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TECHNICAL PAPER

Design and development of methodology for construction of thin white topping for rural roads in India

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Abstract

A large proportion of villages in India have been connected with water bound macadam (WBM) or bituminous roads. Rural roads usually have a low volume of traffic, consisting mostly of light transport vehicles with less frequency of heavy traffic. Maintenance of these roads is neglected because of the paucity of funds and the created road asset is in deteriorated condition. The non-availability of suitable soil and aggregates has made projects unviable and cost prohibitive. This aggregate scarcity will increase further as a result of environmental conservation and restriction on mining. There is a need to develop alternative pavement designs to construct sustainable and durable rural roads. The stabilization of soil/aggregate is being used worldwide towards optimal usage of scarce resources. The concepts of soil/aggregate stabilization and Cold In Place Recycling technique provide a comprehensive solution for rehabilitation of existing road and greenfield road construction. Cold In Place Recycling process allows usage of locally available marginal materials. The stabilization process can use a wide range of stabilization agents such as soil-aggregate mix, lime, cement, fly ash, foamed bitumen, emulsion, polymers, and other proprietary chemical stabilizers. Two rural roads are identified under Mukhya Mantri Gram Sadak Yojana Research and Development Scheme. Pavements are designed considering cement treated base. These roads are constructed using the Cold In Place Recycling technique. The existing water bound macadam (WBM)/deteriorated bituminous surface is stabilized with cement. Bituminous concrete and Thin White Topping are provided as wearing course. The performance of pavement is evaluated after 2 years of construction. Also, the balance life of the pavement is checked and the results are satisfactory. The stabilized pavements offer superior strength and longevity, even in extreme climatic conditions, and provide better performance. The design charts for Thin White Topping for rural roads are not available, hence the design charts for Thin White Topping of M30/M35/M40 grade concrete on Cement Treated Base of varying thickness and different subgrade CBR are prepared based on IRC 62-2014 for traffic less than 50 CVPD, 51 to 150 CVPD, and less than 450 CVPD. These charts are ready to use and act as a guide to the Field Engineers. The optimum thickness of Thin White Topping can be selected from the chart for known subgrade CBR and Traffic. The effect of variation of CTB thickness on Thin White Topping thickness can be determined from the chart.

Keywords Cement treated base (CTB) · Thin white topping (TWT) · Cold in place recycling (CIPR) · Rural roads · Stabilization · California bearing ratio (CBR)

Introduction

A large proportion of villages in India have been connected with water bound macadam (WBM) or bituminous roads. Rural roads usually have a low volume of traffic, consisting mostly of light transport vehicles with less frequency of heavy traffic. Mostly flexible pavements with granular subbase and base having thin bituminous carpet as wearing course are adopted in rural roads, which deteriorate during monsoon seasons leading to costly maintenance every year. Maintenance of these roads is neglected because of the

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paucity of funds and the created road asset is in deteriorated condition. The non-availability of suitable soil and aggregates has made projects unviable and cost prohibitive. This has necessitated the exploration of other alternative pavements. The stabilization of existing local available material provides an effective solution. Wu et al.[1] constructed six full scale accelerated pavement testing tracks with cement treated base with thin white topping and after testing in laboratory concluded that, the Roller Compacted Concrete pavement structures over adequate base support would have superior load carrying capability hence thin RCC-surfaced pavement structure recommended as a pavement design alternative in low-volume pavement design. Ramachandra, [2] studied a technology demonstration project in Banglore to demonstrate the advantages of white topping by making use of the advances in construction equipment and methods and concluded that concrete roads and white topping provide a sustainable as well as cost-effective option for pavement construction. The guidelines for construction of cement concrete roads are presented by. Kadiyalie [3] which includes advantages and disadvantages of concrete roads, techno-economic aspects, properties and testing of concrete, design mixes, drainage considerations, specifications for subgrade, subbase, concrete pavement design, joints, quality control, a special technique of concrete paving, and use of fly ash in concrete roads. Skanda Kumar et al. [4] conducted performance evaluation studies to determine the functional and structural condition of a white topping overlay. Li and Vandenbossch [5] developed three dimensional finite-element model for thin white topping subjected to environmental and wheel loads and concluded that the maximum tensile stress is induced in the wheel path and at the bottom of the PCC overlay, which results in a longitudinal crack. S K Bagui [6] developed design curves to estimate thickness of soil–cement base and that of the soil–lime subbase for different traffic and different values of modulus of soil–cement and soil–lime mix. Kumar et al. [7] provides a cost-effective solution to problematic clayey soils by adding jute fibres. Erdawaty et al. [8] presented that the addition of asbuton with waterglass could increase soil's load capacity and reduce the settlement of soft soils. The design charts for flexible pavements using cement treated base are published in IRC 37-2018 [9]. Guidelines for The design of plain jointed rigid pavements for highways are published in IRC 58-2015 [10], and guidelines for design and construction of cement concrete pavements for low volume roads are published in IRC SP 62-2014 [11]. Harrington et.al [12] provides a guide for evaluating existing pavements to determine if they are good candidates for concrete overlays, selecting the appropriate overlay system for specific pavement conditions, and managing concrete overlay construction work zones under traffic. Guidelines for conventional and Thin White Topping are published by IRC 76-2015 [13]. The design charts for Thin White Topping for rural roads are not available. The goal of present research is to design and develop methodology for construction of Thin White Topping for rural roads. The development of these charts can be useful for Field Engineers. Thin White Topping design charts with variable thickness of cement treated base and different subgrade CBR are developed for rural roads.

Cement treated base with cold in place recycling technique

Quality road aggregates have become rare and costly in many places in India due to the massive construction activities required for the development of new infrastructure facilities. It is a need to look for ways of improving lower quality materials that are readily available for use in roadway construction. Cement/ lime treatment has become an accepted method for increasing the strength and durability of soils and marginal aggregates. Soil cement is a highly compacted mixture of soil/aggregate, cement, and water. The advantages of the soil–cement mixture are great strength and durability combined with low first cost.

Advantages of Cement stabilization are—

- Cement is easily available
- Cost is relatively low
- Highly durable
- Weather resistant and strong
- Reduces swelling characteristics of the soil

Many existing rural roads in India are unpaved low volume roads. Heavy rainfall and floods affect almost all these roads frequently. The roads are severely damaged due to floods, currents, and wave action. This situation requires the maintenance of these roads frequently. These adverse effects together with inadequate compaction significantly impair the durability of these roads. The ultimate effect is comparatively low subgrade strength and eventually higher pavement thickness if paved roads are to be constructed. Based on this treatment of locally available materials has become necessary for satisfactory and economic construction of roads in these regions. Cement stabilized bases or lime stabilized sub-bases may be provided for the construction of rural roads for low volume light traffic.

An increasing emphasis has been placed on the use of stabilized pavement materials in recent years. Using stabilizing agents, low-quality materials can be economically upgraded to the extent that these may be effectively utilized in the pavement. Stabilized pavement materials are generally used in the pavement structure as base courses and sub-bases. In a layered system of elastic materials, where the overlying layers have higher moduli of elasticity than underlying layers, tensile stresses are developed at the interfaces between the layered materials. This layered system analysis is commonly presumed to apply to a pavement where stiffer materials are used in the upper layers. Since many stabilized materials are relatively weak in tension, any type of rational design procedure must take their tensile strength into account.

The key machinery required for the CIPR technique is—Streau Master (Automatic Cement Spreader), recycler, pad foot roller, grader, etc.

Field trial stretch

Two roads having different types of traffic, geography and existing soil conditions have been selected from Pune district in Maharashtra State under the Research and Development Scheme of Mukhya Mantri Gram Sadak Yojana.

(1) Sanaswadi to Dhanore Road Taluka Shirur District Pune
(2) Pimpre to Ozare Road Taluka Indapur District Pune

Preliminary data

Preliminary data like subgrade soil, surface condition, carriageway width, crust thickness, rainfall and drainage condition have been collected. The preliminary data of the two road sites are as tabulated below (Table 1).

Laboratory tests are conducted on subgrade soil for classification of soil, proctor density, and CBR. Unconfined Compressive Strength (UCS) is strength indicator of cement treated base (CTB). It is conducted on existing WBM material with 4% cement content. According to IRC: 37-2018 [9] 7 days UCS of cement stabilized base should be minimum 4.5 to 7 MPa. The UCS test results fit in this limit, specified by the Indian Road Congress (IRC). The laboratory test results are given in Table 2.

Pavement design

The Thin White Topping (TWT) Pavements are designed as per IRC SP 62-2014 [11].

(A) Name of Road: Sanaswadi Dhanore Road Tal. Shirur Dist. Pune

Initial design traffic (A)	283 CVPD	Grade of concrete	M30
Design life (n)	20 years	Design flexural strength = 90 days strength considered $f_f = 1.1\times 0.7\times\sqrt{fck}$	4.22 MPa
Traffic growth rate (r)	5%	Poisson's ratio of concrete	0.15
Reliability	60%	Coefficient of thermal expansion (α)	10×10^{-6} per °C
% Cracking at the end of design life	40%	Trial Concrete Thickness =	200 mm with CTB 200 mm
Fatigue check criteria for a vehicleexceeding 50 kN Wheel load	10%	Transverse Joint spacing (L)	2.00 m
Wheel load for a single axle with dual wheel	50 kN	Temperature Zone	III (Maharashtra)
Spacing of Wheel	310 mm		
Tyre pressure (p)	0.80 MPa		

Table 1 Preliminary data of two road

Sr. No.	Road name	Length km	Initial Traffic CVPD	Carriageway width m	Surface condition	Crust thicknessmm
1	Sanaswadi To Dhanore	1.80	283	3.75	Deterioted BT	200
2	Pimpri To Ozare	0.50	102	3.00	WBM	100

Table 2 Subgrade soil properties and UCS of WBM with 4% cement

Sr. no.	Road name	Subgrade soil classification			MDD KN/m^3	OMC %	CBR %	(WBM + 4% Cement) 7-day UCS MPa
		Gravel %	Sand %	Silt and Clay %				
1	Sanaswadi To Dhanori	25.08	71.33	3.60	19.71	11.00	6.79	5.6
2	Pimpri To Ozare	28.03	67.70	4.27	21.67	10.81	8.00	

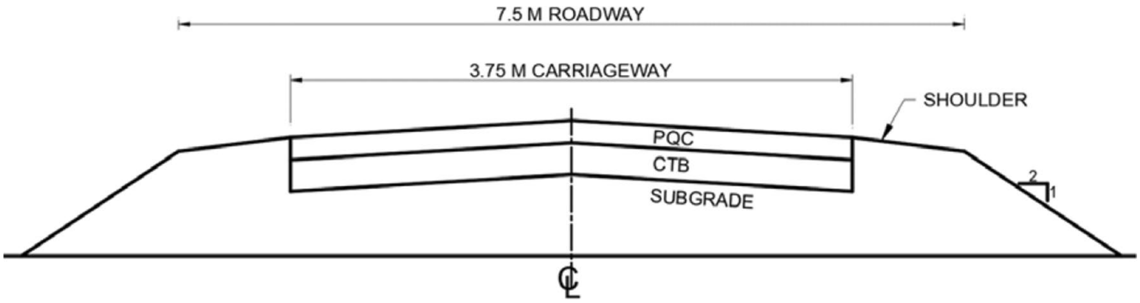

Fig. 1 Typical cross section of rigid pavement

A typical cross section of rigid pavement is shown in Fig. 1.

Edge Stress using Westergaard equation

$\sigma_e = 2.16$ MPa

Temperature stress (σ_{te}) is calculated by equation (1)

$$\sigma_{te} = \frac{0.67 \times C \times \alpha \times \Delta T \times E}{2} - \frac{E \times \alpha \times \Delta T}{3 \times 3.91} \tag{1}$$

C = correction factor based on L/l = 0.34

l = radius of relative stiffness.

α =: coefficient of thermal expansion

ΔT=: temperature differential °C

E = Modulus of Elasticity of concrete in MPa

$\sigma_{te} = 0.16$ MPa

Combined stress (σ) = wheel load stress + temperature stress

$\sigma = 2.16 + 0.16 = 2.32$ MPa < 4.22 MPa

Check for Fatigue criteria with 60% reliability as given by Eq. (2)

$$Log_{10} N_f = \frac{SR^{-2.222}}{0.523} \tag{2}$$

$N_{f\text{-}}$ = Fatigue life with combined wheel load + temperature stresses.

SR = Sress Ratio = combined flexural stress/flexural strength.

SR = 0.56.

Allowable repetitions given by Eq. (2) N_f = 15,129,009.

For rural roads fatigue criteria checked for 10% of CVPD over design life.

Expected repetitions (N) = 10% of Total traffic over design life = 10% of $\frac{A\times(1+r)^n-1}{r}$.

N = 362,072 < N_f.

As the cumulative fatigue damage factor (N/N_f) is less than 1; hence the design is safe.

(B) Name of Road:—Pimpre Ozare Road Tal. Indapur Dist. Pune

- Initial traffic (A): 102 CVPD, Design thickness of M30 grade TWT: 150 mm with CTB 200 mm
- Subgrade CBR: 8%
- Modulus of subgrade reaction for subgrade CBR 8% and 200 mm CTB (k) = 237 MPa/m
- Edge stress σ_e = 3.27 MPa
- Temperature stress σ_{te} = 0.61 MPa
- Combined stress (σ) = 3.88 MPa.

Since calculated combined stress (3.88 MPa) is less than design flexural strength (4.22 MPa), the design is safe.

Construction methodology

Cement treated base

The existing road is having a WBM/deteriorated bituminous surface. To utilize existing coarse aggregates Cold in Place Recycling (CIPR) technology has been adopted for the construction of CTB. The machinery required for CTB work is Streau Master (Automatic Cement Spreader), Recycler, Pad foot roller, and grader. The CTB thickness requirement is 200 mm, hence additional Wet Mix Macadam (WMM) material laid of required thickness. 4% Cement by weight basis is spread on the coarse aggregate surface with help of Streau Master. The width of the spreader is 2 meters. Hence, cement is spread in half lane width in one go. Recycling of WBM/WMM material is done with the help of a Recycler. Recycler can recycle material up to 500 mm depth. For the trial stretch, 200 mm thick CTB is required; accordingly, the depth of recycling is adjusted, so that compacted 200 mm thick CTB is obtained. (Fig. 2) Water is added as per optimum moisture content (OMC) requirements at the time of recycling. After recycling the surface is rolled with a pad foot roller to achieve the required compaction. The surface is graded to the required profile and rolled with the help of a smooth wheeled roller. Curing of CTB is done for 7 days before laying of wearing course.

Fig. 2 Recycling of base course with Recycler

Fig. 3 Laying of PQC

Wearing course

Channels of required sizes are placed on the outer edge side of the carriageway. M30 grade Pavement Quality Concrete (PQC) of required thickness as per design has been provided on CTB (Fig. 3). A polythene sheet of 125-micron thickness has been laid on CTB before laying of PQC. Concrete is properly compacted with the help of needle vibrators. The finished surface of the concrete is broomed with the help of a wire broomer to obtain texturing of 1.5 mm depth (Fig. 4). The transverse contraction joints at the spacing 2 meter center to center and 3 to 5 mm width sawed to the depth 1/3 of the thickness of TWT within 24 hours after laying of TWT. The joints are filled with a sealant material (Fig. 5).

Fig. 4 Texturing of concrete

Fig. 5 Joint cutting and filling with sealant

The curing of concrete is done for 14 days by ponding/placing wet gunny (jute) bags. Light vehicles are allowed after 14 days. Heavy vehicles are allowed after 28 days.

Problems during construction

(1) During constructing the CTB roads, it is necessary to divert traffic to alternative nearest road otherwise surface profile of the freshly constructed CTB layer will get disturbed.
(2) A set of machinery is required for construction CTB using the CIPR technique, hence it becomes uneconomical to construct smaller stretches.
(3) The construction of the road should be in a continuous stretch; otherwise indirect expenses could be increased.

Performance evaluation

Pavement performance evaluation includes a range of qualitative and quantitative measurements, intended to capture the structural and functional condition of pavements [14]. The information collected provides a ‘‘report card’’ of pavement condition at a particular point of time. Normally the collected pavement evaluation information is grouped into three broad categories, namely:

(A) Serviceability (B) Structural capacity (C) Surface distress

Serviceability

The pavements are built for serving the traffic which represents serviceability. This principle has motivated the use of a rating scale for pavement serviceability which ranges from 0 to 5. In which 0 signifies very poor and 5 signifies very good rating. Serviceability of pavement is observed with roughness index. The roughness index test has been carried out on two constructed roads using axle mounted bump integrator.

Structural capacity

The capability of pavement to handle the traffic loads anticipated over its life is known as structural capacity. There is a variety of commercially available devices for measuring in-situ pavement deflections, referred to as deflectometer. Deflectometer applies a known load to the surface and uses geophones arranged to yield a ‘‘bowl’’ of deflection measurements. These devices provide information not only on the structural capacity of pavement sections but also on the structural properties of their layers and the subgrade. The latter is done through back-calculation. Falling Weight Deflectometer (FWD) is used to assess the structural capacity of pavement [4] (Fig. 6). Response of pavement to falling weight is recorded in terms of deflection and the structural capacity of pavement is worked out through back-calculations. Program KUAB PVD software module is used to calculate moduli and strain analysis with lifetime for required strength from respective input data. In-built calculations include calculations of modulus of elasticity for the layers in a pavement, given the values for each layer thickness and Poisson’s ratio. It uses an iterative procedure, where theoretical deflection values in a mathematical model are compared to the measured data, and the program adjusts the layer modulus until no further improvement is required. The program then calculates the strains in the layers and works out which layer will fail first according to the strain criteria and predicts balance life. In situ strength of concrete pavement is assessed with the nondestructive testing method using a rebound hammer (Fig. 7).

Fig. 6 FWD test

Fig. 7 Rebound hammer test

Surface distress

This component of performance evaluation involves the collection of data related to the condition of the pavement surface. Distresses are defined as the manifestations of construction defects, as well as the damaging effects due to traffic, the environment, and their interactions. They encompass a broad variety of cracks and surface distortions. Data are typically collected manually through condition surveys. The variety of distresses encountered in concrete pavements is grouped into three main categories: cracking, surface defects, and joint deficiencies. Joint deficiencies apply to jointed concrete pavements only.

(a) Cracking: Cracking appears in various forms that allow identification of its causes. Some are fatigue-related, caused by the accumulation of fatigue damage from repetitive vehicle axles, such as corner cracks. Other cracks, either longitudinal or transverse, can be caused by traffic, the environment, or poor construction. The combination of slab warping under thermal gradients and load may result in transverse cracks. Longitudinal and transverse crack severity is quantified as:

(i) Low: mean crack opening smaller than 3 mm.
(ii) Moderate: mean crack opening between 3 and 6 mm.
(iii) High: mean crack opening larger than 6 mm.

(b) Surface Defects Map cracking consists of interconnected cracks that extend only into the upper surface of the slab. It may be caused by poor construction. Spalling is the result of the dislodgement of surface blocks created by map cracking.

(c) Joint Deficiencies: Seals of transverse/longitudinal joints can be damaged from a variety of causes, (e.g., splitting or debonding due to age hardening) and result in moisture and foreign object accumulation into the joint. Spalling is the breaking, chipping of slab edges within 0.6 m of transverse/longitudinal joints, and it is caused by either lack of lateral support along a joint edge or by joints that do not allow slab expansion due to the presence of foreign objects. Performance evaluation of two constructed field stretches is done based on the above parameter (Table 3).

Design charts

The Thin White Topping design charts are prepared for traffic less than 50 CVPD, 51 to 150.

CVPD, and less 450 CVPD with variable cement treated base thickness for different subgrade CBR values.

The factors governing TWT pavement design are;

Wheel load

Heavy vehicles are not expected frequently on rural roads. The maximum legal load limit on a single axle with dual wheels in India being 100 kN, the recommended design load on the dual wheel is 50 kN having a spacing of the wheels as 310 mm center to center.

Tyre pressure

The tyre pressure is taken as 0.80 MPa for a truck carrying a dual wheel load of 50 kN. The effect of tyre pressure on the wheel load stresses for the practical thickness of pavement is not significant.

Design period and traffic growth rate

Concrete pavement for rural roads is designed for 20 years life. A traffic growth rate of 5% per year has been considered over the design period.

Subgrade strength

The strength of the subgrade is expressed in terms of the modulus of subgrade reaction (k), which is determined by carrying out a plate load test. Since subgrade strength is affected by the moisture content, it is desirable to determine it soon after the monsoon. Stresses in concrete pavement are not very sensitive to minor variation in *k* values and hence its value for a homogeneous soil subgrade may be obtained from its soaked CBR value. The minimum CBR of the subgrade shall be 4%. The modulus of subgrade reaction for different subgrade CBR is given in Table 4.

Cement treated base (CTB)

The CTB material shall have a minimum unconfined compressive strength (UCS) of 4.5 to 7 MPa as per IRC: SP:89

Table 3 Performance evaluation of rigid pavement

Sr. no.	Name of road	Length km	Pavement composition	Roughness index	Structural capacity	NDT strength MPa	Surface distress
1	Sanaswadi To Dhanori	1.80	CTB-200 mm TWT-200 mm	2046 mm/km Good	adequate	35 Good	No
2	Pimpri To Ozare	0.50	CTB-200 mm TWT-150 mm	2100 mm/km Good	adequate	30 Good	No

Table 4 Modulus of subgrade reaction(k) for different values of subgrade CBR

Soaked subgrade CBR	4	6	8	10	12	16	20
k value (MPa/m)	35	42	49	54	59	65	68

[15] in 7/28 days curing. The strength of cementitious layers keeps on rising with time and an elastic modulus of 5000 MPa can be considered for analysis of pavements with CTB layers having 7/28-day unconfined compression strength values ranging between 4.5 and 7 MPa. The conventional cement treated layer should attain the above strength in 7 days, whereas lime and lime fly ash stabilized granular materials and soils should achieve the strength in 28 days since the strength gain rate is slow in such materials. Curing of cemented bases shall be done for a minimum period of seven days before the commencement of the construction of the next upper layer for achieving the required strength. Poisson's ratio value of CTB material can be taken as 0.25. While preparing design charts for TWT the thickness of CTB varying from 100 to 300 mm has been considered. The design of rigid pavement is based on modulus of subgrade reaction (k). Due to the provision of CTB over subgrade, the composite k value of pavement is improved and it is considered in the design, based on subgrade CBR and CTB thickness. The composite k value is given in Table 5. The relation between composite k value and CTB thickness for different subgrade CBR(%) is shown in Fig. 8.

Concrete strength

Since concrete pavements fail due to bending stresses, their design must be based on flexural strength of concrete. The following relationship is used to determine flexural strength.

$$f_f = 0.7\sqrt{f_{ck}} \tag{3}$$

where

f_f = flexural strength in MPa.

f_{ck} = characteristic compressive cube strength in MPa.

Table 5 Composite modulus of subgrade reaction(k) in MPa/m for different subgrade CBR and CTB thickness

CTB thickness in mm	CBR (%)						
	4	6	8	10	12	16	20
100	105.5	134.7	160.3	183.4	204.7	243.5	278.6
150	134.1	168.8	198.7	225.5	250.1	294.3	334
200	163.1	203.1	237.3	267.8	295.5	345.3	389.6
250	192.5	237.8	276.3	310.3	341.2	396.4	445.2
300	222.5	273	315.7	353.3	387.3	447.8	501.2

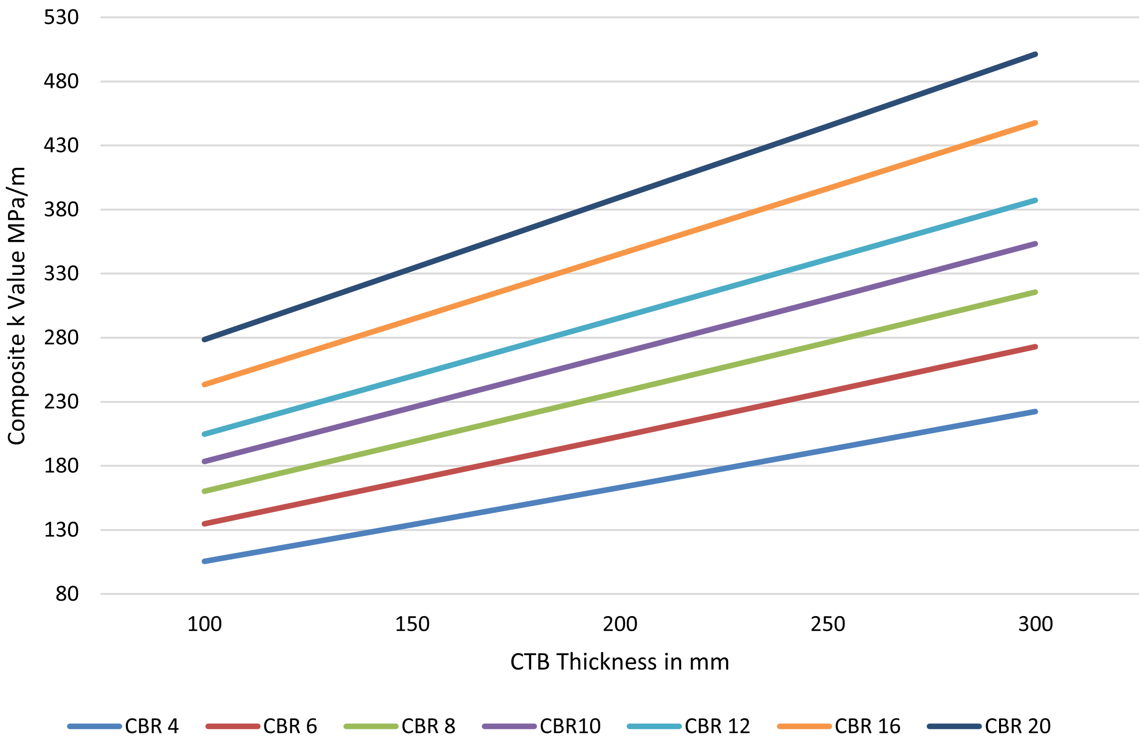

Fig. 8 Composite k value in MPa/m for different CBR(%) and CTB Thickness

For low volume roads, it is suggested that the 90 days strength may be used for design since concrete keeps on gaining strength with time. The 90-days flexural strength may be taken as 1.10 times the 28-day flexural strength as per IRC SP 62–2014. Minimum M30 grade concrete should be used for pavement construction of rural roads,

Modulus of elasticity and Poisson's Ratio

The modulus of Elasticity E of concrete and Poisson's ratio is taken as 30,000 MPa and 0.15, respectively.

Coefficient of thermal expansion

The coefficient of thermal expansion of concrete α is taken as;

$\alpha = 10 \times 10^{-6}$ per °C.

Fatigue behaviour of concrete pavement

For most rural roads, fatigue behaviour is not so important because of a low volume of commercial vehicles. For rural road fatigue criteria with 60% reliability is used considering 40% cracking of slab at the end of design life.

$$\mathrm{Log}_{10} N_f = \frac{\mathrm{SR}^{-2.222}}{0.523} \tag{4}$$

N_f = Fatigue life of a pavement subjected to stresses caused by the combined effect of wheel load of 50 kN and temperature gradient.

$$\mathrm{SR} = \text{Stress Ratio} = \frac{\text{Flexural stress due to wheel load and temperature}}{\text{Flexural strength}}$$

Critical stress condition

Concrete pavements are subjected to stresses due to a variety of factors and the conditions which induce the highest stress in the pavement should be considered for analysis. The factors commonly considered for the design of pavement thickness are traffic loads and temperature gradients. The effects of moisture changes and shrinkage are of a smaller magnitude, and they are neglected in thickness design. The effect of the temperature gradient is very less at the corner, while it is much higher at the edge. Concrete pavements undergo daily cyclic changes of temperature differentials, the top being hotter than the bottom during the daytime and the opposite is the case during the nighttime. The consequent tendency of pavement slabs to curl upwards during the daytime and downwards during the nighttime and restraint offered to curling by the self-weight of pavement induces

Table 6 Thin white topping thickness for traffic less than 50 CVPD and concrete grade M30/M35/M40

CTB thickness mm	Subgrade CBR (%)																				
	4			6			8			10			12			16			20		
Grade	M30	M35	M40	M30	M35	M40	M30	M35	M40	M30	M35	M40	M30	M35	M40	M30	M35	M40	M30	M35	M40
100	140	130	125	135	130	120	130	125	120	130	120	115	125	120	115	125	115	110	120	115	110
150	135	130	120	130	125	120	125	120	115	125	120	110	125	115	110	120	110	105	115	110	105
200	130	125	120	125	120	115	125	115	110	120	115	110	120	110	105	115	110	105	115	105	100
250	130	120	115	125	115	110	120	115	110	120	110	105	115	110	105	110	105	100	110	100	95
300	125	120	110	120	115	110	120	110	105	115	110	100	115	105	100	110	100	95	105	100	95

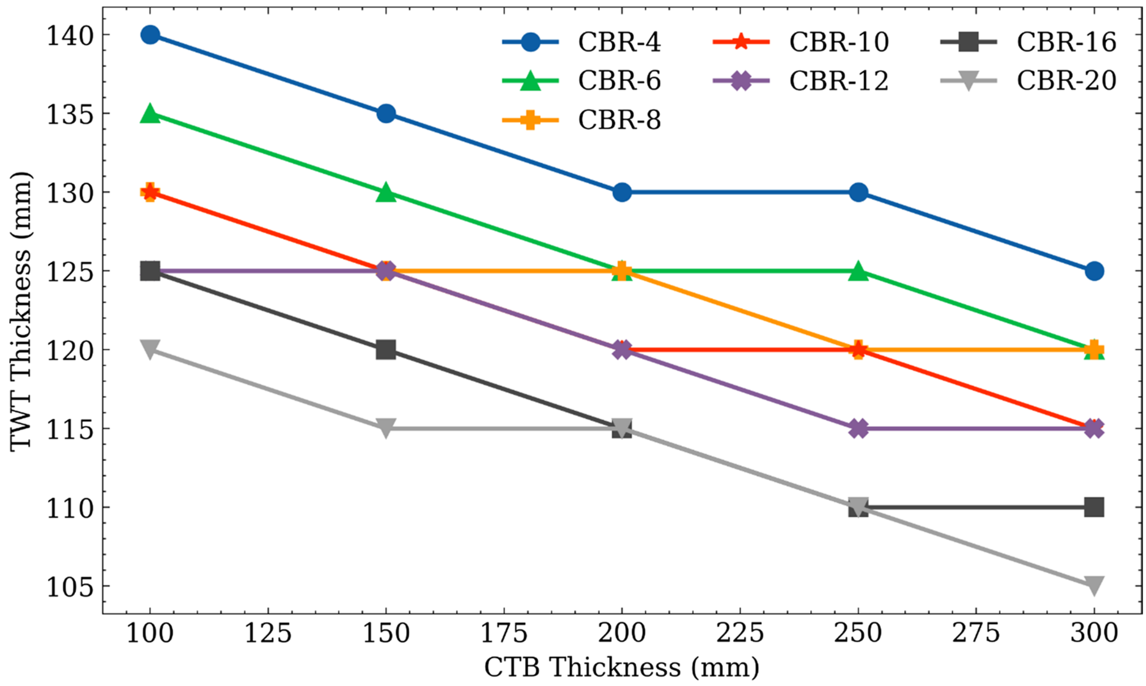

Fig. 9 Thin White Topping thickness for traffic < 50 CVPD and Concrete Grade M30

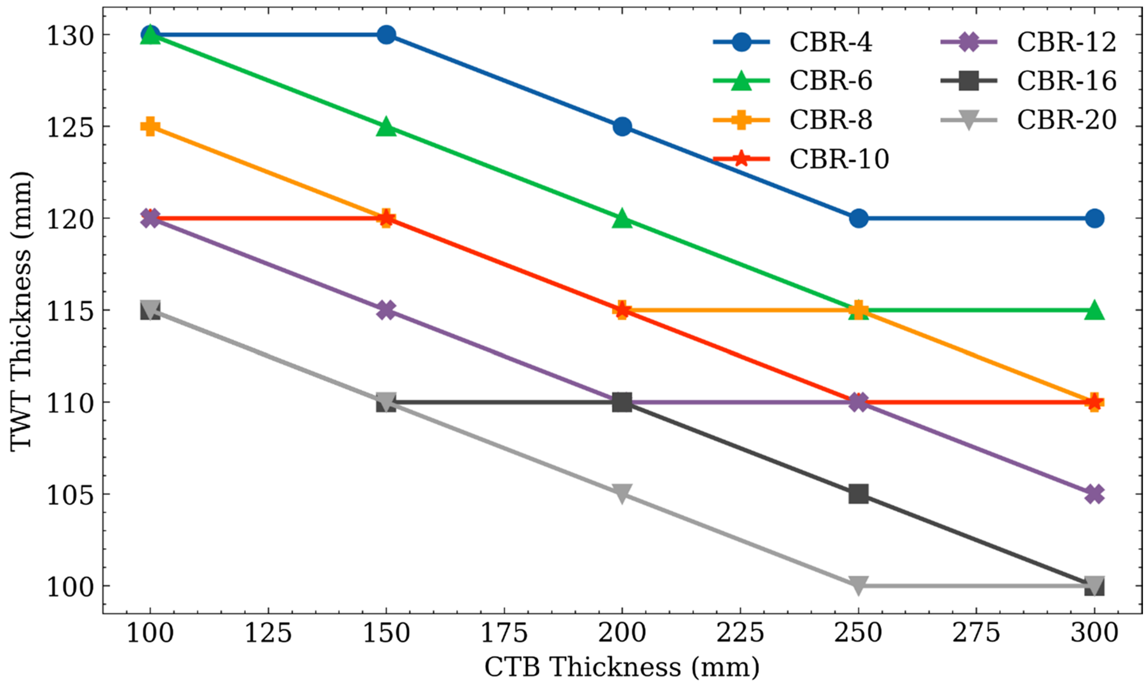

Fig. 10 Thin White Topping thickness for traffic < 50 CVPD and Concrete Grade M35

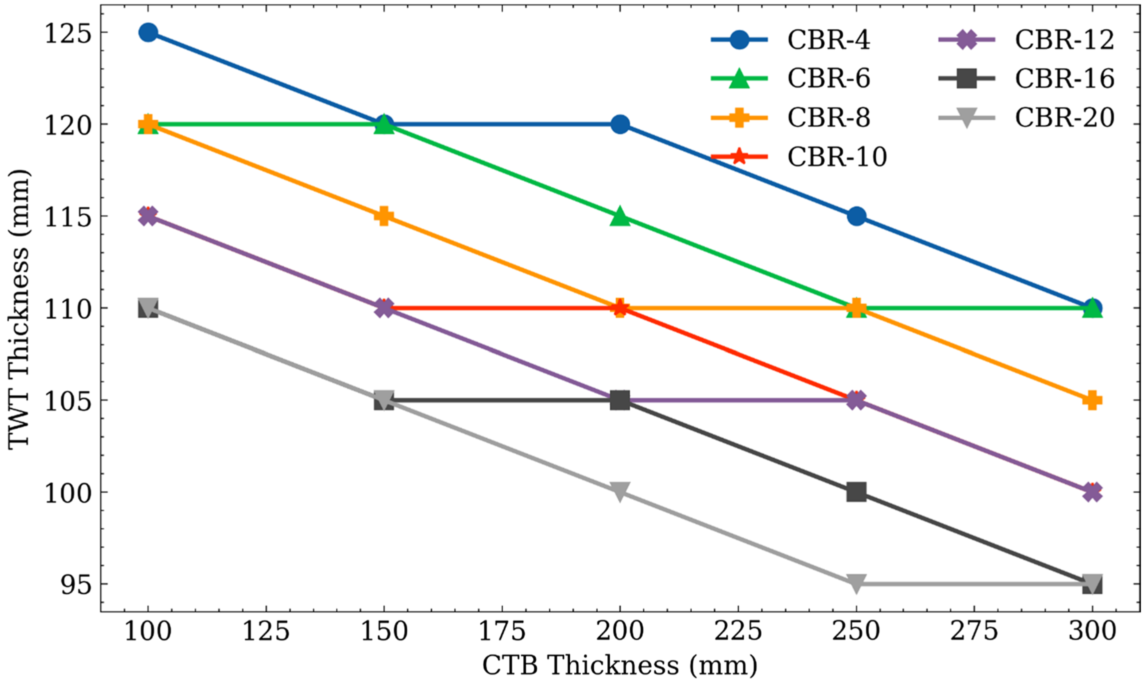

Fig. 11 Thin White Topping thickness for traffic < 50 CVPD and Concrete Grade M40

stresses in the pavement referred to commonly curling stresses. These stresses are flexural, being tensile at the bottom during the daytime and at the top during the nighttime. Corners have very little restraint and temperature stresses in the corner region are negligible. Hence, edge stress is considered critical for the design of pavement thickness. For Thin White Topping with shorter joint spacing, top-down cracking will not take place as both wheels of the vehicle are not placed on the same panel. The maximum tensile stresses in the edge region will be critical during the daytime.

A. Wheel load stress at the edge is calculated using the Westergaard Eq. (5).

$$\sigma_e = \frac{3(1+\mu)P}{\pi(3+\mu)h^2}\left[\ln\left(\frac{Eh^3}{100ka^4}\right) + 1.84 - \frac{4\mu}{3} + \frac{1-\mu}{2} + \frac{1.18(1+2\mu)a}{l}\right] \tag{5}$$

σ_e: edge stress in MPa.

h: Pavement thickness in mm.

k: Modulus of subgrade reaction MPa/m.

P: Single Wheel Load, N

μ: Poisson's ratio for concrete.

E: Modulus of elasticity of concrete in MPa.

l: radius of relative stiffness and calculated by Eq. (6),

$$l = \left(\frac{Eh^3}{12(1-\mu^2)k}\right)^{1/4} \tag{6}$$

a: radius of the equivalent circular area and it is calculated by Eqs. (7) and (8),

$$a = \sqrt{\frac{P}{p\pi}} \text{ for single Wheel} \tag{7}$$

$$a = \sqrt{\frac{0.8521P_d}{p\pi} + \frac{S_d}{\pi}\left(\frac{P_d}{0.5227p}\right)^{1/2}} \text{ for dual Wheel} \tag{8}$$

S_d: Spacing between the center of duel wheel.

P_d: Load on one wheel.

P—Tyre pressure.

Temperature stress (σ_{te})

Bradbury's equation is used for the computation of temperature stress. The temperature gradient across the depth is usually nonlinear. The compressive stress due to bi-linear temperature variation is subtracted. Temperature stress is calculated by equation (9),

$$\sigma_{te} = \frac{0.67 \times C \times \alpha \times \Delta T \times E}{2} - \frac{E \times \alpha \times \Delta T}{3 \times 3.91} \tag{9}$$

σ_{te}: temperature stress in MPa.

C: Correction factor.

α: coefficient of thermal expansion.

Table 7 Thin white topping thickness for traffic 51 to 150 CVPD and concrete grade M30

CTB thickness mm	Joint spacing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II, IV, V, VI	Zone III	Zone I	Zone II, IV, V, VI	Zone II	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	140	140	140	135	135	135	135	135	135	130	130	135	130	130	130	130	130	130	125	130	130
	2.0	145	145	145	145	145	145	140	145	145	140	140	145	140	145	145	140	140	145	135	140	145
	2.5	155	155	160	150	155	155	150	155	155	145	150	155	150	155	155	145	150	155	145	150	155
150	1.5	135	135	135	135	135	135	130	130	130	130	130	130	130	130	130	125	130	130	125	130	130
	2.0	145	145	145	140	145	145	140	145	145	140	140	145	140	140	145	135	140	145	135	140	140
	2.5	150	155	155	150	155	155	150	155	155	145	150	155	145	150	155	145	150	155	140	150	155
200	1.5	135	135	135	130	130	130	130	130	130	130	130	130	125	130	130	125	125	130	125	125	125
	2.0	140	145	145	140	145	145	140	140	145	140	140	145	135	140	140	135	140	140	135	140	140
	2.5	150	155	155	150	155	155	145	150	155	145	150	155	145	150	155	140	150	150	140	145	150
250	1.5	130	130	130	130	130	130	125	130	130	125	130	130	125	125	130	125	125	125	120	125	125
	2.0	140	145	145	140	140	145	135	140	145	135	140	140	135	140	140	135	140	140	130	135	140
	2.5	150	155	155	145	150	155	145	150	155	145	150	155	140	150	150	140	145	150	135	145	150
300	1.5	130	130	130	125	130	130	125	125	130	125	125	130	125	125	125	120	125	125	120	125	125
	2.0	140	140	145	135	140	145	135	140	140	135	140	140	135	140	140	130	135	140	130	135	140
	2.5	145	150	155	145	150	155	140	150	155	140	150	150	140	145	150	135	145	150	135	140	145

Table 8 Thin white topping thickness for traffic 51 to 150 CVPD and concrete grade M35

CTB thick-ness mm	Joint spac-ing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	130	130	130	130	130	130	125	130	130	125	125	125	125	125	125	120	125	125	120	120	125
	2.0	140	140	140	135	140	140	135	135	140	135	135	140	135	135	135	130	135	135	130	135	135
	2.5	145	150	150	145	145	150	145	145	150	140	145	145	140	145	145	135	145	145	135	140	145
150	1.5	130	130	130	125	125	125	125	125	125	125	125	125	120	125	125	120	120	125	120	120	120
	2.0	135	140	140	135	135	140	135	135	135	130	135	135	130	135	135	130	135	135	125	130	135
	2.5	145	145	150	140	145	150	140	145	145	140	145	145	135	140	145	135	140	145	130	140	140
200	1.5	125	125	130	125	125	125	120	125	125	120	125	125	120	120	125	120	120	120	115	120	120
	2.0	135	135	140	135	135	135	130	135	135	130	135	135	130	135	135	125	130	135	125	130	130
	2.5	140	145	150	140	145	145	140	145	145	135	140	145	135	140	145	130	140	140	130	135	140
250	1.5	125	125	125	120	125	125	120	120	125	120	120	120	120	120	120	115	120	120	115	120	120
	2.0	135	135	135	130	135	135	130	135	135	130	130	135	125	130	135	125	130	130	125	130	130
	2.5	140	145	145	135	145	145	135	140	145	135	140	145	130	140	140	130	135	140	125	135	135
300	1.5	125	125	125	120	120	125	120	120	120	120	120	120	115	120	120	115	120	120	115	115	120
	2.0	130	135	135	130	135	135	130	130	135	125	130	135	125	130	130	125	130	130	120	125	130
	2.5	140	145	145	135	140	145	135	140	145	135	140	140	130	135	140	125	135	135	125	130	135

Table 9 Thin white topping thickness for traffic 51 to 150 CVPD and concrete grade M40

CTB thickness mm	Joint spacing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	125	125	125	125	125	125	120	120	120	120	120	120	120	120	120	115	120	120	115	115	120
	2.0	130	135	135	130	135	135	130	130	135	130	130	130	125	130	130	125	130	130	125	125	130
	2.5	140	140	145	135	140	140	135	140	140	135	140	140	130	135	140	130	135	140	130	135	135
150	1.5	125	125	125	120	120	120	120	120	120	120	120	120	115	120	120	115	115	120	115	115	115
	2.0	130	135	135	130	130	130	125	130	130	125	130	130	125	130	130	120	125	130	120	125	125
	2.5	135	140	140	135	140	140	135	140	140	130	135	140	130	135	135	125	135	135	125	130	135
200	1.5	120	120	120	120	120	120	115	120	120	115	120	120	115	115	115	115	115	115	110	115	115
	2.0	130	130	130	125	130	130	125	130	130	125	125	130	120	125	130	120	125	125	120	125	125
	2.5	135	140	140	130	136	140	130	135	135	130	135	135	125	135	135	125	130	135	120	130	130
250	1.5	120	120	120	115	120	120	115	115	120	115	115	115	115	115	115	110	115	115	110	110	115
	2.0	125	130	130	125	130	130	125	125	130	120	125	125	120	125	125	120	125	125	115	120	125
	2.5	135	140	140	130	135	140	130	135	135	125	130	135	125	130	135	120	125	130	120	125	130
300	1.5	120	120	120	115	120	120	115	115	115	115	115	115	110	115	115	110	110	115	110	110	110
	2.0	125	130	130	125	125	130	120	125	125	120	125	125	120	125	125	115	120	125	115	120	120
	2.5	130	135	140	130	135	135	125	130	135	125	130	130	120	130	130	120	125	130	115	125	125

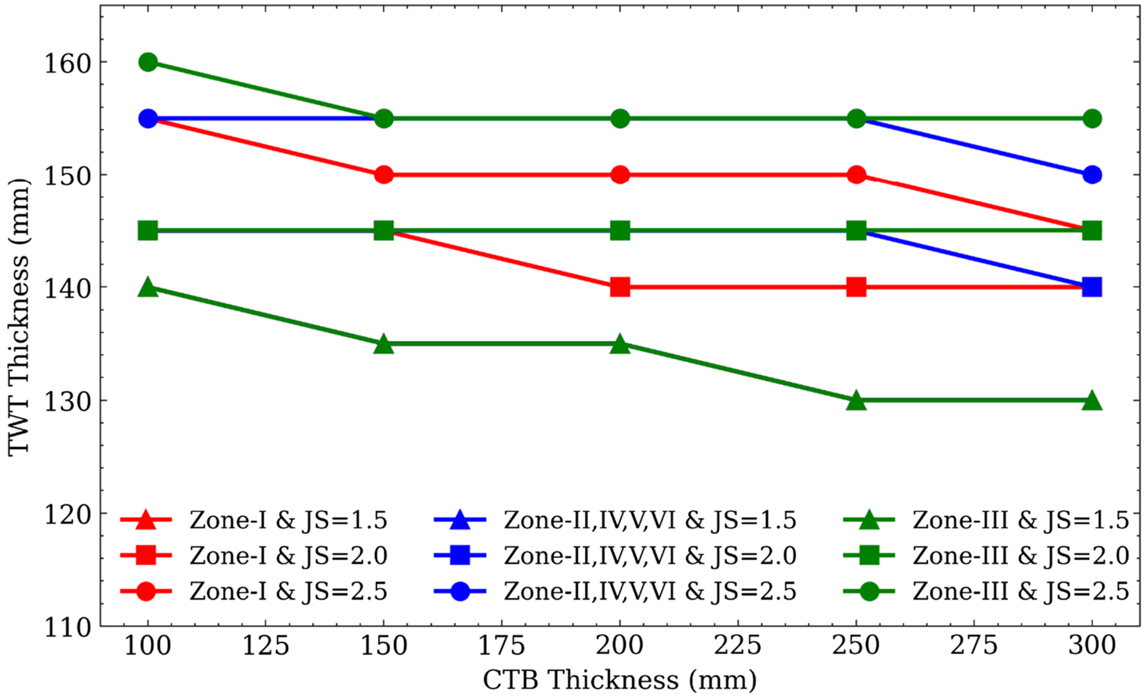

Fig. 12 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Subgrade CBR 4%

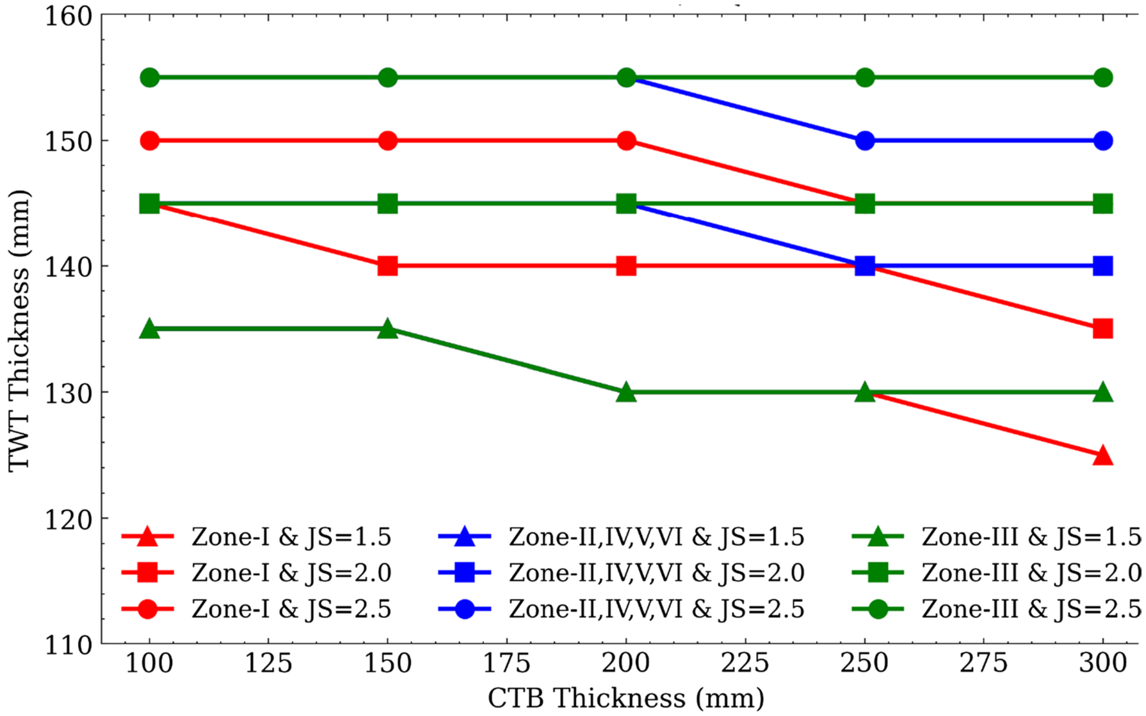

Fig. 13 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30, and Subgrade CBR 6%

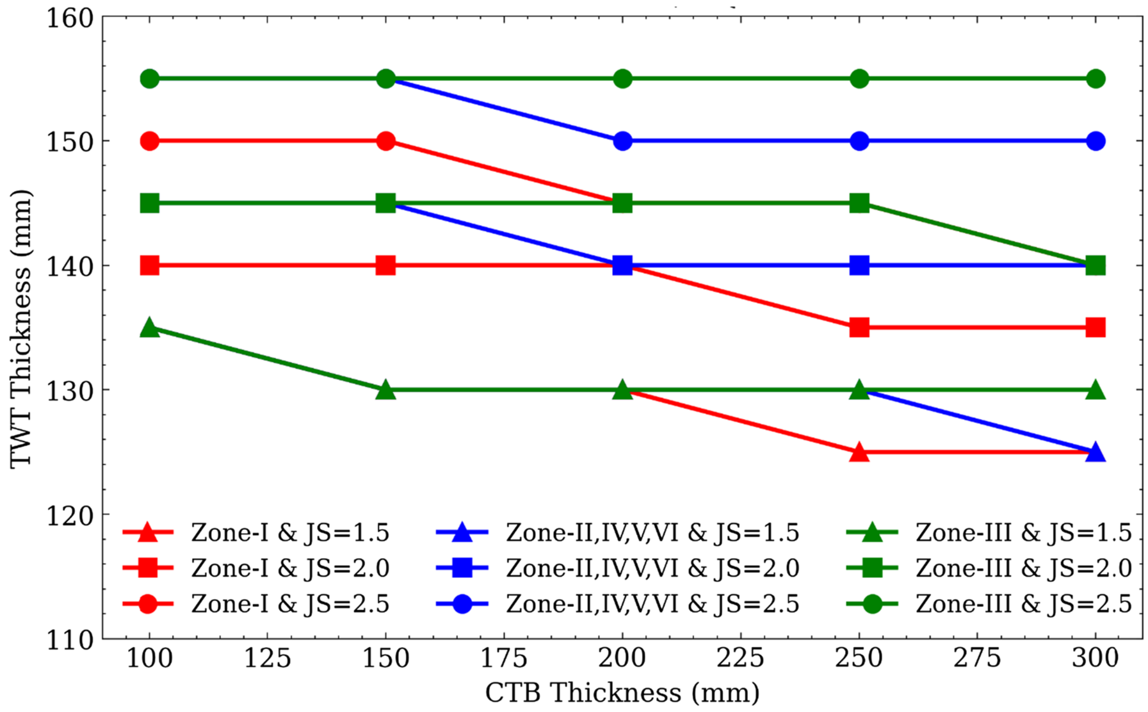

Fig. 14 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Subgrade CBR 8%

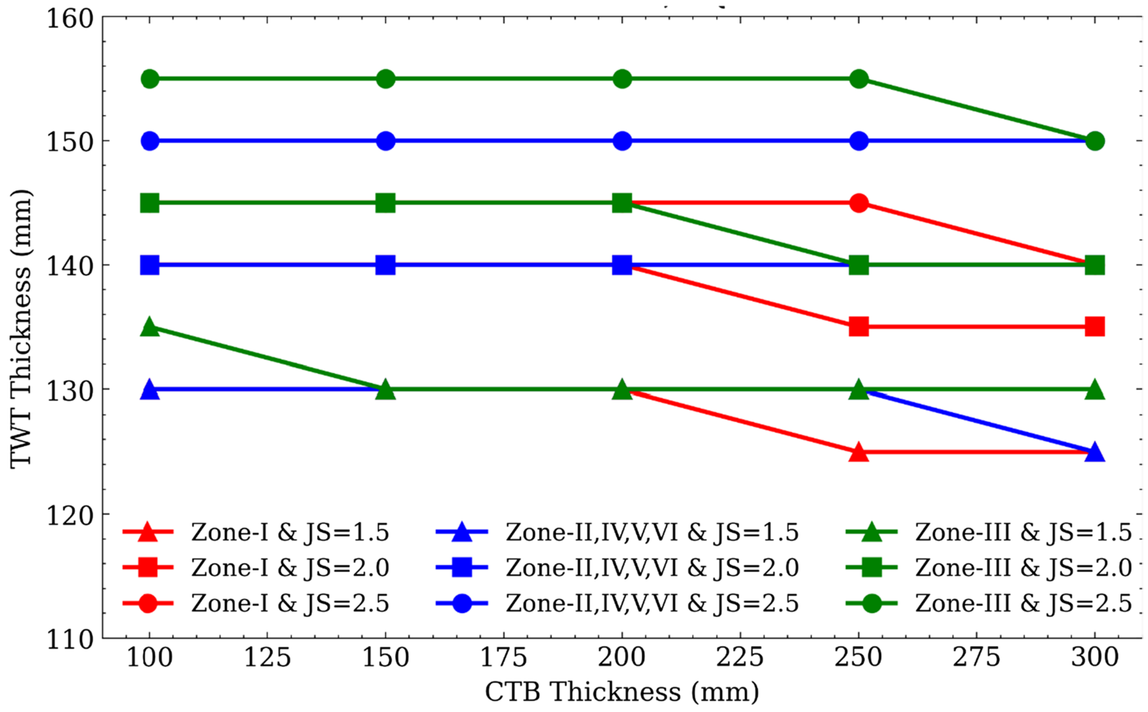

Fig. 15 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Subgrade CBR 10%

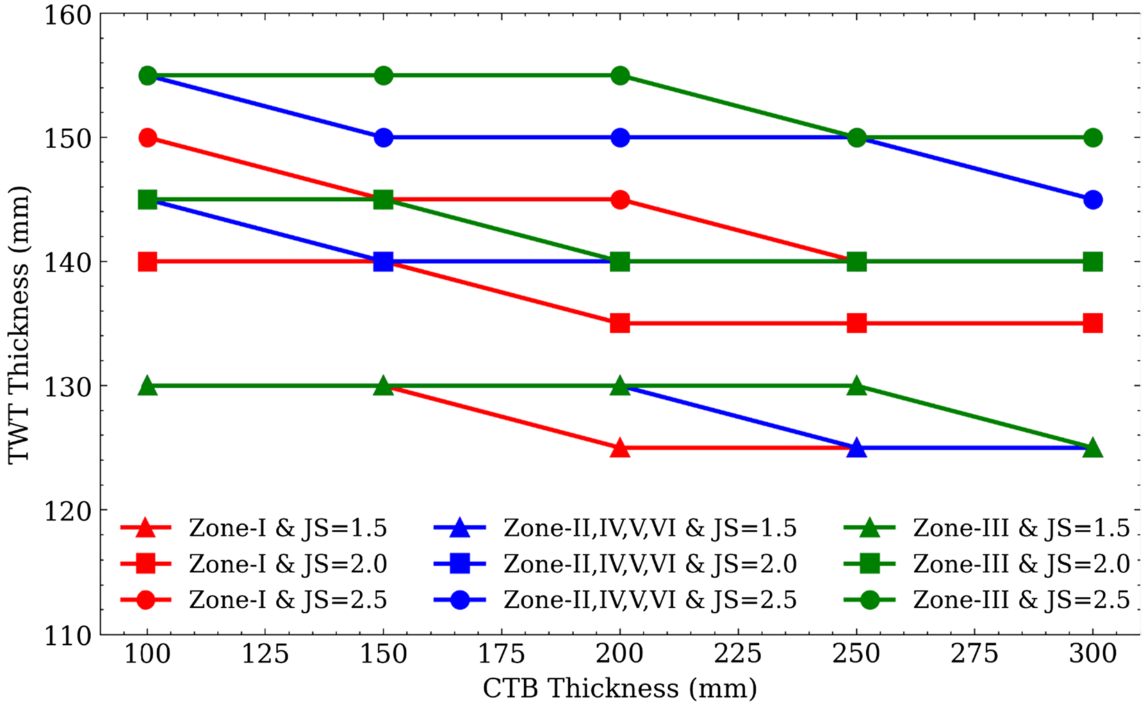

Fig. 16 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Subgrade CBR 12%

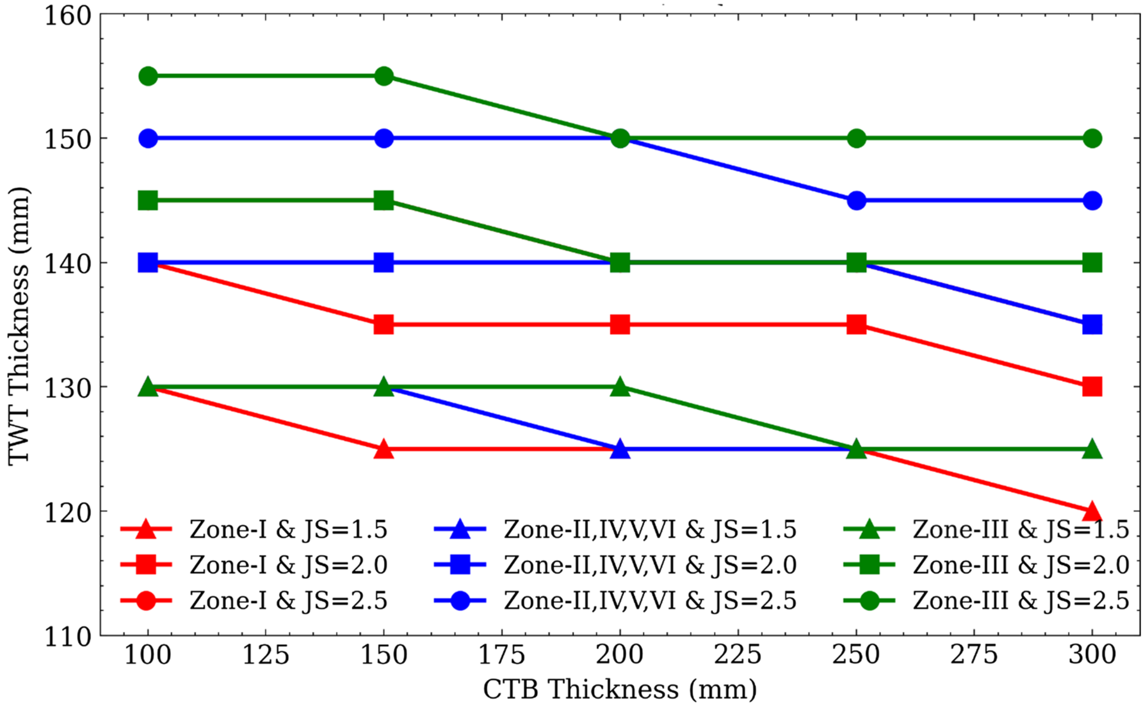

Fig. 17 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Sibgrade CBR 16%

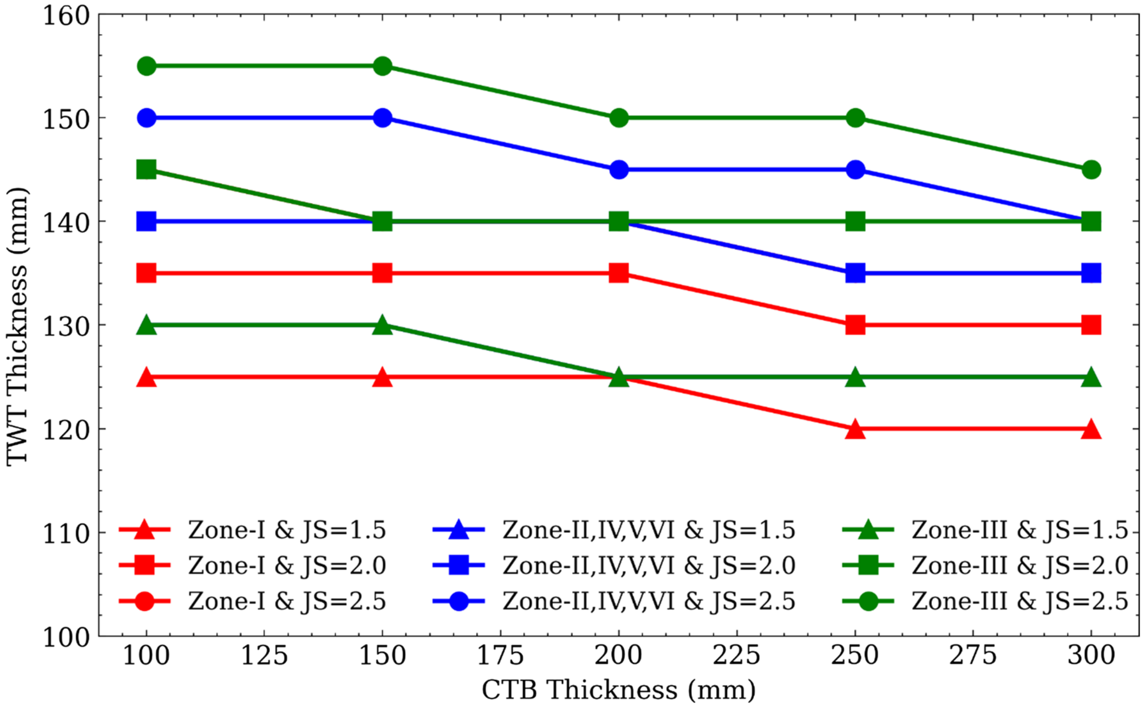

Fig. 18 Thin White Topping thickness for traffic 51 to 150 CVPD, Concrete Grade M30 and Subgrade CBR 20%

ΔT: temperature differential °C.

Temperature differentials in different zones in India are taken as recommended by Central Road Research Institute Table 4.1 of IRC SP 62-2014 [11]. For Thin white topping, the concrete thickness is less than 200 mm hence temperature differential values in zone II, IV, V, VI are nearly the same and hence clubbed in single group.

Joint spacing

The Joint spacing for concrete pavement is recommended 12 to 15 times the thickness of concrete. From the construction point of view, joint spacing of 1.5-m, 2.0 m, and 3.00 m has been considered in the design.

Pavement design charts

Pavement design charts are prepared considering traffic, Subgrade CBR, CTB thickness, grade of concrete, and transverse joint spacing.

(a) Traffic less than 50 CVPD:

For traffic, less than 50 CVPD only wheel load stresses for a load of 50 kN on dual wheel need be considered for thickness estimation since there is a low probability of maximum wheel load and highest temperature differential between the top and bottom of the rigid pavement occurring at the same time. The TWT thickness design chart for M30, M35, and M40 concrete grades is given in Table 6. As temperature stresses are not considered in the design, spacing of joint and temperature zone does not have effect on thickness of TWT. Preferably joint spacing should be provided 12 to 15 times the thickness of TWT. For a particular subgrade CBR value, the TWT thickness requirement decreases with increase in CTB thickness up to certain extent. Also for a particular CTB thickness, the TWT thickness requirement decreases with increase in subgrade CBR value. Effect of CTB thickness on TWT thickness for concrete grade M30, M35 and M40 is shown in Figures 9, 10, 11.

(b) Traffic 51 to 150 CVPD:

For traffic higher than 50 and less than 150 CVPD, the thickness evaluation should be done based on total stresses resulting from wheel load of 50 kN and temperature differential. The TWT thickness design charts for M30, M35, and M40 concrete grades are given in Tables 7, 8, 9. As temperature stresses are considered in the design, joint spacing and temperature zone has effect on thickness requirement of TWT. For a particular subgrade CBR value and CTB thickness, the TWT thickness requirement increases with increase in joint spacing. TWT thickness requirement for zone III is higher and lower for zone I. For lower joint spacing effect of zone is insignificant. The effect of CTB thickness on TWT thickness for different temperature zones

Table 10 Thin white topping thickness for traffic < 450 CVPD and concrete grade M30

CTB thickness mm	Joint spacing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV,V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV,V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	185	185	185	185	185	185	180	180	180	180	180	180	175	175	175	175	175	175	175	175	175
	2.0	195	195	195	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	195
	2.5	205	205	205	205	205	210	205	205	210	205	210	210	205	210	215	205	210	215	205	215	220
150	1.5	185	185	185	180	180	180	175	175	175	175	175	175	175	175	175	175	175	175	170	170	175
	2.0	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	195	190	190	195
	2.5	205	205	205	205	205	210	205	210	215	205	210	215	205	210	215	205	215	220	205	215	220
200	1.5	180	180	180	175	175	175	175	175	175	175	175	175	175	175	175	170	170	170	170	170	170
	2.0	190	190	190	190	190	190	190	190	190	190	190	195	190	190	195	190	190	195	190	195	195
	2.5	205	205	210	205	210	210	205	210	215	205	210	215	205	215	220	205	215	220	205	215	225
250	1.5	180	180	180	175	175	175	175	175	175	170	175	175	170	170	170	170	170	170	170	170	170
	2.0	190	190	190	190	190	190	190	190	195	190	190	195	190	190	195	190	195	195	190	195	200
	2.5	205	210	210	205	210	210	205	215	220	205	215	220	205	215	220	205	215	225	205	215	225
300	1.5	175	175	175	175	175	175	170	175	175	170	170	170	170	170	170	170	170	170	170	170	170
	2.0	190	190	190	190	190	195	190	190	195	190	190	195	190	195	195	190	195	200	190	195	200
	2.5	205	210	215	205	215	215	205	215	220	205	215	220	205	215	225	205	215	225	205	220	230

Table 11 Thin white topping thickness for traffic < 450 CVPD and concrete grade M35

CTB thickness mm	Joint spacing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	180	180	180	175	175	175	170	170	170	170	170	170	170	170	170	165	165	165	165	165	165
	2.0	185	185	185	185	185	185	180	185	185	180	185	185	180	185	185	180	180	185	180	185	185
	2.5	195	195	200	195	200	200	195	200	200	195	200	205	195	200	205	195	200	205	195	205	210
150	1.5	175	175	175	170	170	170	170	170	170	170	170	170	165	165	165	165	165	165	165	165	165
	2.0	185	185	185	180	185	185	180	185	185	180	180	185	180	180	185	180	185	185	180	185	185
	2.5	195	200	200	195	200	200	195	200	205	195	200	205	195	200	205	195	205	210	195	205	210
200	1.5	170	170	170	170	170	170	165	165	165	165	165	165	165	165	165	165	165	165	160	165	165
	2.0	180	185	185	180	185	185	180	180	185	180	185	185	180	185	185	180	185	185	180	185	190
	2.5	195	200	200	195	200	205	195	200	205	195	205	210	195	205	210	195	205	210	195	205	210
250	1.5	170	170	170	165	165	165	165	165	165	165	165	165	165	165	165	160	165	165	160	165	165
	2.0	180	185	185	180	180	185	180	185	185	180	185	185	180	185	185	180	185	190	180	185	190
	2.5	195	200	205	195	200	205	195	205	210	195	205	210	195	205	210	195	205	210	195	205	215
300	1.5	170	170	170	165	165	165	165	165	165	165	165	165	160	165	165	160	165	165	160	160	165
	2.0	180	180	185	180	185	185	180	185	185	180	185	185	180	185	190	180	185	190	180	185	190
	2.5	195	200	205	195	205	210	195	205	210	195	205	210	195	205	210	195	205	215	195	205	215

Table 12 Thin white topping thickness for traffic < 450 CVPD and concrete grade M40

CTB thickness mm	Joint spacing m	Subgrade CBR (%)																				
		CBR 4%			CBR 6%			CBR 8%			CBR 10%			CBR 12%			CBR 16%			CBR 20%		
		Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III	Zone I	Zone II,IV, V,VI	Zone III
100	1.5	170	170	170	170	170	170	165	165	165	165	165	165	165	165	165	160	160	160	160	160	160
	2.0	180	180	180	175	175	180	175	175	175	175	175	175	175	175	175	175	175	180	175	175	180
	2.5	190	190	190	190	190	195	190	190	195	190	195	195	190	195	195	190	195	200	185	195	200
150	1.5	170	170	170	165	165	165	165	165	165	160	160	160	160	160	160	160	160	160	155	160	160
	2.0	175	175	180	175	175	175	175	175	175	175	175	175	175	175	180	175	175	180	175	175	180
	2.5	190	190	195	190	195	195	190	195	195	190	195	200	190	195	200	185	195	200	185	195	200
200	1.5	165	165	165	165	165	165	160	160	160	160	160	160	160	160	160	155	160	160	155	155	160
	2.0	175	175	175	175	175	175	175	175	175	175	175	180	175	175	180	175	175	180	170	175	180
	2.5	190	195	195	190	195	195	190	195	200	185	195	200	185	195	200	185	195	200	185	195	205
250	1.5	165	165	165	160	160	160	160	160	160	160	160	160	155	160	160	155	155	160	155	155	155
	2.0	175	175	175	175	175	175	175	175	180	175	175	180	175	175	180	170	175	180	170	175	180
	2.5	190	195	195	190	195	200	185	195	200	185	195	200	185	195	200	185	195	205	185	195	205
300	1.5	160	160	160	160	160	160	160	160	160	155	160	160	155	155	160	155	155	155	155	155	155
	2.0	175	175	175	175	175	180	175	175	180	170	175	180	170	175	180	170	175	180	170	175	180
	2.5	190	195	200	185	195	200	185	195	200	185	195	200	185	195	205	185	195	205	185	195	205

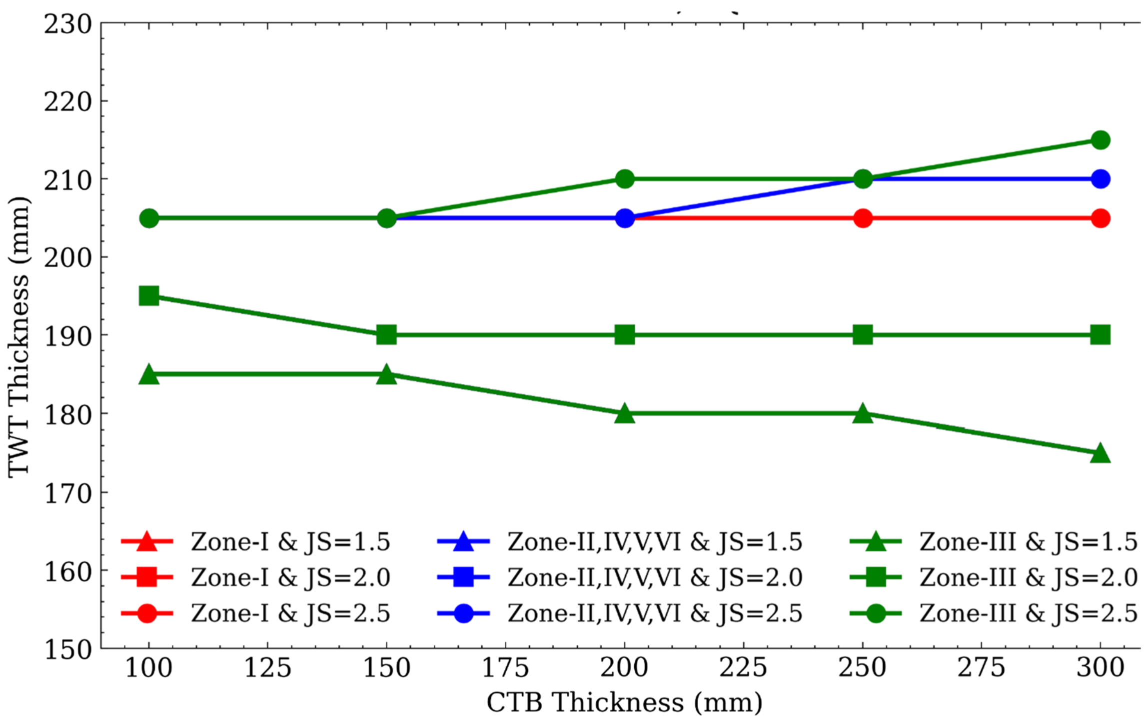

Fig. 19 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 4%

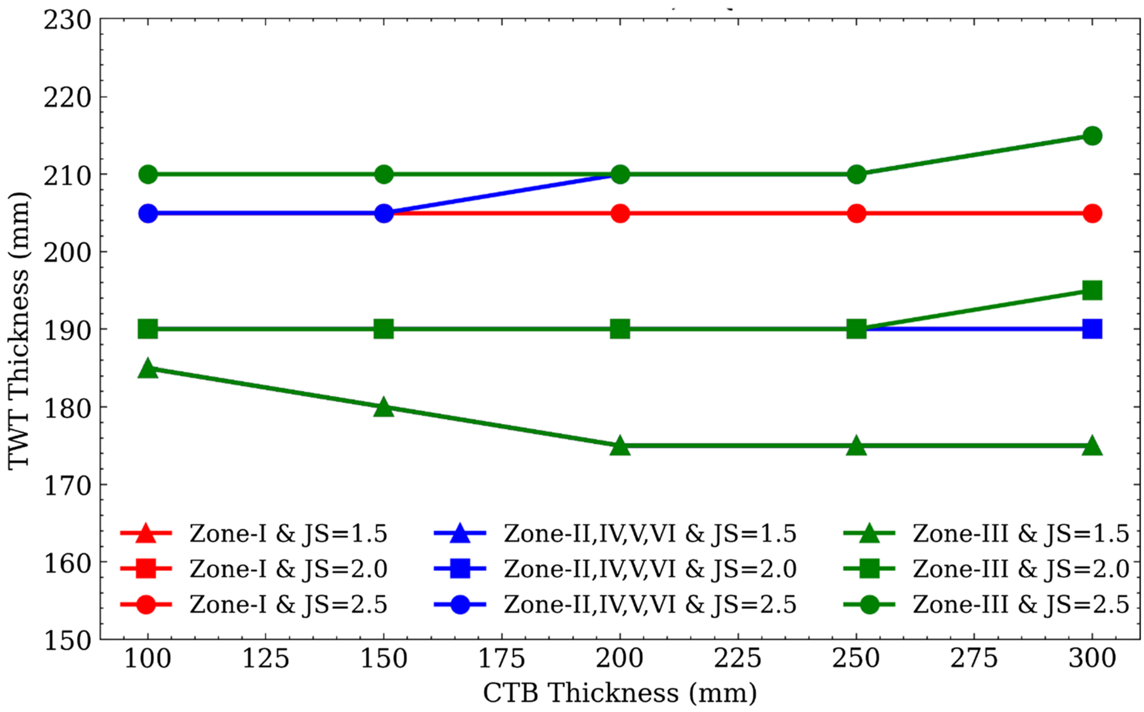

Fig. 20 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 6%

and joint spacing for M30 grade concrete and different subgrade CBR is shown in Figures 12, 13, 14, 15, 16, 17, 18.

(c) Traffic less than 450 CVPD:

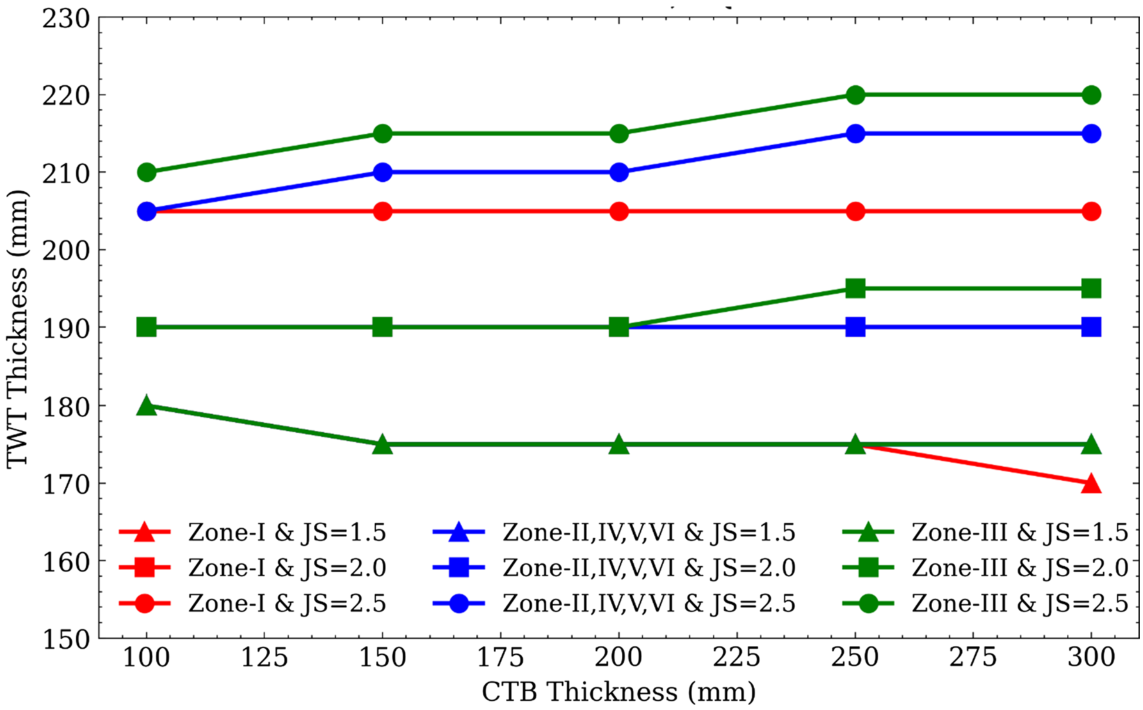

Fig. 21 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 8%

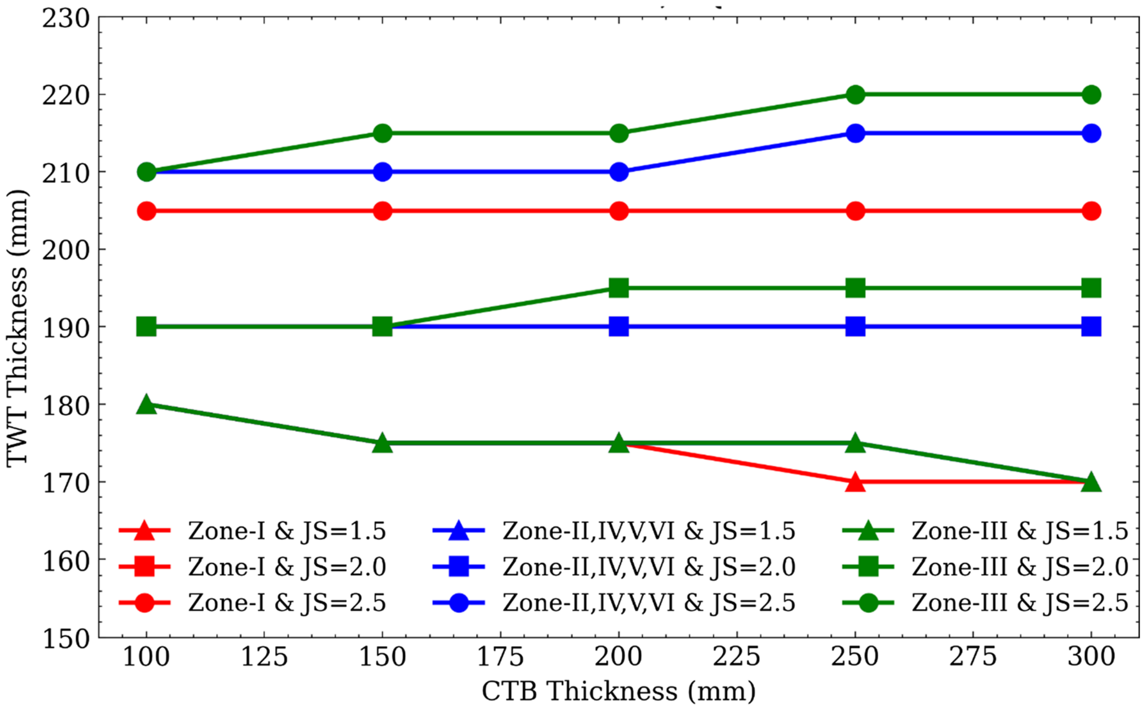

Fig. 22 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 10%

For traffic exceeding 150 CVPD, fatigue can be a real problem, and thickness evaluation based on fatigue fracture with 60% reliability should be considered. Pavement thickness is designed considering combined stresses due to wheel load edge stress for the dual wheel of 50 kN and temperature gradient. Also, concrete pavement is checked

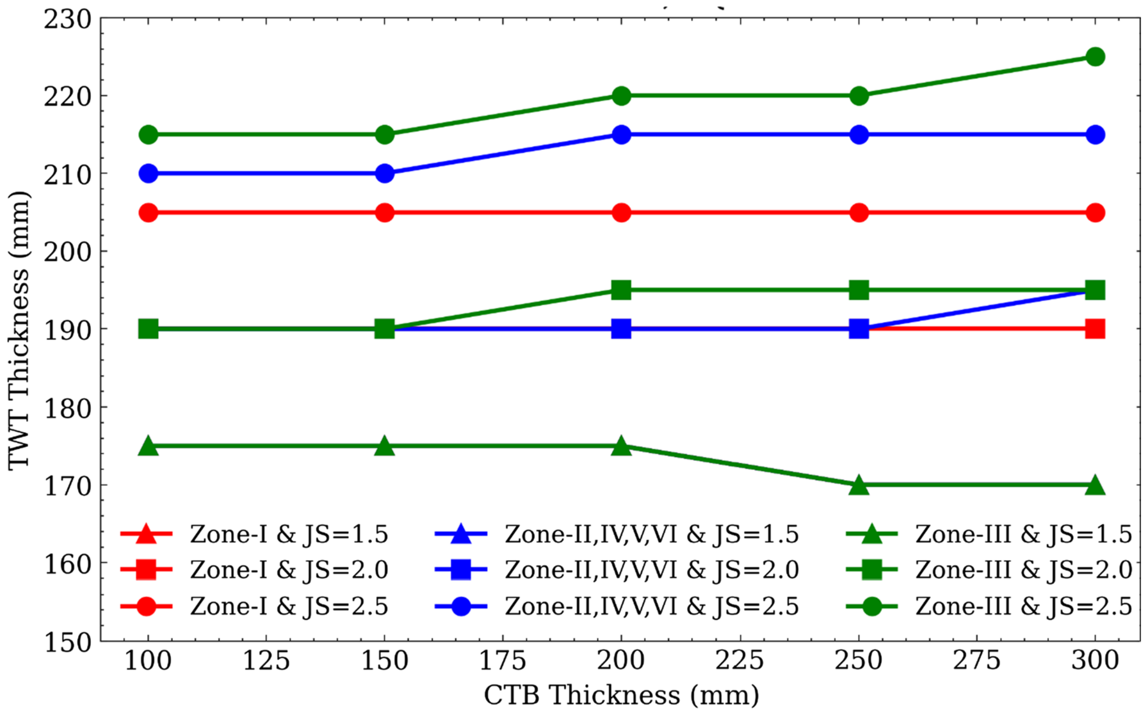

Fig. 23 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 12%

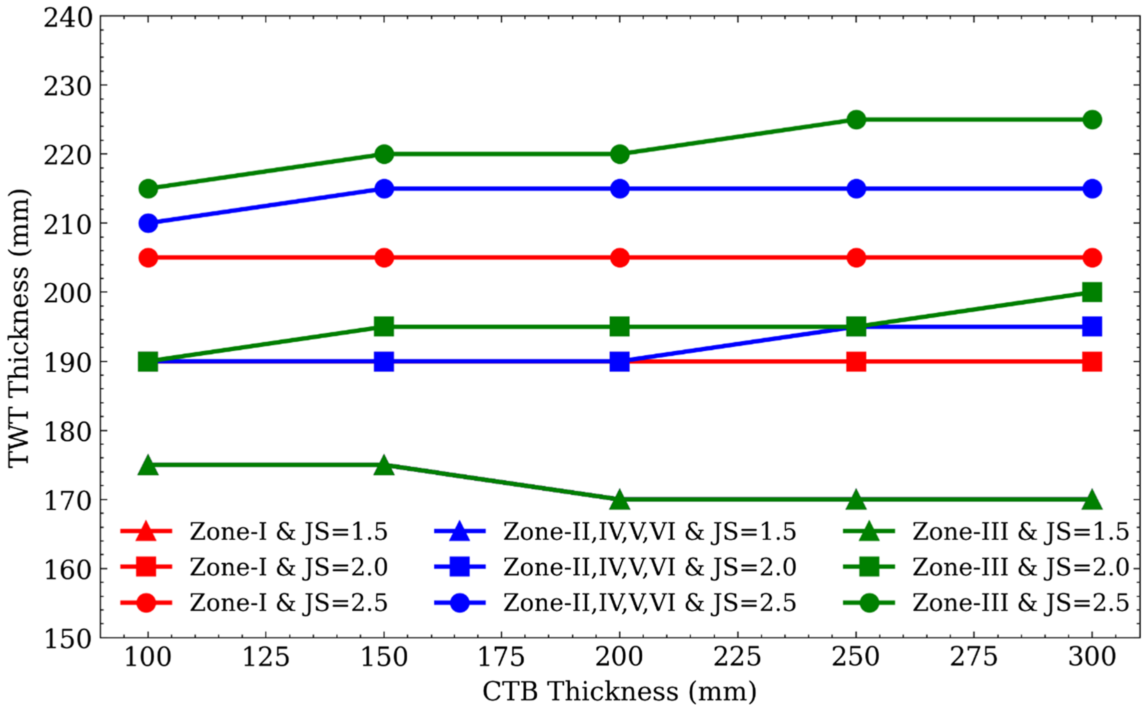

Fig. 24 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 16%

for fatigue criteria. Assuming 10% of total traffic is having an axle load of more than 100 kN, the expected number of vehicles is computed over the design period. The allowable number of repetitions is computed considering 60% reliability from the fatigue equation. Cumulative fatigue damage is computed and it should be less than 1. The TWT thickness

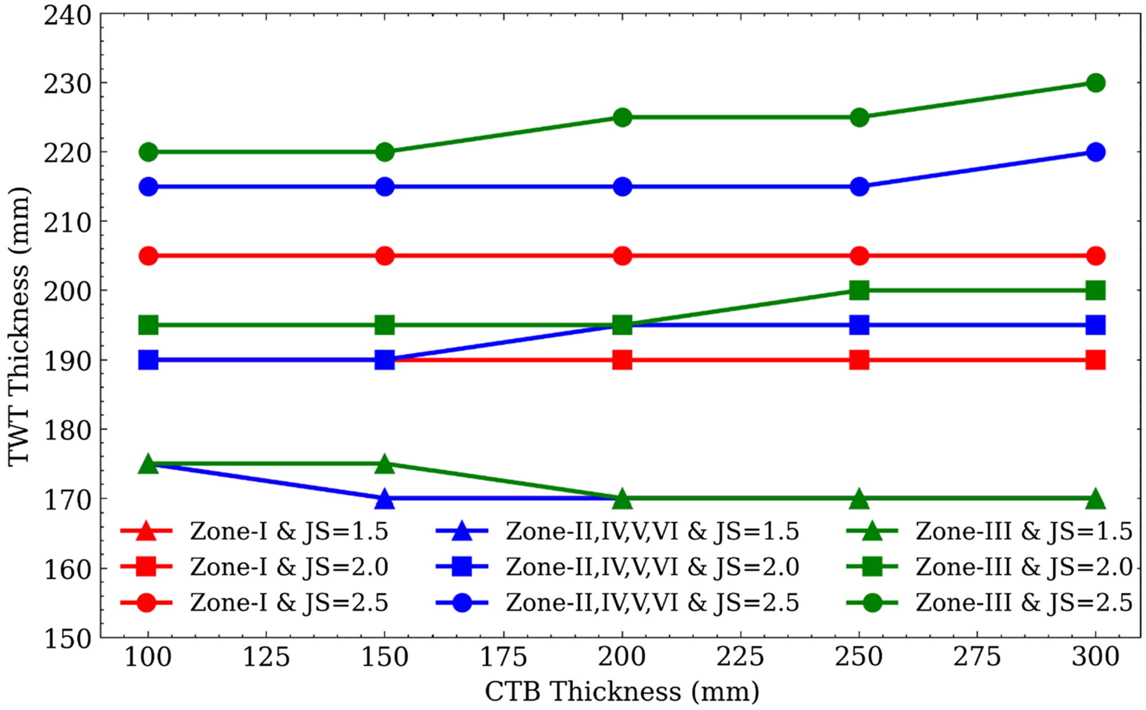

Fig. 25 Thin White Topping thickness for traffic < 450 CVPD, Concrete Grade M30 and Subgrade CBR 20%

charts for concrete grades M30, M35, and M40 are given in Tables 10,11,12. The TWT thickness requirement increases with increase in joint spacing. The effect of zone is insignificant keeping all other parameters constant. TWT thickness requirement decreases with increase in CTB thickness for 1.5 meter joint spacing The TWT thickness requirement decreses with increase in subgrade CBR value upto certain extent for same CTB thickness and joint spacing. The effect of CTB thickness on TWT thickness for different temperature zones and joint spacing for M30 grade concrete and different subgrade CBR is shown in Figures 19, 20, 21, 22, 23, 24, 25.

Conclusions

The design charts for Thin White Topping with variable thickness of cement treated base and different subgrade CBR are prepared for rural roads. With Cold In Place Recycling technique, existing local material can be utilized and the strength of subgrade and subbase shall be improved with cement stabilization. From field experiments the performance evaluation rating after two years of construction is good for pavement constructed with CTB using CIPR technique and Thin White Topping. Surface cracking, potholes, rutting, or any defects are not observed. Thin White Topping thickness design charts of M30, M35 and M40 are developed for varying thickness of cement treated base and different subgrade CBR for rural roads. From the development of design charts following are the significant observations,

- Composite modulus of subgrade reaction (k) value increases with an increase in thickness of CTB.
- The optimum thickness of TWT can be obtained from Design Chart and the economy in the Pavement design can be achieved.
- For low CBR Subgrade value, increase in CTB thickness can reduce TWT Thickness only up to the certain extent
- For an increase in Joint spacing the required TWT thickness increases.
- For Joint spacing of 1.5 m, TWT thickness is the same for all zones.
- For Joint spacing 2.0 m and 2.5-m, TWT thickness requirement is higher for Zone III and lower for Zone I.

The Thin White Topping pavement structures over adequate base support would have superior load carrying capability hence Thin White Topping pavement structure recommended as a pavement design alternative in low-volume rural roads. The construction of rural roads with CTB using the CIPR technique is an effective and environmentally friendly solution.

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Authors' contribution Designed and developed the methodology for the construction of rural roads with Cement Treated Base. Trial stretches are constructed using cement treated base with Cold In Place Recycling technology. Performance evaluation of these roads has been carried out after two years of construction. Thin White Topping thickness design charts with variable cement treated base thickness for different subgrade CBR values and Traffic are prepared for rural roads. These charts are useful for construction of rural roads to the Field Engineers.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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