JUTE GEOTEXTILES IN ROADS – ECONOMICS & DESIGN ELEMENTS

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ECONOMICAL ADVANTAGES USING JUTE GEOTEXTILES (JGT)

Assessment of Economical Benefits using Jute Geotextiles over Conventional Design in Low Volume Road Construction

Introduction

Geotextiles in road construction is not a new technology however this innovative technology needs support from the frontline engineers so that it can be used and datas related to its performance can be gathered. Geotextiles both Synthetic and Natural serve the basic functions of a Geo-textile, i.e, Separation, Filtration, Drainage & Reinforcement. Construction of any road requires assessment of loads (dynamic), geotechnical characteristics of the sub-grade and adoption of proper design methodology, careful choice of materials for construction.

In this text, rural road constructed with basic assumptions stated below to evaluate economical benefits of using geotextiles i.e., Jute Geotextiles over conventional method. In this respect a comparative analysis have been done in three cases as below –

Case1 - Cost Analysis of Pavement Constituents with conventional method
Case2 - Cost Analysis of Pavement Constituents with JGT with 1.5 times improvement in CBR value

Basic Assumptions for Computation of Construction Cost of a rural road–

The calculated construction cost depends on variable parameters like region of construction, choice of materials, distance of construction site from sources of raw materials, type of sub-grade soil (CBR) over which road will be constructed and traffic volume (Cumulative ESAL) for design life of road. The following text is an example to indicate the economical benefits of using JGT in a rural road over a conventionally design road and with SGT design road for common value of CBR and ESAL range.

As an example CBR of sub-grade soil is taken as 4% which is enhanced by 1.5 times the control value by use of JGT to 6%. The following are the assumptions for the example -

a) CBR of sub-grade soil : 4%
b) Considering Enhancement of CBR of sub-grade soil by 1.5 times from control value of 4% : 6%
c) Cumulative Traffic ESAL : 60,000 – 1,00,000
d) Length of Pavement : 1000 m
e) Carriageway Width of Pavement : 3.75 m
f) Roadway Width : 7.5 m
g) Thickness of sub-grade : 300 mm
h) Width of JGT with 10% overlapping : 8.6 m
i) Site selected for construction of road is near Howrah and is about 20 km from Dankuni station.
j) The rates of materials are taken from SoR, PWD, Roads & Bridges, West Bengal, August, 2014.
k) The rates of riding surface not included

The calculated savings are considered under idealized conditions of road construction. Also the calculated savings may vary from region to region and distance between worksite from source of materials.

Cross-section of pavement is designed as per guidelines mentioned in IRC:SP:72-2007

ITEMS	**Pavement Thickness with Conventional Design**	**Pavement Thickness with JGT**
	CBR 4%	***Enhanced CBR 6% (1.5 times of 4% CBR)***
WBM – III	75mm	75mm
WBM – II	75mm	75mm
GSB – III	75mm	125mm
GSB-II	100mm	**---**
Total	**325 mm**	**275 mm**

Granular Sub-base Grading II consists of 1st class brick aggregates (40mm down) & sand (in proportion 60:40) and Granular Sub-base Grading III consists of stone chips and sand (2.36 mm below) distributed as per Technical Specifications of Rural Road. Water Bound Macadam Grading II consists of 63 – 45 mm size and Grading - III consists of 53 – 22.4 mm size with stone screening Type B. Rate of JGT is considered as per prevailing market price and transportation charges are included in the rates.

Case 1: Cost Analysis of Pavement Constituents with Conventional Design (Cost per km Basis)

Conventional Design follows IRC:SP:72-2007 guidelines

Table 1 – Road Design with Conventional Method

S.No.	DESCRIPTION OF ITEMS	LENGTH (m)	WIDTH (m)	THICKNESS (m)	QUANTITY (m^3)	RATE (Rs.)	AMOUNT (Rs.)
1.	GSB – II	1000	8.8	0.1	880	1962.5	1727000
2.	GSB – III	1000	4.05	0.075	303.75	1456.335	442362
3.	WBM (Gr. II)	1000	3.9	0.075	292.5	2725.37	797171
4.	WBM (Gr.III)	1000	3.75	0.075	281.25	2757.205	775464
	Total						**3741997**

Case 2: Cost Analysis of Pavement Constituents with JGT (Cost per km Basis)

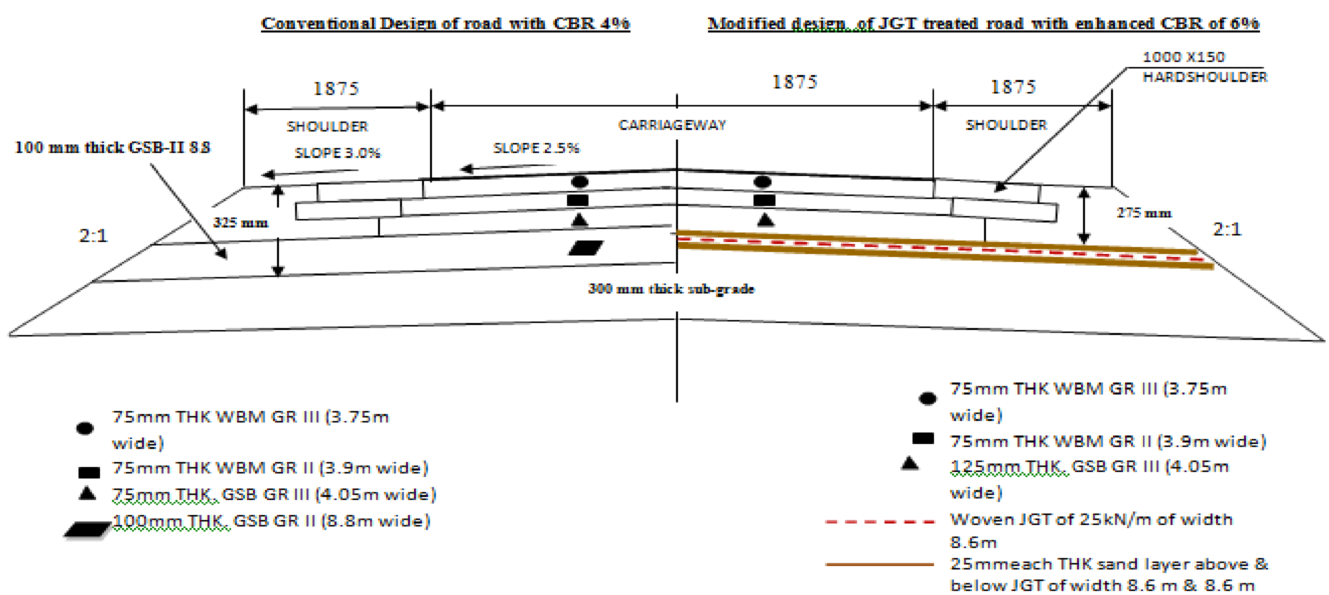
It has been found from laboratory studies corroborated by approximately 50 field trials that with JGT application, CBR enhances by 1.5 times atleast over the control value of sub-grade in all cases and even more in few field trials. The design example assumes a minimum 150% increment of CBR of sub-grade by use of JGT.

N.B.: An additional 25 mm each thin layer of sand is to be laid above and below woven JGT fabric to overcome puncturing from sub-base layer and to delay its degradation respectively.

Table 2 - Road Design with JGT

S.No.	DESCRIPTION OF ITEMS	LENGTH (m)	WIDTH (m)	THICKNESS (m)	QUANTITY (m^3)	RATE (Rs.)	AMOUNT (Rs.)
1.	Medium Sand below JGT	1000	8.6	0.025	215	896	192640
2.	Woven JGT	1000	8.6	-	8600 m^2	73.70	633820
3.	Medium Sand above JGT	1000	8.6	0.025	215	896	192640
4.	GSB – III	1000	4.05	0.125	506.25	1456.335	737270
5.	WBM (Gr. II)	1000	3.9	0.075	292.5	2725.37	797171
6.	WBM (Gr.III)	1000	3.75	0.075	281.25	2757.205	775464
	Total						**3329005**

Typical Comparative Cross-sectional View - JGT vis-à-vis Conventionally Designed Rural Road



Inference Drawn on Comparative Cost Analysis (Cost per km basis)

Conventional Method vis-à-vis with JGT	**11.4% Savings using JGT**

DESIGN METHODOLOGY WITH JUTE GEOTEXTILE

Design Approach for Low Volume Roads with Woven Jute Geotextiles (JGT)

The methodology developed for use of JGT in low volume roads follows a semi-theoretical semi-empirical pavement design concept. The thickness of base course of low volume roads is developed considering mechanical property of 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 ten years. Design curves have been drawn for a range of CBR% of sub-grade. 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 said Indian Standard.

DESIGN ELEMENTS

Traffic

The design traffic is considered in terms of cumulative number of Standard Axle to be carried during the design life of a rural road.

Assuming a uniform traffic growth rate r of 6% over design life (n) of 10 years, the cumulative ESAL applications (N) over design life can be computed using following formula –

$$N = T_0 \text{ x } 365 \text{ x } \left[\frac{(1+0.01\,r)^n\ -1}{0.01\,r}\right] \text{ x } L \qquad \textbf{(1)}$$

where, r = Traffic Growth rate = 6%

T_0 = ESAL per day = Number of commercial vehicles per day x Vehicle Damage Factor

L = Lane Distribution Factor = 1 for single lane

n = Design life = 10 years for rural roads

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.

Properties of Base Course Material and Sub-grade

In the study, the base course modulus and sub-grade soil modulus is used to determine thickness of pavement that may be calculated from CBR% as recommended in IRC:37-2001.

$$E_{sg}\ (\text{MPa}) = 10 \text{ x } CBR_{sg}\ (CBR \leq 5) \qquad \textbf{(2)}$$

$$E_{sg}\ (\text{MPa}) = 17.6 \text{ x } CBR_{sg}^{0.6}\ (CBR > 5) \qquad \textbf{(3)}$$

Similarly E_{bc} can also be ascertained from the following relation.

$$E_{bc}(MPa) = 36\ CBR_{bc}^{0.3} \qquad \textbf{(4)}$$

Where, CBR_{sg} = California Bearing Ratio of sub-grade soil and CBR_{bc} = California Bearing Ratio of Base Course material.

As specified in IRC:SP:72-2007, CBR of Base Course i.e.,Water Bound Macadam (WBM) should be minimum of 80 % and maximum of 100%. If these values are evaluated in equation (4) then E_{bc} is assumed to be an average of 100 MPa.

DESIGN METHODOLOGY

Computation of Pavement Thickness based on California Bearing Ratio Method

Extensive studies carried out by U. S. Corps of Engineers have shown that there exists a relationship between pavement thickness, wheel load, tyre pressure and C.B.R value within a range of 10 to 12 percent. This method of design was also used by Indian Road Congress to determine the thickness of individual layers of pavement. Therefore it is possible to extend the CBR design curves for various loading conditions, using the following expression –

$$\mathbf{T} = \sqrt{\boldsymbol{P}}\left(\frac{\mathbf{1.75}}{\boldsymbol{CBR}} - \frac{\mathbf{1}}{\boldsymbol{p\pi}}\right)^{\mathbf{1/2}} \qquad \textbf{(5)}$$

where, P = wheel load (kg), T = Base course thickness (cm), p = Tyre pressure (kg/cm^2), 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 will remain the same though the pavement component layers are of different material with different CBR.
2. Total thickness of pavement does not consider load repetitions for designed period.

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.

To overcome the limitations of the CBR design method, Burmister's Two Layer has been incorporated in the aforesaid relation (Equation 5 above) taking into account a stiffness factor $(E_{sg}/E_{bc})^{1/3}$. This modification is, in fact, based on Burmister's concept as shown below.

$$\mathbf{T} = \sqrt{\boldsymbol{P}}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \mathbf{x} \left(\sqrt[3]{\frac{\mathrm{E_{sg}}}{\mathrm{E_{bc}}}}\right) \tag{6}$$

The design thickness equation 6 is based on elastic theory which will further be modified due to placement of Jute Geotextile (JGT) between the base course and the sub-grade, the resultant stiffness of the composite pavement gets better. JGT as well as base course both acts as a reinforcing material. Therefore, the resultant stiffness factor stands modified as $\left(\sqrt[3]{\frac{\mathrm{E_{sg}}}{E_{bc}+E_{JGT}}}\right)$. Thickness of pavement is accordingly modified as below -

$$\mathbf{T} = \sqrt{\boldsymbol{P}}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \mathbf{x} \left(\sqrt[3]{\frac{\mathrm{E_{sg}}}{E_{bc}+E_{JGT}}}\right) \tag{7}$$

where, E_{JGT} = Elastic Modulus of Woven JGT (MPa), E_{sg} = Elastic Modulus of Sub-grade (MPa), E_{bc} = Elastic Modulus of Base and Sub-base (MPa).

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 & Witczak (1975) and F. M. Hveem & R. M. Carmany (1948) that base course thickness varies directly with logarithm of load repetitions (N). Therefore, Eqn (6) and (7) thickness of pavement without JGT and with JGT respectively can be refined as:

$$\mathbf{T} = \sqrt{\boldsymbol{P}}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \mathbf{x} \left(\sqrt[3]{\frac{\mathrm{E_{sg}}}{E_{bc}}}\right) \mathbf{x}\ \mathrm{k}\ \mathbf{log\ N} \tag{8}$$

$$\mathbf{T} = \sqrt{\boldsymbol{P}}\left(\frac{1.75}{CBR} - \frac{1}{p\pi}\right)^{1/2} \mathbf{x} \left(\sqrt[3]{\frac{\mathrm{E_{sg}}}{E_{bc}+E_{JGT}}}\right) \mathbf{x}\ \mathrm{k}\ \mathbf{log\ N} \tag{9}$$

where, N = Cumulative Equivalent Standard Axle Load (ESAL) over 10 years, k = Numerical coefficient.

In equation (8) and (9), numerical cofficient 'k' has been employed as multiplying factors to the pavement thickness value which was modified in aforesaid equations above

Determination of 'k' factor

The value of 'k' varies with ESAL and CBR. Attempts have been made to calculate the value of 'k' for different ranges of ESAL through checks and trials taking design methodology of IRC:SP:72-2007 as the bench mark for validation. The coefficient is balanced by attaching a suitable 'k' value that design thickness without JGT i.e., equation (8) matches thickness specified in the Indian standard and with that coefficient then the design thickness with JGT i.e., equation (9) is developed. Listed below the respective values of 'k' for set of different ESAL's and CBR's.

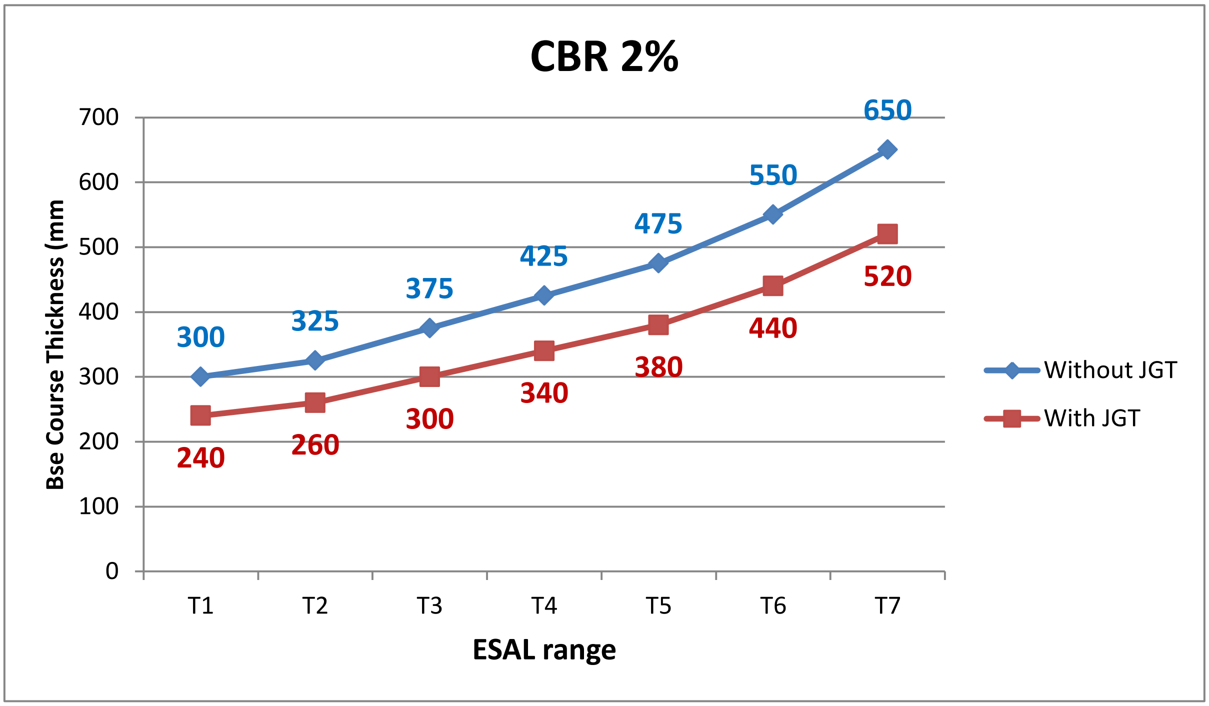
CBR (%)	Cumulative ESAL						
	10000 - 30000	30000 - 60000	60000 - 100000	100000 - 200000	200000 - 300000	300000 - 600000	600000 - 1000000
2	0.197	0.2	0.22	0.235	0.255	0.28	0.318
3	0.115	0.148	0.167	0.181	0.2	0.211	0.224
4	0.152	0.195	0.22	0.24	0.263	0.278	0.296
5	0.14	0.186	0.196	0.202	0.211	0.231	0.252
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

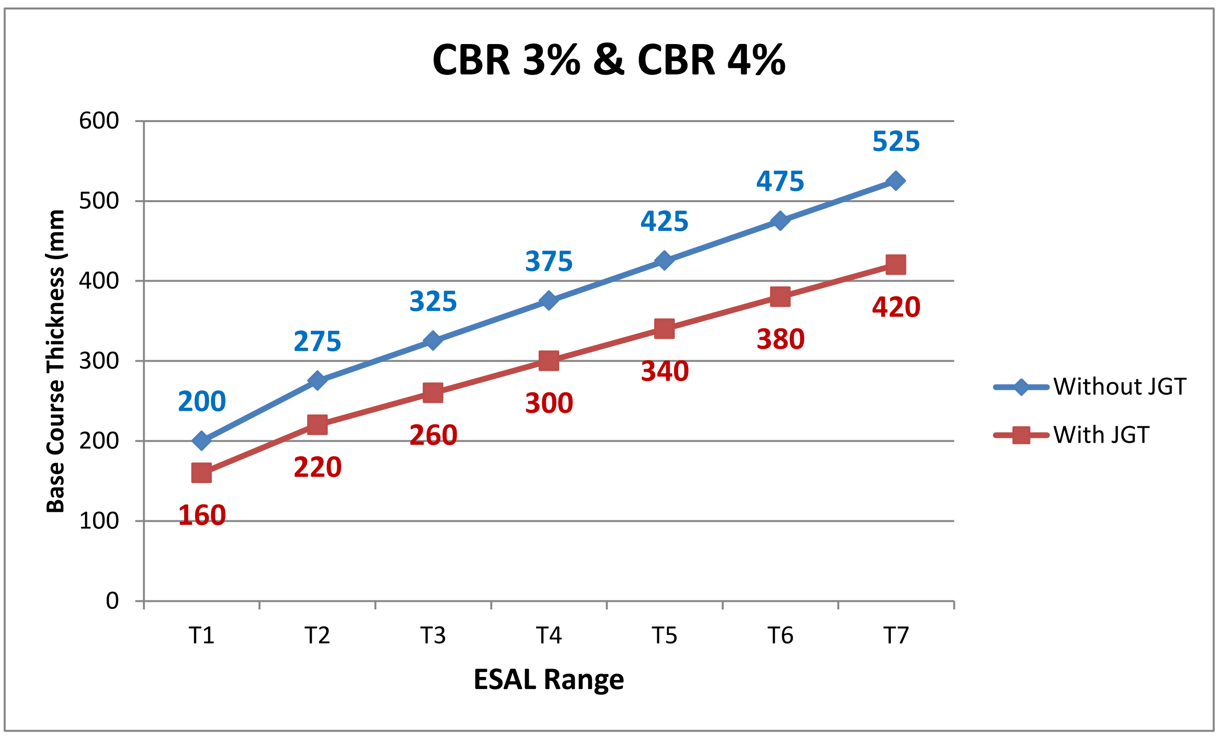
CBR v/s Pavement Thickness Curves under a set of different ESAL range :

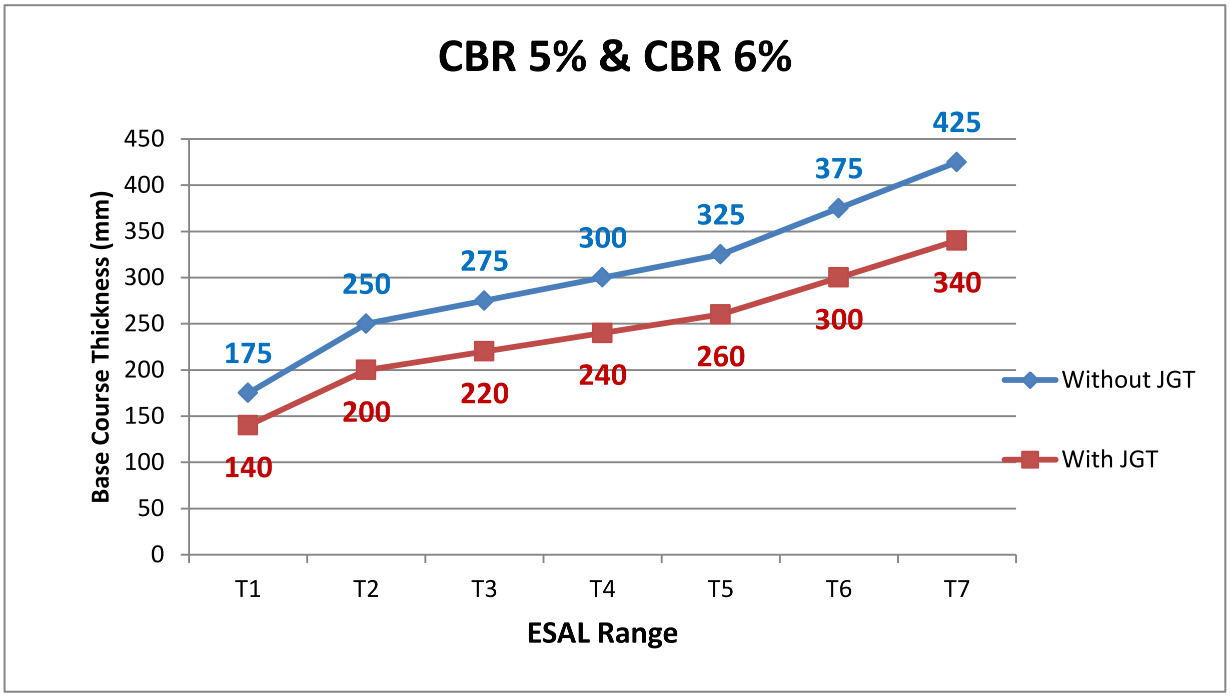
Applying equation (8) and (9), thickness of pavement can be determined for a range of low CBR values and ESAL taking wheel load (P) = 4100 kg**,** Tyre pressure (p) = 7.134 kg/cm^2, Elastic Modulus of JGT (E_{JGT}) = 100 MPa, Elastic Modulus of Base and Sub-base (E_{bc}) = 100 MPa.

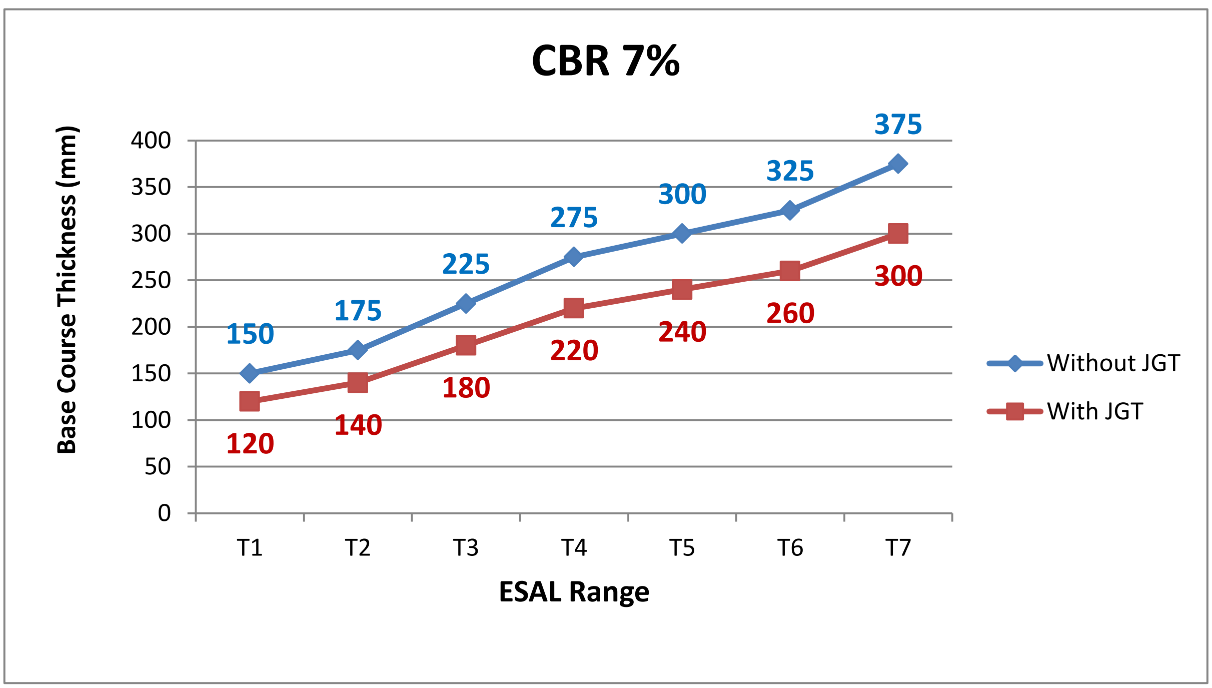
Design curves have been drawn with different ranges of ESAL (from 30,000 to 10,00,000) vs values of sub-grade CBR% from 2 to 7). Thickness of pavement can be directly read from the graph. In the graphs shown below Cumulative ESAL range along X-axis categorized as -

T1 : 10,000 – 30,000
T2 : 30,000 – 60,000
T3 : 60,000 – 1,00,000
T4 : 1,00,000 – 2,00,000
T5 : 2,00,000 – 3,00,000
T6 : 3,00,000 – 6,00,000
T7 : 6,00,000 – 10,00,000


CBR 2%
Bse Course Thickness (mm
ESAL range
T1
T2
T3
T4
T5
T6
T7
0
100
200
300
400
500
600
700
300
325
375
425
475
550
650
240
260
300
340
380
440
520
Without JGT
With JGT


CBR 3% & CBR 4%
Base Course Thickness (mm
ESAL Range
T1
T2
T3
T4
T5
T6
T7
0
100
200
300
400
500
600
200
275
325
375
425
475
525
160
220
260
300
340
380
420
Without JGT
With JGT


CBR 5% & CBR 6%
Base Course Thickness (mm)
450
400
350
300
250
200
150
100
50
0
175
250
275
300
325
375
425
140
200
220
240
260
300
340
T1
T2
T3
T4
T5
T6
T7
ESAL Range
Without JGT
With JGT


CBR 7%
Base Course Thickness (mm)
400
350
300
250
200
150
100
50
0
150
175
225
275
300
325
375
120
140
180
220
240
260
300
T1
T2
T3
T4
T5
T6
T7
ESAL Range
Without JGT
With JGT

INCREMENTAL BEHAVIOUR OF CBR OF SUB-GRADE WITH JUTE GEOTEXTILES – RESULTS OF FIELD TRIALS

Increment of CBR values in some of the rural road projects using JGT after different period lapsed

Sl No.	Road sites	State & District	Year of construction	Initial Subgrade CBR (%)	Using Woven JGT CBR value (%)		
					15KN	20KN	25KN
1.	Kakinada Port Connecting Road	A.P Kakinada	1997	1.61	-	4.7 (after 30 months)	-
2.	Munshirhat Rajput Road	W.B Howrah	2001	3.5	-	6.0 (after 1year)	-
3.	Andulia to Boiratala Road	W.B N. 24 Parganas	2005	3.22	-	10.47 (after 18 months)	-
4.	U. T. Road to Jorabari	Assam Darrang	2006	4.0	13.45 (after 23 months)	14.00 (after 23 months)	-
5.	Rampur Satra to Dum Dumia	Assam, Nagaon	2006	3.0	12.9 (after 23 months)	19.7 (after 23 months)	-
6.	Chatumari to MDR-14	Oridsa, Jajpur	2006	3.0	8.8 (after 23 months)	8.73 (after 23 months)	-
7.	Gehlawan village to PMGSY road	M.P Raisem	2007	2.0	10.6 (after 23 months)	15.5 (after 23 months)	-
8.	Khairjhiti to Ghirgosha	Chhatisgarh, Kawardaha,	2007	2.0	10.65 (after 23 months)	15.5 (after 23 months)	-
9.	Udal to Chakrbrahma	W.B D. Dinajpur	2011	2.8	-	-	7.82 (after 38 months)
10.	Nihinagar to Hazratpur	W.B D. Dinajpur	2011	2.2	-	-	7.55 (after 26 months)
11.	Bagdimarimulo Barada Nagar to Domkal Kheyaghat	W.B South 24parganas	2013	3.6	-	-	5.54 (after 16 months)
12.	Kansa to Bati	W.B Mursidabad	2013	3.9	-	-	7.2 (after 16 months)
13	Promod Nagar to Muga Chandra Para	Tripura West Tripura	2013	7.0	-	-	9.51 (after 18 months)
14.	V. Koracharahatti to T-10 Road	Karnataka Davanagere	2012	4.0	-	-	11.8 (after 16 months)
15.	Devarahospet to Gundur	Karnataka Havery	2012	4.3	-	-	12.1 (after 16 months)