state frequencies between 100 and 196 Hz. Stiffness is determined at each frequency and the average from 25 frequencies is displayed.

Fig.8 Humboldt Geo-Gauge

The Technical Specification that conforms to ASTM D6758 for Soil Measurement ranges are shown below in Table 3

Table 3 Technical specifications for Humboldt Geo-Gauge (ASTM D 6758)

Particulars	Range of values	
	From	To
Stiffness (MN/m)	3	70
Young's Modulus (MPa)	26.2	610
Depth of Measurement from surface (mm)	220	310
Measurement Precision	Coefficient of Variation< 10 %	

In the field the geo-gauge is placed at three locations along the pavement stretch including the two wheel path locations and at the middle of pavement. Measurements were repeated at every 5 metre chainage along the length of the pavement. The Geo-Gauge displayed stiffness and Young's Modulus values in SI units. The Geo-Gauge displays and logs the data in memory with sufficient capacity for a full day of data gathering (100s of measurements). The data may be downloaded to a PC for archiving and further analysis can be done easily. Geotextile reinforced sections showed increase in Young's Modulus and Stiffness values. It is observed that improvement is higher at the centre of pavement section. Coir geotextile reinforced sections showed an increase of 5 to 15.51 % for both modulus and stiffness values. Hence coir geotextile reinforcement proved to be beneficial. The average stiffness and Young's Modulus measured for unreinforced and coir geotextile reinforced pavement sections using Geogauge are shown in the table 4 as below

Table 4 Average stiffness and E value measured using Geogauge.

Left		Centre		Right		Remark
Stiffness (MN/m)	E (Mpa)	Stiffness (MN/m)	E (Mpa)	Stiffness (MN/m)	E (Mpa)	
22.4	194.3	23.83	206.75	22.74	197.31	CONTROL

23.86	206.97	25.04	217.2	21.73	188.54	GT

2.4 Merlin Test for Roughness Measurement.

Road surface roughness is an important measure of road condition. The Merlin road roughness measurement machine was developed by the Transport Research Laboratory for use in developing countries. Schematic sketch and fig of Merlin are shown in figure14

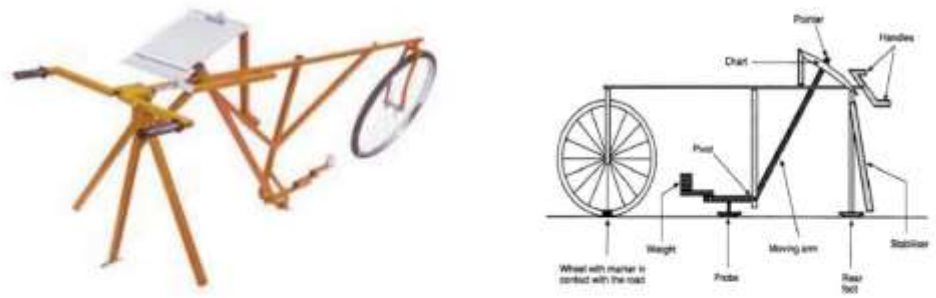

Fig.9 Merlin Equipment

The Merlin consists of a metal frame with a wheel at front and handles and a foot at the rear. The distance between the rear foot and the bottom of the wheel is 1.8 m. Attached to the frame is a pivoted moveable arm which has a probe at one end which rests on the road surface half way between the wheel and the rear foot. At the other end of the arm is a pointer which moves over a prepared chart. The arm is pivoted close to the probe so that a vertical displacement of the probe of 1 mm will produce a displacement of the pointer of 1 cm.

For most road surface the road roughness can be determined using the equation,

$$IRI = 0.593 + 0.0471D$$
$$(2.4 < IRI < 15.9)$$

Where IRI is the roughness in terms of the International Roughness Index (in m/km) and D is measured from the Merlin chart (in mm). The procedure is repeated for left wheel path, right wheel path and centre of the pavement for geotextile modified section and control section without geotextiles calculated as per the standard Merlin equation and consolidated result as shown as below in table 5.It showed max 24% reduction in IRI value.

$$IRI = 0.593 + 0.0471D$$
When D =90.0 mm
$$IRI = 0.593 + (0.0471*90)$$
$$= 4.832 \qquad (2.4 < IRI < 15.9)$$

Table 5 Result of IRI using MERLIN test

Type of pavement	International roughness index (IRI) *(mm/km)*	
Controlled section	Left wheel path	6.362
	Right wheel path	6.01
Geotextile modified section	Left wheel path	4.832
	Right wheel path	5.0675

2.5 Pavement Quality Indicator (PQI)

The density of asphalt pavement is directly proportional to the measured dielectric constant of the material. PQI uses electrical waves to measure dielectric constant using toroid electrical sensing field established by the sensing plate. The electronics in the PQI convert the field signals into material density readings and displays the results.

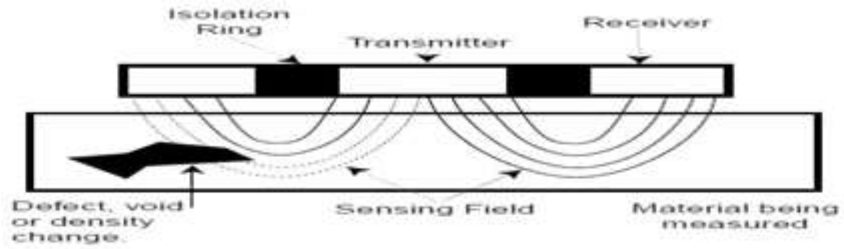

Fig .10 Line diagram of PQI

PQI uses no nuclear elements, and is instead based on a safe, low voltage direct current measurement technique. The PQI is powered by nickel metal hydride batteries. Under normal operations, the PQI unit can operate in excess of 13 hours at full charge. The internal 12 volt battery is designed to be recharged in approximately 2 hours, using the 120 volt AC battery charger. The PQI is designed to be an extremely flexible unit, with several useful modes of operation. Each mode of operation is accessed through the keypad controls. The number, letter and arrow keys have several functions. The immediate function is shown by the text in the display panel. The display can show four lines of text at a time called a page. The display tells the operator what the PQI unit is ready to do or indicates that a reading is being taken or that more key setting information is needed from the operator. Fig 10 and fig11 shows the PQI working principle. Table 6 shows the average field density of the pavement of control and geotextile modified section at left, middle and right wheel paths positions.

Fig 11: Pavement Quality Indicator

Table. 6 PQI test results

Section	Position	Average density (kg/ cu.m)
Control	Left	2036.57
	Right	2064.853
	Middle	2034.85
Geotextile	Left	2038.445
	Right	2069.106
	Middle	2019.234

2.6 Visual Evaluation

Visual evaluation of the trial section conducted and inspected formation the various types of distress over the pavements. The fig 11 shows signs of distress on control section. The observations tabulated in table 7

Fig. 12 Potholes and ravelling on control road section

Table 7: Visual Evaluation Results

Distress type	Reinforced	Unreinforced
Alligator cracking	x	✓
Block cracking	x	x
Transverse cracking	x	✓
Joint reflection cracking	x	x
Patching	x	x
Polished aggregate	x	x
Potholes	x	✓
Corrugation and shoving	x	x
Depression	x	x
Rutting / Permanent	x	x
Stripping	x	✓

2.7 Cost Analysis

Additional cost incurred in implementing coir geotextiles in road stretch and the extra cost of tack coat to be applied under and over geotextiles to ensure proper bonding is calculated per 100 m stretch as follows. The single lane road of 3.5 m road stretch is considered. Geotextiles available in 50 m role having 2m width. So for laying 3.5 m width two roles required with a longitudinal overlap of 0.5 m.

Average cost of geotextiles of 400 GSM	=60/sq.m
Quantity of geotextile required for 100m road stretch	=100X4=400 sq.m
Tack coat required to coat under and over geotextiles@0.9 kg/m^2	= 0.9X3.5X100X2
	= 630kg/m^2
Deduct normal rate of tack coat applied say 0.5 kg/m2 at one side only in control section	=0.5X100X3.5
	=175 kg/m^2
So additional amount of tack coat required in geotextile modified road	=630-175
	= 455kg/100 m^2
Cost for 100 m^2	
Cost of geotextiles	= 400X 60
	= Rs 24000
Cost of bitumen	= 455X10
	= RS 4550
Total additional cost	**=Rs 28550/100m stretch**

An amount of Rs 285000/ km road stretch required towards the cost of geotextiles and additional bitumen required. Compared to the increase in durability and savings in material thickness it is a feasible option.

III. SUMMARY AND CONCLUSIONS

3.1 Summary

The Investigation was to discern the real field performance of coir geotextile modified pavement section. A medium traffic road was selected and coir geotextiles laid on the road stretch with the help of Kerala PWD.100 meter stretch was kept as control section without geotextiles. Field studies were conducted on unreinforced and coir geotextile reinforced sections to evaluate the benefits of coir geotextiles in flexible pavements. Benkelman Beam Deflection tests were conducted to arrive at the deflection values at different seasons. Young's Modulus and Stiffness values of the sections were measured using an instrument called Geo-Gauge. NDT equipment PQI used to analyse variation in density and there by any structural anomaly because of induction of geotextile at the interface. Surface unevenness measured in terms of IRI using a simple equipment merlin and visual examination done to check the pavement surface condition. From the results it is found that coir geotextile reinforcement improve the performance of flexible pavements.

3.2 Conclusions

From field studies the following conclusions can be drawn

- Coir geotextile reinforcement decreases the deflection in pavement by an amount of 21. 1% at the initial stages.
- Coir geotextile reinforced sections showed an increase of 5 to 15.5 % for both modulus and stiffness values
- There is no appreciable variability in density in reinforced and unreinforced sections
- There is reduction in IRI value up to 21% indicates good condition of geotextile modified pavements.
- There is no visual sign of cracks pot holes ravelling or other distress on the geotextile modified section where as some signs are observed in unmodified section after 3 seasons.

Hence from the results it can be concluded and recommended that the coir geotextile perform functions like reinforcement, separation, and as stress absorbing interlayer as it act as elastic cushion and reduce permanent deformation satisfactorily well. Inclusion of coir geotextile reduces the deflection and other distresses on the pavement.

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