Performance Evaluation and Modified CBR Prediction of Coir Geotextile-Reinforced Pavement Using ABAQUS

B. S. Sabitha, P. P. Jishna, Y. Sheela Evangeline, P. K. Sayida, and Ajin Krishna

Abstract Most of the rural roads in India are over soft subgrade which requires improvement. Structural performance of pavement can be evaluated by Benkelman beam deflection test as well as field CBR test. Improving the soil with coir geotextiles is a good option, as coir geotextiles are natural and indigenous materials with higher durability compared to other natural geotextiles. This paper is focusing on the simulation of a numerical model which could predict the modified CBR value of coir geotextile-reinforced soil and variation in deflection with different coir geotextiles using ABAQUS. Such a model could be effectively used to choose the type of coir geotextile suitable for a particular type of soil. Numerical simulation for predicting the variation in deflection of pavement could be effectively used to evaluate the reduction in pavement deflection with the inclusion of coir geotextiles.

Keywords Rural road · Coir geotextile · ABAQUS · CBR · BBD

B. S. Sabitha · P. P. Jishna (✉) · Y. Sheela Evangeline · P. K. Sayida · A. Krishna
College of Engineering, Trivandrum, India
e-mail: ppjishna95@gmail.com

B. S. Sabitha
e-mail: sabithabs1994@gmail.com

Y. Sheela Evangeline
e-mail: sheelabala2000@gmail.com

P. K. Sayida
e-mail: sayidamk@rediff.com

A. Krishna
e-mail: ajin4krishna@gmail.com

M. Latha Gali and R. R. P. (eds.), *Geotechnical Characterization and Modelling*, Lecture Notes in Civil Engineering 85,
https://doi.org/10.1007/978-981-15-6086-6_61

1 Introduction

1.1 Background of the Present Study

In a country like India, construction of rural road networks plays a pivotal role in its socio-economic development. However, many of the existing rural roads are becoming structurally ineffective because of the rapid growth in traffic volume and axle loading. Another major problems faced by rural roads across the country are that they are built in poor subgrade with low California bearing ratio (CBR). Low CBR increases the construction cost due to large pavement thickness. IRC specifies a minimum CBR of 4% for rural roads. To achieve the specified CBR, subgrades are nowadays reinforced with geotextiles. Natural geotextiles like coir are good alternatives to geosynthetics due to its cost-efficient and eco-friendly nature. From the previous studies conducted by Vinod and Minu (2010), it has been found that the inclusion of coir geotextile as reinforcement in soil improves the California bearing ratio of lateritic soil. Sajikumar et al. (2014) studied the performance of coir geotextile reinforced using Benkelman beam deflection (BBD) test and concluded that the variation in deflections of reinforced roads is less compared to unreinforced roads. In the present study, two flexible pavements constructed by incorporating coir geotextile were considered and their deflection under traffic load was found out using ABAQUS. Also, a finite element model of laboratory CBR test for both coir geotextile-reinforced and geotextile-unreinforced section has been developed. Such a model could be effectively used to choose the type of coir geotextile suitable for different soils. In addition to this, pavement thickness reduction and overlay thickness reduction due to coir reinforcement are also found out for six pavement field data as per IRC specifications and catalogues.

1.2 Data Collection

Six roads reinforced with coir geotextiles were selected for the study. They are presented in Table 1. They are designated as road 1 to road 6.

The properties of coir geotextiles used for reinforcing the roads are presented in Table 2. The BBD values of the road after 6 years of construction are presented in Table 3, and the CBR values of the reinforced and unreinforced soil are presented in Table 4.

1.3 Plan for Numerical Analysis

Numerical analysis was carried out for finding the deflection of road 1 and road 2 with two different coir geotextiles GT1 and GT2. For both the road sections, deflections were found out with and without incorporating coir geotextiles. Laboratory CBR

Table 1 Road details

Designation	Name of road	Date of construction
Road 1	Attukal–Pampady road	23/09/11
Road 2	ANC Mulamoottil Padi road	12/03/12
Road 3	Manakodam–Ration Kada road	01/01/13
Road 4	Puthusseri Kadavu–Kakkattikara road	08/12/11
Road 5	Chirakkad–Kumbakad road	16/10/11
Road 6	Mangalabharathy–S N Kadavu road	24/10/11

Table 2 Properties of coir geotextile (Sajikumar 2014)

Properties	GT1	GT2
Mass per unit area (gsm)	681	425
Opening size (mm)	9 × 12	15 × 22.5
Thickness (mm)	7.16	8.10
Tensile strength (kN/m)	18.8	7.10

Table 3 BBD values (Sajikumar 2014)

Name of road	BBD results (values in mm)	
	Without GT	With GT
Road 1	0.31	0.06
Road 2	1.58	1.29
Road 3	1.84	1.21
Road 4	0.12	0.08
Road 5	5.66	1.57
Road 6	3.68	1.86

Table 4 CBR of subgrade

Name of road	CBR without geotextile (%)	CBR with geotextile (%)	% increase in CBR
Road 1	5.85	7.52	28.54
Road 2	3.34	4.68	40.12
Road 3	3.47	4.30	23.91
Road 4	3.64	4.85	33.24
Road 5	2.22	3.58	61.26
Road 6	3.64	4.43	21.70

Fig. 1 Model of reinforced road section

prediction was conducted for worst condition, i.e. for clayey soil. All the analyses were done for with and without coir geotextile. Laboratory CBR prediction and deflection of reinforced section were analysed with two different coir geotextiles GT1 and GT2.

2 FE Modelling Methodology

2.1 Geometry Idealization

In this study, the road sections were idealized as a plain strain condition and hence modelled as a 2D deformable body. Soil and coir geotextile were idealized as a 3D deformable body. The road section model and laboratory CBR model used for the analysis are shown in Figs. 1 and 2, respectively

2.2 Material Behaviour

Subgrade soil has been considered as an elasto-plastic material. The plastic behaviour of soil is defined by Mohr–Coulomb model (friction angle and cohesion), and coir geotextile has been considered as a deformable material. The elastic modulus of GT1 and GT2 is 132 and 90 kPa, respectively. Poisson's ratio of coir geotextile has been taken as 0.35. The subgrade soil used in the study is clayey soil.

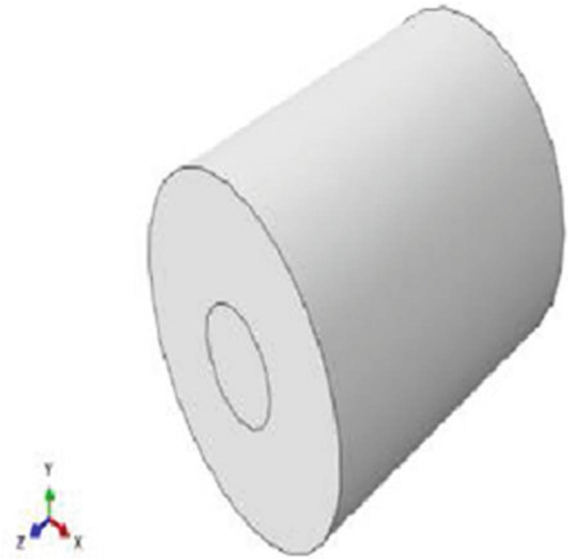

Fig. 2 Model of laboratory CBR model

2.3 Load and Boundary Condition

Traffic load for performance evaluation was simulated by giving moving load of corresponding cumulative standard axles (CSA). CSA were calculated as per IRC 37: 2001 load. The bottom portion of the road section is fully encastred, and vertical movement is allowed only on the sides. CSA calculated for each road from the traffic data collected are presented in Table 5.

For laboratory CBR prediction, displacement of 5 mm is given over a circular area of 50 mm diameter which could simulate the actual laboratory condition of load applied through a plunger of 50 mm diameter. The bottom portion is fully encastred, and vertical movement is only allowed in the sides.

Table 5 Cumulative standard axle load

Designation	CSA in msa
Road 1	0.39
Road 2	1.68
Road 3	0.87
Road 4	1.50
Road 5	2.10
Road 6	2.47

msa million standard axles

2.4 *Meshing and Interaction*

Road section has been modelled as a 2D plain strain condition with uniform mesh size. A 4-noded bilinear plain strain quadrilateral (CPE4R) was selected as the mesh element type. Coir geotextile also has the same element type and meshing. For CBR prediction, soil was modelled as a 3D object with finer mesh at loading surface and coarser mesh at far ends. An 8-noded linear brick element (C3D8R) has been used as the mesh element. Coir reinforcement was modelled as a 3D object with hexahedral shape and C3D8R element type. Interaction between coir geotextile and soil has been simulated by giving surface to surface contact with coefficient of friction. The meshed CBR model is shown in Fig. 3.

3 Data Analysis

From the available field data of BBD values, the reduction in overlay thickness due to the inclusion of coir geotextile has been calculated as per IRC 81:1997.The overlay thickness depends on two major factors, namely stability of the existing flexible pavement and anticipated traffic loading in terms of CSA load repetition during the desired design life of the overlay. In addition to this, the reduction in pavement thickness has also been evaluated from the CBR data of six roads as per IRC SP 72: 2015.

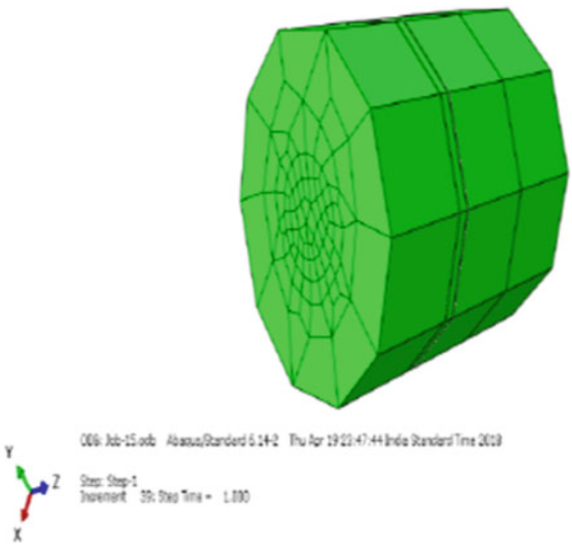

Fig. 3 Meshed CBR model

3.1 Overlay Thickness Reduction

Overlay thickness is generally provided for continuous maintenance of roads. Additional overlay thickness is determined using overlay thickness design curves of IRC 81: 1997. For this curve, two parameters are needed for evaluation which are BBD values in mm and CSA. As per IRC 81: 1997, there is no need of any upgradation work when the deflection is below 0.45 mm for 100 million standard axle loads.

3.2 Pavement Thickness Reduction

As per IRC SP 72: 2015, pavement thickness for low volume rural roads is calculated based on CSA and CBR of the subgrade.

4 Results and Discussion

4.1 Numerical Study for CBR Prediction

Numerical simulation of laboratory CBR has been done for both reinforced and unreinforced soil. Reinforcement is placed at the centre of the section. The deformed shape of the soil subgrade is shown in Fig. 4.

CBR prediction of reinforced soil has been done by using two different grade coir geotextiles, i.e. GT1 and GT2. The load versus penetration curve for GT1 coir geotextile-reinforced subgrade soil is shown in Fig. 5. The reaction force developed in GT1-reinforced clayey soil is shown in Fig. 6.

The reaction force developed in GT2-reinforced clayey soil is shown in Fig. 7. The load versus penetration curve for GT2 coir geotextile-reinforced subgrade soil is shown in Fig. 8 (Table 6).

4.2 Numerical Study for Deflection

The displacement is considered as a response of applying traffic loads. The magnitude of the displacement beneath the centre of the load at the end of loading is taken as the maximum deflection experienced by the road section. Displacement contours on deformed shape for unreinforced road Sects. 1 and 2 are shown in Figs. 9 and 10, respectively.

The same road section is reinforced with two different geotextiles GT1 and GT2. Displacement contours of the reinforced sections are shown in Figs. 11 and 12, respectively.

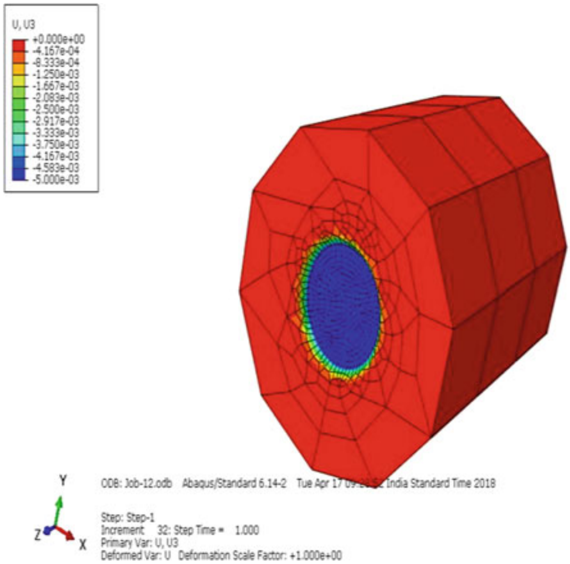

Fig. 4 Deformed shape of unreinforced soil

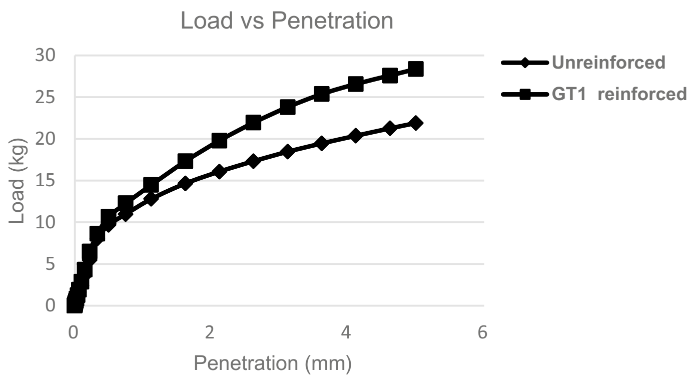

Fig. 5 Load versus penetration curve of GT1-reinforced and GT1-unreinforced section

The maximum deflection obtained from the numerical analysis for both road 1 and road 2 is as shown in Table 7.

From the BBD values and CSA loads, the overlay thickness is calculated for all six roads with the help of overlay thickness design curves as per IRC 81: 1997. The allowable limit of deflection having no need of any improvement works in the pavement as per IRC 81: 1997 is 0.45 mm. Roads 1, 2, 3 and 4 have the deflection values less than the allowable limit of deflection for both unreinforced and reinforced case. So, there is no need of upgradation of pavement. The deflection values for road 5 and 6 are not within the allowable limits. So, the upgradation is required for road 5

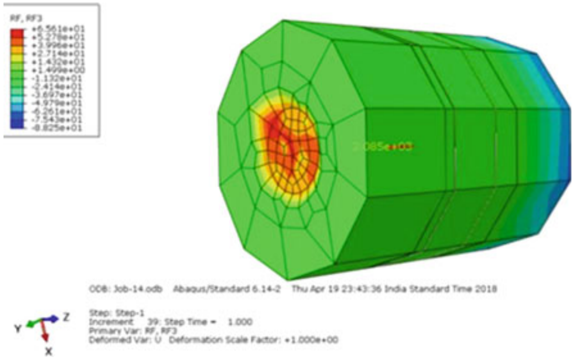

Fig. 6 Reaction force developed in GT1-reinforced section

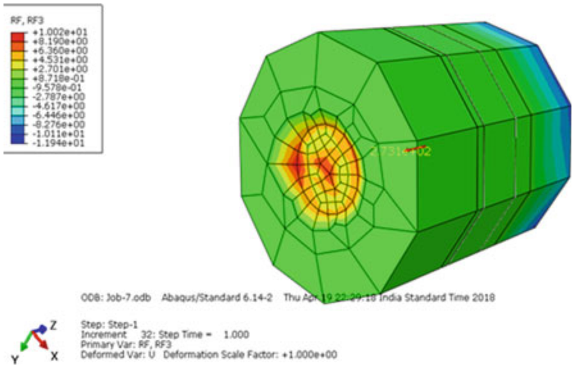

Fig. 7 Reaction force developed in GT2-reinforced soil section

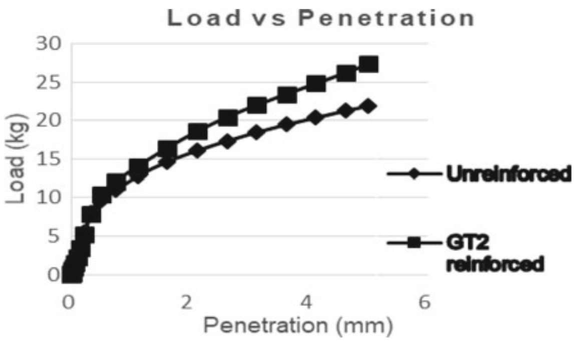

Fig. 8 Load versus penetration curve for GT2-reinforced and GT2-unreinforced section

Table 6 Results obtained from analysis

Designation	CBR (%)	% increase in CBR
Unreinforced clay	1.24	
GT2-reinforced clay	1.42	14
GT1-reinforced clay	1.53	23

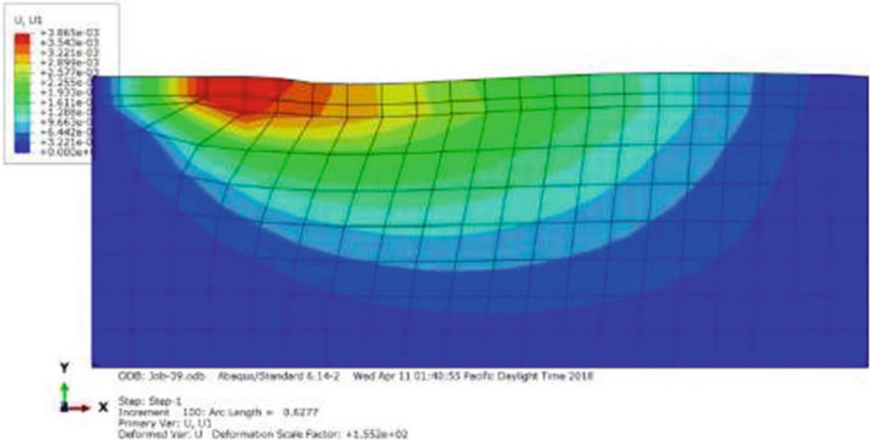

Fig. 9 Displacement contour of unreinforced road 1

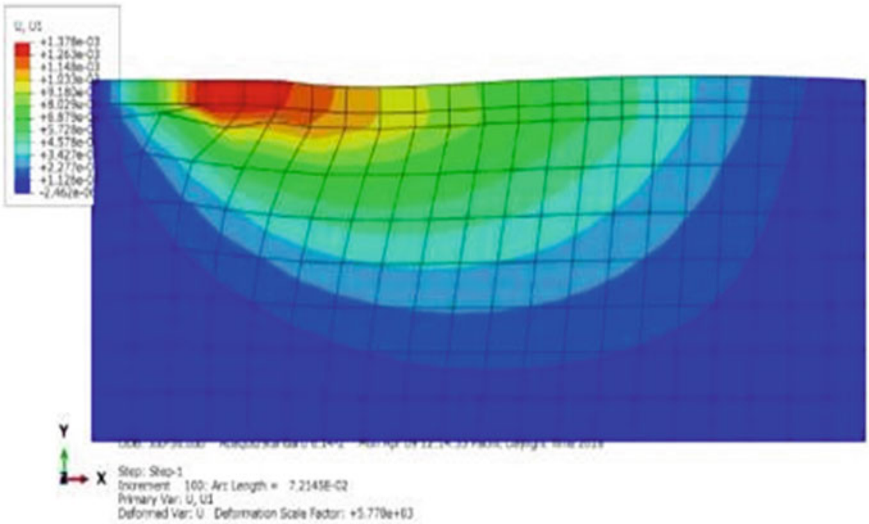

Fig. 10 Displacement contour of unreinforced road 2

and 6. The calculated overlay thickness for road 5 and 6 is shown in Table 8. Overlay thickness required for coir geotextile-reinforced pavement is much less than that of unreinforced section.

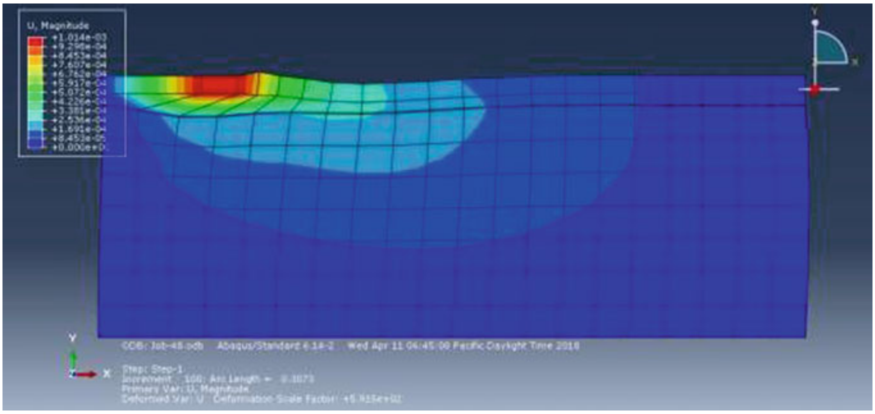

Fig. 11 Displacement contour of GT1 reinforced road1

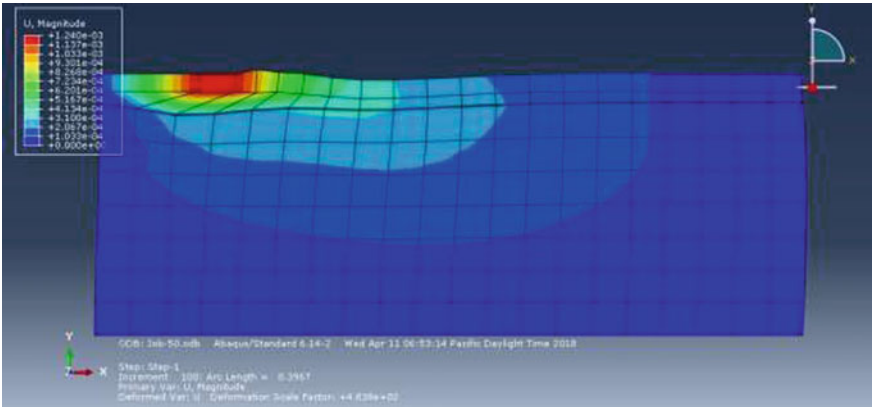

Fig. 12 Displacement contour of GT2 reinforced road1

Table 7 Maximum deflection obtained from the analysis

Road	Deflection (mm)		
	Unreinforced	GT1	GT2
Road 1	3.86	1.01	1.24
Road 2	1.75	0.83	0.97

Table 8 Overlay thickness

Designation	Overlay thickness	
	Without GT (mm)	With GT (mm)
Road 5	230	24
Road 6	185	70

Table 9 Pavement thickness

Road	Pavement thickness (mm)		% reduction in thickness
	Without GT	With GT	
Road 1	525	425	19
Road 2	375	300	20
Road 3	375	300	20
Road 4	525	425	19
Road 5	650	525	19
Road 6	525	425	19

4.3 Reduction in Pavement Thickness

The pavement thickness of roads both with and without coir geotextiles calculated as per IRC: SP 72: 2015 is presented in Table 9.

The average reduction in pavement thickness is about 20% was observed in coir geotextile-reinforced roads.

5 Conclusion

The pavement thickness reduction of six roads due to modified CBR value and a numerical simulation was also made to predict the modified CBR values of coir geotextile-reinforced soil, and the following are the conclusions drawn from the study.

- From the numerical simulation, it is found that GT1 coir geotextile improves the CBR better than with GT2, which is in accordance with the actual case as reported by various researches.
- Pavement thickness reduction was evaluated to be about 20% as per IRC design charts due to coir geotextile reinforcement.

From the study on the structural and numerical performance of coir geotextile-reinforced roads, the following conclusions can be drawn from the study.

- The defection result shows that there is considerable reduction of deflection due to the coir reinforcement which reflects the rigidity and increased load bearing capacity of pavement.
- The percentage reduction of overlay thickness of reinforced road is about 60–80 percentage of unreinforced section.

References

Beena S (2004) Suitability of using California bearing ratio test to predict resilient modulus. In: FAATT conference

IRC 37 (2001) Guidelines for the design of flexible pavements

IRC: 81 (1997) Guidelines for strengthening of flexible road pavements using benkelman beam deflection technique

IRC: SP 72 (2015) Guidelines for the design of flexible road pavements for low volume rural roads

Lidia SC, Giovanni L, Rocco P (2017) Finite element modelling of unpaved road reinforced with geosynthetics. Transp Geotech Geoecol TGG: 99–104

Sajikumar PR, Sheela EY, Sayida MK, Mariamma J (2014) Structural performance of coir geotextile reinforced rural roads. Int. J Sci Eng Res 5(7). ISSN 2229-5518

Souvik P, Ashis KB (2016) Field and numerical investigation on time dependent behaviour of jute geotextile (JGT) reinforced rural road. In: Indian geotechnical conference IGC, pp 15–17

Vinod P, Minu M (2010) Use of coir geotextiles in unpaved road construction, Geosynthetics Int 17(4)