Malaysian Journal of Civil Engineering 29(1):108-119(2017)

TECHNICAL NOTE

PAVEMENT DESIGN FOR THIN BITUMINOUS LAYER AND GREENHOUSE GAS BENEFIT

Swapan Kumar Bagui, Atasi Das, Tanmoy Das & Anukul Saxena

Intercontinental Consultants and Technocrat Private Limited., A- 8 Green Park, New Delhi

*Corresponding Author: *swapan.bagui@ictonline.com*

Abstract: Bituminous layer thickness is determined based on fatigue life and granular layer thickness is determined based on rut life. Higher bituminous thickness is required for increasing the fatigue life in pavement design thus increasing the project cost as well. In order to reduce project cost in some cases and places, fatigue life is not considered and pavement is allowed to design for rut life only and minimum bituminous layer is provided for protecting granular layer to avoid early distress. It depends on country practices and local experience. Cement treated sub base with granular base may be provided with thin bituminous surfacing of 40 - 90 mm to economize the project cost. This paper presents the development of Pavement design chart for thin surfacing and compare with conventional thickness and cost for few hypothetical case studies. Carbon credit is also compared for both cases. It is found from the case study that thin surfacing entails 20 % less cost and 28 % reduction of greenhouse gas (GHS) emissions compared to conventional pavement design.

Keywords: *Pavement, bituminous layer, fatigue*

1.0 Introduction

Basic principle of pavement design is that bituminous layer thickness and granular layer thickness should be sufficient to sustain fatigue design life and rut design life during the service period. Low volume road is designed based on the consideration of rut life. Indian Roads Congress Guidelines for the Design of Flexible Pavements (IRC: 37-2012) recommended that pavement composition is proposed based on rut life and minimum asphalt thickness of 40-50 mm be provided for protecting underlying layer for design traffic less than 5 Million Standard Axle (MSA). There is a need for development of pavement composition for thin surfacing for design traffic of more than 5 MSA. An analytical pavement design has been carried for developing pavement design for thin surfacing for high volume traffic. Literature review has been carried out based on the practices of international practices.

2.0 Literature Review

A new mechanistic-empirical design approach was developed in Germany which is focused on limiting the main sources of rutting of thinly sealed pavement structures: 1) excessive plastic deformation in the subgrade and 2) excessive plastic deformation of the unbound granular materials in the base course in the vicinity of the wheel load. The procedure is based on two steps: first, a response step is carried out where the response of the structure is calculated due to traffic loading, taking into account the effect of climatic conditions on material properties. Thereafter, a distress prediction is undertaken to evaluate the accumulated damage in terms of rutting originated in the subgrade and granular base course (Werkmeister *et al.*, 2015).

Inverted base pavements offer potential structural and economic benefits when compared with conventional flexible pavements. They have been used in countries where the price of asphalt and concrete is high and have performed satisfactorily for all traffic volumes. Inverted base pavements can be built using conventional techniques, by placing a well compacted graded aggregate base layer between a thin asphalt concrete layer and a cement-treated sub base. The proximity of the graded aggregate base layer to the load makes its behavior critical to the performance of the pavement structure (Papadopoulos and Santamarina, 2014).

About 80 % of the total road network in the India is categorized as rural roads carrying traffic less than 450 commercial vehicles per day. Huge network of rural roads are being built under the country's most ambitious prime minister's rural connectivity program (PMGSY) since its launch in December 2000. These roads are mostly designed as granular pavements with thin bituminous surfacing following the guidelines given in IRC: SP: 20 (2002), which does not refer to any documented performance data. Collecting performance data on such type of pavements under different subgrade, climatic and traffic conditions is crucial for developing rational pavement design criteria and also for systematic maintenance management of the pavements. Moving a step in this direction, 19 rural road test sections were selected in the eastern part of the country for a long-term performance study, and this paper presents the data collected over a period of four and half years. The reported performance data will be extremely helpful for developing rational design criteria and systematic management of rural roads. Also a performance criterion has been developed (considering vertical stress over subgrade) for thin surfaced rural roads using the limited data available under this study (Sahoo *et al.* , 2014).

Although minimum thickness depends somewhat on local practice and condition, individual agencies design for their own use. Honolulu department of transportation highways proposed minimum asphalt thickness of 2.5 inches and base course thickness of 4 inches.

Thin Asphalt Layer (TAL) as defined in this project with layer thickness 10 – 30 mm have approximately 11 mm nominal maximum aggregate size (NMAS) or smaller. When winter conditions call for extensive use of studded tyres and snow chains, TAL may not be an optimum surface layer: “The larger the aggregate the better" is an appropriate advice from a durability point of view (ERA –NET ROAD, 2011)

The South African Mechanistic Pavement Design Analysis Method (SAMDM) was used to determine the pavement structures of the typical thin asphalt pavements. The thin asphalt surface layer was modeled as viscoelastic and all other remaining layers (asphalt surface, cement stabilized base, cement stabilized sub-base, selected subgrade, and subgrade) were assumed as linear elastic. In order to get the pavement responses, the KENLAYER and the ABAQUS programs were used to model the layered linear elastic system. The KENLAYER program was also used to simulate the viscoelastic-layered system. Computational results show that the performance of the surface layer in a typical flexible pavement is greatly influenced by the layer's thickness, elastic modulus and temperature, as they are related to mechanical proprieties. The viscous nature of asphalt surfaces may also have strong effects on surface layers than in remaining elastic layers. In this study the deformation analysis was performed and the results showed that the surface layer presents higher deformations than the underlying granular layers (Theyse *et al.* , 2011).

The mechanistic design procedures may be used to design granular pavements with thin bituminous surfacing. Designers are cautioned, however, that the mechanistic design model has not been validated for granular pavements having asphalt surface layers less than 40 mm thick and that there is considerable uncertainty associated with the use of the model for these pavements. In particular, while the design model may suggest that pavements with thin asphalt surfacing can perform comparably to thick asphalt pavements at high traffic loadings, it does not adequately account for the impact of traffic loads on these thin surfacing. These inadequacies include the assumption that the tyre loading is applied as a uniform, vertical stress distribution (Austroads, 2010):

- the assumption that the interface between the surfacing and the underlying pavement is fully bonded
- the omission of horizontal loads due to braking, accelerating, turning and climbing movements
- the assumed moisture levels of the granular base courses
- construction variability
- the omission of environmental effects.

The required thickness for a granular thin surfaced pavement, for particular conditions, is determined using ‘Figure 8.4’ of AUSTROADS (2004). AUSTROADS (2004) has an equation presented with ‘Figure 8.4’ that describes the granular thicknesses required for various traffic and subgrades; this equation is reproduced here in (Gribble and Patrick 2008).

$$t = [219 - 211(\log CBR) + 58(\log CBR)2]\log(DESA/120) \quad (1)$$

Where:
t = pavement thickness (mm),
CBR = California Bearing Ratio (%) of the subgrade; and
DESA = design traffic (ESA).

This design methodology does not address the failure of pavement surfacing.

The pavement thickness indicated is the total thickness of the constructed pavement and is a function of both the subgrade CBR and the design traffic.

The SN (equation does not have a single unique solution; i.e., there are many combinations of layer thicknesses that are satisfactory solutions. The thicknesses of the flexible pavement layers should be rounded to the nearest 0.5 inch. When selecting appropriate values for the layer thicknesses, it is necessary to consider their cost effectiveness along with the constraints in order to avoid the possibility of producing an impractical design. From a cost effective point of view, if the ratio of costs for layer 1 to layer 2 is less than the corresponding ratio of layer coefficients times the drainage coefficient, then the optimum economical design is one where the minimum base thickness is used. Since, it is generally impractical and uneconomical to place surface, base or sub-base courses of less than some minimum practical thickness for each pavement course (AASHTO, 1993), it proposed minimum thickness depending on design MSA as presented in Table 1.

Table 1 : Minimum Proposed Pavement Thickness

Design Traffic (MSA)	*Pavement Composition (Inch)*	
	Asphalt Thickness	*Aggregate Base*
< 0.05	1.0	4
0.05 – 0.15	2.0	4
0.15 – 0.50	2.5	4
0.50 – 2.0	3.0	6
2.00- 7.00	3.5	6
> 7	4.0	6

3.0 Lead from Past Study

Thin bituminous layer thickness has been considered in different countries throughout the world. In this case, a filling layer of 40-50 mm BC is proposed over granular base as protecting the proposed pavement only and it does not contribute as fatigue resistance layer. Only rut life is considered for design purpose for the case of thin surfacing layer. IRC: 37-2012 and Austroads both recommend thin surfacing layer. This concept is used for low volume / rural road for traffic up to 1-2 MSA as recommended in AASHTO 1993 and IRC. It is found in IRC: 37-2012, 40 mm BC is provided over Recycled Asphalt Pavement (RAP). 40 mm BC cannot take any tension / fatigue failure. Compression is found at the bottom of asphalt thickness with thickness 50 mm or less. Therefore fatigue equation is not applicable for thin layer surfacing which is clearly reported in Austroads (2010). Chart has been developed up to design traffic of 100 MSA for Australian situation. Similar concept has been used for development of design catalogue for Indian condition.

3.1 Proposed Methodology

Presently, there is dearth of aggregate material in India and throughout the world. The concept of the design is based on the consideration of lesser amount of use of aggregate. Again based on the lead from past study, it is felt that thin surfacing layer should be designed for Indian condition. Following pavement compositions are proposed for the development of pavement compositions:

- Thin bituminous surface
- WMM
- Cement treated sub base
- Subgrade and embankment

Pavement catalogue has been developed using IIT Pave software developed by Indian Institute Technology (IIT).

Presently, World Bank, Asian Development Bank and local fund encourage less emission (GHG) for pavement construction, so carbon credit from different options has been calculated for the case study for comparison using ROADEO software, developed by World Bank (2011).

4.0 Pavement Design

Structural deterioration, and ultimately failure of a flexible pavement are generally “defined” by the development of cracks in the bituminous surfacing and ruts in the wheel paths. Rutting is, in turn, indicated by elastic strains at critical locations within the pavement system.

4.1 Model for Pavement Design

The resilient modulus of the subgrade is estimated from its respective California Bearing Ratio (CBR)-value which is based on the following empirical relationship:

The relation between resilient modulus and the CBR is given as:

$$E\ (MPa) = \begin{cases} 10*CBR & \text{for } CBR < 5 \text{ and } \ldots \\ 17.6*(CBR)^{0.64} & \text{for } CBR > 5 \end{cases} \quad (2)$$

E= Resilient modulus of subgrade soil in MPa

Resilient Modulus (MR) of the untreated Granular Sub-base (GSB) above the subgrade of modulus, $MR_{subgrade}$ is given as:

$$MR_{gsb} = 0.2h^{0.45} * MR_{subgrade} \quad (3)$$

Where h=thickness of sub base layer in millimeter.

Fatigue life of a bituminous has not been considered for thin surfacing.

4.2 Subgrade Rutting Criteria

The equation for rutting is given as (IRC: 37-2012):

For 80 % reliability

$$N = 4.1656 \times 10^{-08} [1/\varepsilon_v]^{4.5337} \quad (4)$$

For 90 % reliability

$$N = 1.41 \times 10^{-08} [1/\varepsilon_v]^{4.5337} \quad (5)$$

Where, ε_v= Subgrade strain at the top of subgrade.
N= Design life of Pavement in Number

80 % reliability shall be considered for design traffic up to 30 MSA and 90 % for design traffic above 30 MSA.

4.2.1 Input Parameters

Tire pressure for design is assumed as 0.56 MPa; Spacing between two wheels is taken as 310 mm for design purpose. μ value of subgrade, granular layer, asphalt layer and cement treated subbase is taken as 0.35 and 0.25. Axle load is taken as 80 kN. Unconfined Compressive Strength of cement treated sub base (15 cm Cube size) at 7 days is taken as 1.5 -3.0 MPa for minimum cement content of 2%. E value is adopted as 600 MPa for the determination of pavement compositions.

Following minimum bituminous thickness is proposed for thin surfacing depending on the design traffic and local experience and mentioned in Table 2.

Table 2: Proposed Bituminous Thicknesses

Design Traffic (MSA)	*Proposed Bituminous Thickness (mm)*
0 -5	30
5-30	40
30 - 50	50
50-100	60
100-150	90

Considering Table 2, pavement compositions have been finalized using IIT Pave software and presented in Figures 1 to 5.

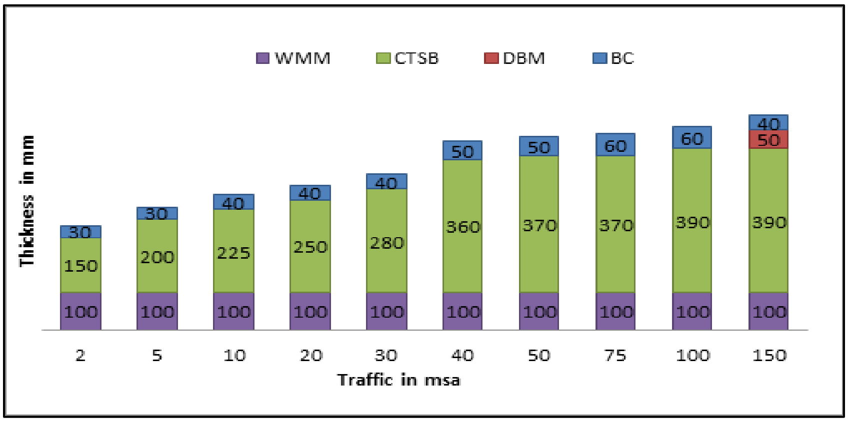

Figure 1: Design Table for CBR 5 %

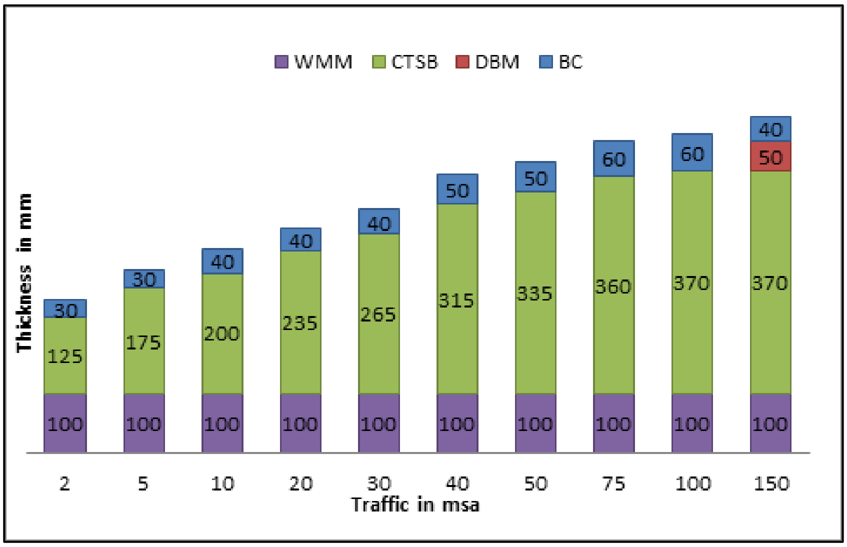

Figure 2: B Design Table for CBR 7 %

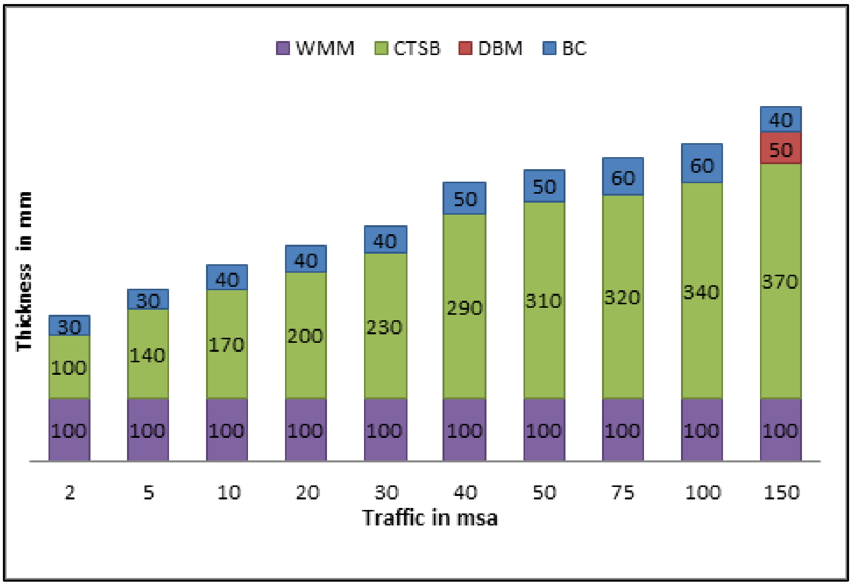

Figure 3: Design Table for CBR 10 %

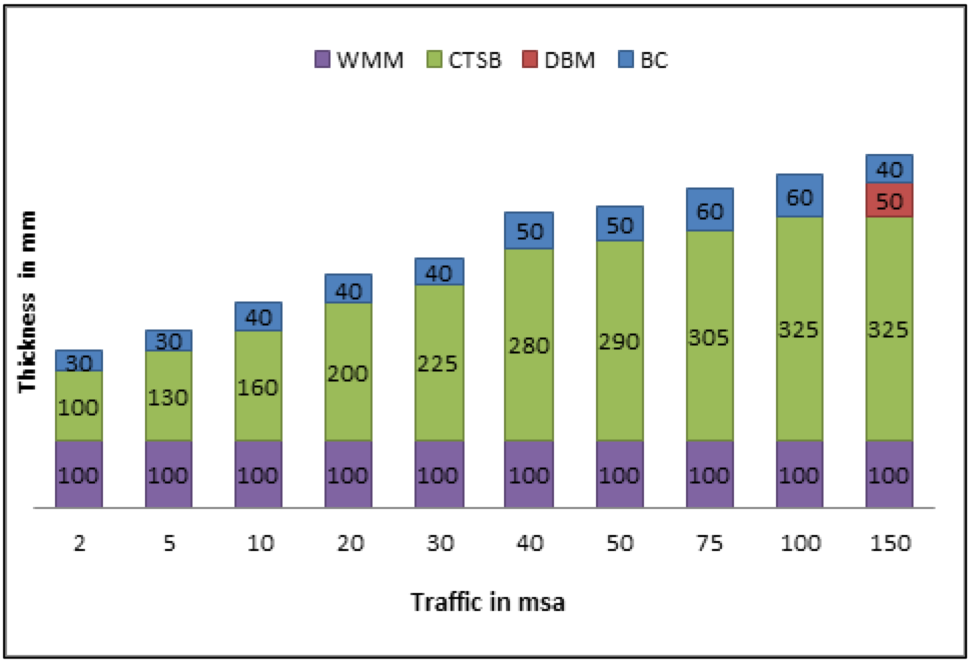

Figure 4: Design Table for CBR 12 %

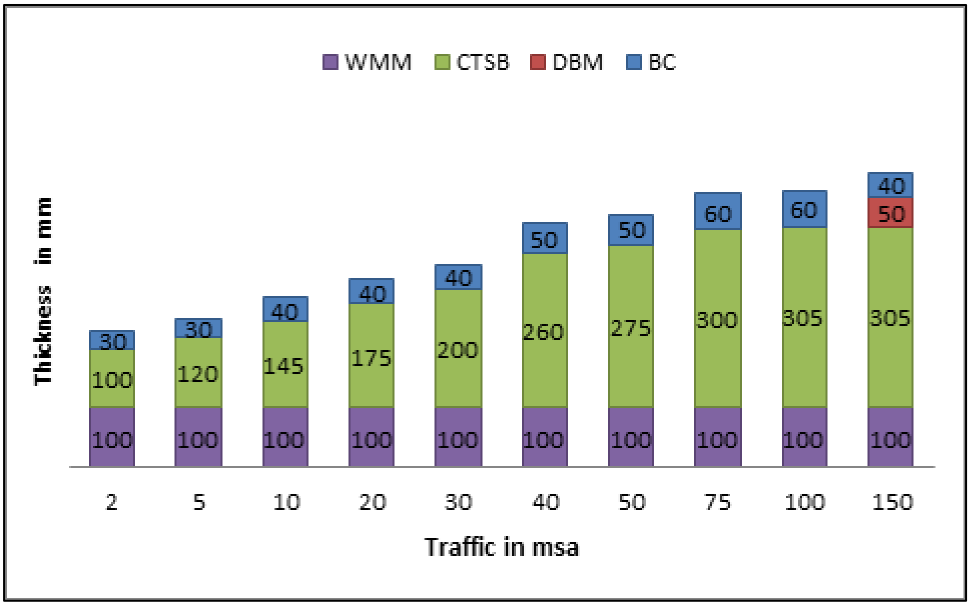

Figure 5: Design Table for CBR 15 %

4.2.2 Sample Calculation

Pavement compositions have been presented in Chart 1. Pavement compositions from this table and that proposed in IRC: 37-2012 for conventional pavement are compared; it is found that lesser thickness is required for providing cement treated sub base. This reduces consumption of processed aggregate. Bituminous thickness reduces substantially thus reducing project cost.

CBR 10 %: 50 BC+110 DBM+250 WMM+200 GSB for 100 MSA for conventional pavement design (IRC: 37-2012).

Thin surfacing: 60 BC+100 WMM+340 Cement treated sub base. The output of this sample calculation is presented below which is determined based on four layer pavement model.

```
No. of layers            4
E values (MPa)           1700.00  450.00  600.00   76.83
µ values                 0.350.350.250.35
thicknesses (mm)         60.00  100.00  340.00
single wheel load (N)   20000.00
tyre pressure (MPa)      0.56
Dual  Wheel

Z          R        SigmaZ     SigmaT     SigmaR    TaoRZ     DispZ     epZ      epT      epR
500.00    0.00-0.2211E-01 0.8364E-01 0.6917E-01-0.3688E-02 0.2685E+00-0.1005E-03 0.1198E-03 0.8964E-04
500.00L   0.00-0.2205E-01 0.1358E-02-0.3663E-03-0.3688E-02 0.2685E+00-0.2915E-03 0.1198E-03 0.8949E-04
500.00  155.00-0.2378E-01 0.9029E-01 0.7864E-01-0.5771E-02 0.2761E+00-0.1100E-03 0.1276E-03 0.1034E-03
500.00L 155.00-0.2378E-01 0.1537E-02 0.1535E-03-0.5730E-02 0.2761E+00-0.3172E-03 0.1276E-03 0.1033E-03
```

Design life has been calculated based on maximum compressive strain of 317 micro-strains at 90 % reliability. Design life is found to be 102 MSA≈ 100 MSA. Therefore design is safe. Total thickness and cost are calculated and compared in Table 3.

Table 3: Total Thickness and Cost Comparison

Design Traffic	*Total Thickness (mm)*		*Cost Per km (USD)*		*Remarks*
100	*Conventional*	*Thin Surfacing*	*Conventional*	*Thin Surfacing*	*Cost Saving*
	610	500	1370000	1100000	19.8 %

From Table 3, it is found that proposed thin surfacing is 19.8 % cheaper than conventional pavement.

4.2.3 GHG Emission Calculation

Carbon credit for conventional pavement construction and thin surfacing construction has been calculated for the same case study as mentioned above. CO_2 emission for construction of one kilometer with four lanes construction is found equal to 1310 t and 940 t for conventional construction and thin surfacing i.e. approximately 28 % reduction CO_2. Therefore, thin surfacing may be allowed for road and it will be most suitable for places where rain fall is low.

5.0 Conclusions

Pavement compositions for thin asphalt surface have been developed for low volume and heavy traffic loading for Indian condition. The proposed compositions may be useful for reducing cost of the project. Reduction of project cost varies depending on various factors namely availability of material, labour cost and other factors.

Unconfined compressive strength of cement treated sub base should be in the range of 1.5-1.6 MPa at seven days and resilient modulus has been adopted as 600 MPa based on experimental tests carried out in different projects. This value may be reduced to 400 MPa for using local materials (natural morrum / gravel) as cement treated sub base.

The thickness presented in Chart 1A to 1E may be useful as guideline. Thicknesses may be revised based on the project specific requirement using IIT Pave Software or any analytical software giving the stress / strain values.

Proposed composition is useful for low budget and may be constructed where rain fall is low and it reduces CO2 Emission.

Following additional conclusions may be drawn from this present work:

- Thickness of Wet Mix Macadam is considered as 100 mm for analysis with resilient modulus value of 400 MPa. It will work as inter-granular crack relief layer.
- Asphalt concrete layer thickness varies from 30 mm to 90 mm for design traffic 2 MSA to 150 MSA. It will work in protecting the underlying layer.
- Thickness of cement treated sub base varies and it increases with increasing traffic. It varies from 100 mm to 305 mm for CBR value of 15 % and similar trend observed for other CBR value.
- For known design traffic, thickness of cement treated sub base varies depending on the CBR value of subgrade. It is higher value for lower CBR.

- Cost of conventional pavement and thin surfacing has been compared for the case study presented in this paper and it is found that construction cost is 20 % cheaper than that of conventional pavement design.
- Similarly carbon foot credit has been calculated and it is found that 28 % reduction in CO2 emission for using thin surfacing for new construction.

References

AASHTO (1993). *Pavement Design Guideline Gribble*, M., Patrick, J. 2008. Adaptation of the AUSTROADS Pavement Design Guide for New Zealand conditions. Land Transport New Zealand Research Report 305. 72pp.

Austroads (2004). A Guide to the Structural Design of Road Pavements. Pavement Design Guide for New Zealand conditions

Austroads (2010). Part 2, Guideline for Pavement Design. Pavement Design Guide for New Zealand conditions

ERA NET –ROAD (2011). Danish Pavement Design Software.

Gribble M. & Patrick J. (2008), Adaptation of the AUSTROADS Pavement Design Guide for New Zealand Conditions

IRC: 37-2012. Tentative Guideline for New Pavement Design.

IRC: SP: 20 (2002), Indian Road Congress, Special Publication 20, Rural Road Manuals, published by The Indian Road Congress

Papadopoulos, E. and Santamarina, J. (2014). *"Optimization of Inverted Base Pavement Designs with Thin Asphalt Surfacing"*. Geo-Congress 2014 Technical Papers: pp. 2996-3004.

Sahoo, U., Ahmed, S., and Reddy, K. (2014) *Long-Term Performance Evaluation of Rural Road Pavements in India*. Design, Analysis, and Asphalt Material Characterization for Road and Airfield Pavements: pp. 91-98.

Theyse H. L., De Beer M., and Rust F. C. (2011). *"Overview of South African Mechanistic Pavement Design Method".*

Werkmeister, S., Canon Falla, G., and Oeser, M. (2015). *"Analytical Design Methodology for Thin Surfaced Asphalt Pavements in Germany".* Airfield and Highway Pavements 2015: pp. 730-741.

World Bank (2011), ROADEO-Road Emission Optimisation- *A Toolkit for Greenhouse Gas Emissions Mitigation in Road Construction and Rehabilitation*, January 2011, World Bank