Thin White Topping on Cement Treated Base for Rural Roads

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Abstract:- Most of the Indian villages have been connected with granular sub base(GSB), water bound macadam (WBM) or bituminous roads. Rural roads usually have low volume of traffic, consisting mostly of light transport vehicles with less frequency of heavy traffic. Maintenance of these roads is neglected because of paucity of funds and the road asset created is in deteriorated condition. The non-availability of suitable soil and aggregates have made projects unviable and cost prohibitive. This aggregate scarcity will increase further as part of environmental conservation and restriction on mining. The stabilization of soil/aggregate is being used for optimal usage of scares resources. Cold in place recycling technique provides a comprehensive solution for rehabilitation of existing road and green field road construction. In order to construct durable roads Thin White Topping is laid on cement treated base. Cement treated base can be achieved with Cold In Place Recycling process, which allow usage of locally available marginal materials.

Two rural roads are identified in Pune district. Pavements are designed considering Thin White Topping on cement treated base. These roads are constructed using cold in place recycling technique. The existing base course is stabilised with cement. Thin White Topping is provided as wearing course. The performance of pavement is evaluated after construction. The paper describes construction aspect, analysis and design, difficulties encountered and remedial measures suggested. The life cycle cost analysis of pavement is made. The stabilised pavements with Thin White Topping offer superior strength and longevity, economic solution and provide better performance.

Keywords: *CTB, TWT, Cold in place recycling (CIPR), Rural roads, Stabilization*.

1. Introduction

A large proportion of villages in India have been connected with granular sub base (GSB), water bound macadam (WBM) or bituminous roads. Rural roads usually have low volume of traffic, consisting mostly of light transport vehicles with less frequency of heavy traffic. Maintenance of these roads is neglected because of paucity of funds and the road asset created is in deteriorated condition. The non-availability of suitable soil and aggregates have made projects unviable and cost prohibitive. This aggregate scarcity will increase further as part of environmental conservation and restriction on mining. The stabilization of soil/aggregate is being used worldwide towards optimal usage of scares resources. The concepts of soil / aggregate stabilization and cold in place recycling technique provides a comprehensive solution for rehabilitation of existing road and green field road construction. Also, in order to provide durable wearing course thin white topping is considered.

2. Cement Treated Base with Cold in Place Recycling Technique

Quality road aggregates have become rare and costly in many places in India due to 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 soil-cement mixture is great strength and durability combined with low cost.

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 flood, currents and wave action. This situation needs maintenance of these roads every year 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 into 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 resumed to be applicable to a pavement where the 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 CIPR technique are- Streau Master (Automatic Cement Spreader), recycler, pad foot roller, grader etc.

3. Field Trial Stretch

Two roads having different type of traffic and geography and existing soil condition have been selected from Pune district of Maharashtra under 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

3.1 Preliminary Data

Preliminary data like subgrade soil, surface condition, carriageway width, crust thickness, rainfall drainage condition etc. has been collected. The preliminary data of two road site is tabulated below (Table 1)

Table 1. Preliminary Data of two road.

Sr. No.	Road Name	Length km	Initial Traffic cvpd	Carriage way Width m	Surface Condition	Crust thickness mm
1	Sanaswadi To Dhanore Road	1.80	283	3.75	Deterioted BT	200
2	Pimpri To Ozare Road	0.50	102	3.00	WBM	100

Figure 1: Typical Cross Section of Rigid Pavement

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

Table 2. Subgrade Soil Properties and UCS of WBM with 4% cement

Sr. No.	Road Name	Subgrade Soil Classification			MDD KN/m³	OMC %	CBR %	(WBM + 4 % Cement) 7 day UCS MPa
		Graval %	Sand %	Silt & Clay %				
1	Sanaswadi To Dhanore Road	25.08	71.33	3.60	19.71	11.00	6.79	5.6
2	Pimpri To Ozare Road	28.03	67.70	4.27	21.67	10.81	8.00	

3.2 Pavement Design

3.2.1 Design of Thin White Topping (TWT) as per IRC SP 62- 2014

A. Sanaswadi Dhanore Road Taluka Shirur District Pune

Initial Design traffic (A) - 300 cvpd	Tyre pressure (p)– 0.80 MPa
Design Life (n) - 20 years	Grade of Concrete – M30
Traffic growth rate (r)- 5 %	Design flexural strength = 90 days strength considered f_f = 1.1 x 0.7 x $\sqrt{fck}$ = 4.22 MPa
Reliability- 60 %	Poisson's ratio of concrete – 0.15
% cracking at the end of design life – 40 %	Coefficient of thermal expansion (α) = 10 x 10^{-6} per °C
Fatigue check criteria for vehicle exceeding 50 kN Wheel load = 10 %	Trial Concrete Thickness = 200 mm with CTB 200 mm
Wheel load for single axle with duel wheel - 50 kN	Transverse Joint spacing – 2.00 meter
Spacing of Wheel – 310 mm	Temperature Zone – III (Maharashtra)

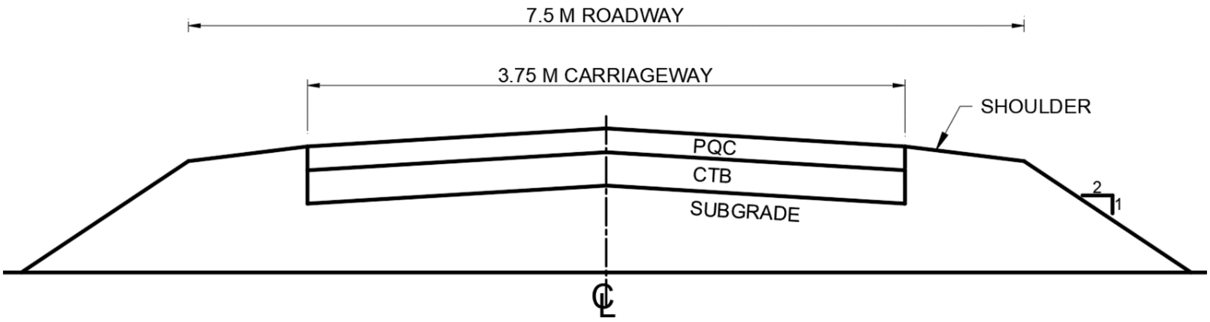

Figure1. Typical cross section of pavement

Typical cross section of rigid pavement is shown in figure 1. The design of rigid pavement is based on modulus of subgrade reaction k. It is calculated from CBR of subgrade by Portland Cement Association (PCA) method. Also composite k value considering cement treated base is taken in the design using PCA method.

- Edge Stress using Westerguard equation

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

σ_e – edge stress in MPa

h – Pavement thickness in mm

k- Modulus of subgrade reaction MPa/m for subgrade CBR 6 % & 200 mm CTB

k = 203 MPa/m

l – radius of relative stiffness

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

a – radius of equivalent circular area for duel wheel

$$a = \sqrt{\frac{0.8521P_d}{p\pi} + \frac{S_d}{\pi}\left(\frac{P_d}{0.5227p}\right)^{1/2}}$$

S_d – Spacing between center of duel wheel

P_d – load on one wheel

σ_e = 2.16 MPa

Temperature stress (σ_{te})

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

C – correction factor based on L/ l = 0.34

σ_{te} = 0.16 MPa

Combined stress due to load + temperature

σ = 2.16 + 0.16 = 2.32 MPa < flexural strength 4.22 MPa

Check for Fatigue criteria with 60 % reliability

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

N_f - Fatigue life with stresses combined wheel load + temperature

SR- Stress Ratio = combined flexural stress / flexural strength

SR = 0.56

Allowable repetitions N_f = 15129009

For rural roads, fatigue criteria checked for 10 % of cvpd over design life

$$\text{Expected repetitions} = 10\ \%\ \text{of}\ \frac{A \times (1+r)^n - 1}{r}$$

N = 362072 < N_f

Cumulative fatigue damage factor N/N_f < 1 hence design is safe

B. Design of TWT For traffic 102 cvpd- Pimpre Ozare Road Taluka Indapur

As traffic is less than 150 cvpd flexural stress and temperature stress are considered in the design.

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 < 4.22 MPa hence design is safe

The rigid pavement design also cross verified with Street Pave software of PCA.

4. Construction Methodology

4.1. Embankment/Formation Widening

The existing formation width in field was 5 to 6 m. The widening of formation is done with good quality embankment material i.e. murum. The widened portion is watered and compacted to the 97 % proctor density. The widened portion is useful for temporary diverting traffic during strengthening of existing carriageway.

4.2. Widening of Existing Carriageway

The existing carriageway of trial stretch was 3.00 meter at many locations. The carriageway is widened to 3.75 m by placing WMM material to the required thickness. The WMM portion is watered and compacted to the required degree.

4.3. Cement Treated Base (CTB)

The existing road is having WBM/deteriorated BT surface. In order to utilize existing coarse aggregate, Cold in Place Recycling (CIPR) technology has been adopted for constructing CTB. The machinery required for CTB work is i) Streau Master (Automatic Cement Spreader) ii) Recycler iii) Pad foot roller, iv) grader etc. The CTB thickness requirement is 200 mm, hence accordingly additional WMM material laid of required thickness and 4% cement by weight basis is spread on the coarse aggregate surface with help of streau master . The width of spreader is 2 meter. Hence cement is spread in half lane width in one go. Recycling of WBM/WMM material is done with the help of Recycler. Recycler has capacity to recycle material up to 500 mm depth. For the trial stretch 200 mm thick CTB is required, accordingly depth of recycling is adjusted so that compacted 200 mm CTB is obtained. (Figure 2) Water as per OMC requirement is added at the time recycling. After recycling the surface is rolled with pad foot roller to achieve required compaction. The surface is graded to required profile and rolled with the help of smooth wheeled roller. Curing of CTB is done for 7 days before laying above wearing course.

4.4. Wearing Course

TWT Pavement : Channels of required sizes are placed on the outer edge side of carriageway. M30 grade PQC of required thickness as per design has been provided on CTB(Figure 3) . 125 micron thick polythene has been laid before laying PQC. Concrete is properly compacted with the help of needle vibrators. The finished surface of concrete is broomed with the help of wire broomer to obtain texturing of 2.5 mm texture depth.(Figure 4) The transverse contraction joints of 3 to 5 mm width sawed to the depth 1/3 of thickness of TWT within 24 hours. The joints are filled with sealant material. (Figure 5) 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.

5. Problems During Construction

1) While constructing the CTB roads it is preferred the traffic from the road is diverted to alternative nearest road. Traffic catering on freshly constructed CTB layer disturbs the surface profile.

2) Set of machinery is required for constructing CTB using CIPR technique, so it is uneconomical to construct smaller stretches.

3) The construction of road should be in continuous stretch

Figure 2: Recycling of base course

Figure 3: Laying of PQC

Figure 4: Texturing of Concrete

Figure 5: Joint Cutting and filling with sealant

6. Performance Evaluation

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

A) Serviceability B) Structural capacity C) Surface distress

6.1. Serviceability

The pavements are built for serving the traveling public which represents serviceability. This principle has motivated the use of a rating scale for pavement serviceability, ranging from 0 to 5, whereby 0 signifies very poor and 5 signifies very good. Serviceability of pavement is observed with roughness index. The roughness index test has been carried out on all three constructed roads.

6.2. Structural Capacity

The capability of a 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 deflectometers. Deflectometers apply a known load to the surface and use 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 structural capacity of pavement (Figure 6).

Response of pavement to falling weight is recorded in terms of deflection and the structural capacity of pavement is worked out through back calculation. Program KUAB PVD software module is used to calculate module and strain analysis with life time for required strength from respective input data. In built calculations includes calculations for the E modules for the layers in a pavement, given the values for each layer's thickness and poisson's ratio. It does so using an iteration procedure, where theoretical deflection values in a mathematical model are compared with the measured data, and the program adjusts the layer modules until no further improvement is obtained. The program then calculates the strains in the layers and works out which layer that according to the criteria for strain allowed will fail first and how many years this will take.

Also, in situ strength of concrete pavement is assessed with non destructive testing method i.e using rebound hammer (Figure 7).

6.3. Surface distress

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

Figure 6: FWD Test

Figure 7: Rebound Hammer Test

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 Dhanore Road	1.80	CTB- 200 mm TWT -200 mm	2046 mm/km Good	adequate	35 Good	No
2	Pimpri To Ozare Road	0.50	CTB- 200 mm TWT -150 mm	2100 mm/km Good	adequate	30 Good	No

i) **Cracking:** Cracking appears in various forms that allow identification of its causes. Some are fatigue related, caused by the accumulation of fatigue damage from successive 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:

a) Low: mean crack opening smaller than 3mm

b) Moderate: mean crack opening between 3 and 6mm

c) High: mean crack opening larger than 6mm

ii) 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 dislodgement of surface blocks created by map cracking.

iii) 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 above parameter (Table 3))

7. Life Cycle Cost Analysis

Road pavement construction, maintenance and rehabilitation costs are rising dramatically. It is essential for road agencies to utilise tools and approaches that facilitate proper decision-making by applying economics and operations research such as Life-Cycle Cost Analysis (LCCA) to achieve economically reasonable long-term investments. LCCA is a method based on principles of economic analysis. It improves the estimation of the total long-term economic viability of different investment options. This method finds significant application in pavement design and management. The economic analysis method used most commonly for this study is net present worth.

The analysis depends on the factors such as inflation rate, discount rate and analysis period. The inflation rate and discount rate is considered as 5 % and 7.5% respectively. Analysis period is considered 20 years.

In economic analysis, one has to consider the total transportation cost, which comprises the following:

(1) Construction Cost (2) Maintenance Cost over its design life (3) Road User Cost

Road User Cost is composed of the following main components:

(1) Vehicle Operating Cost (2) Time Cost (3) Accident Cost

The component (Time cost, Accident cost) which is similar in different types of pavements is not taken into account for life cycle cost analysis. The vehicle operating cost is calculated considering roughness index 2000 mm/km for TWT, 2500 mm mm/km for flexible pavement with CTB and 3000 mm/km for conventional flexible pavement as per norms given in IRC SP 30: 2019 Manual on Economic Evaluation of Highway Projects in India

7.1 Life Cycle Cost Analysis for Sanaswadi Dhanore Road

Carriageway Width- 3.75 m, Initial Traffic – 300 CVPD, CBR - 6 % , Design 20 year Traffic - 12.6 msa,

The design crust requirement is given in Table 4.

The life cycle cost analysis of rigid pavement, flexible pavement with CTB and conventional flexible pavement is given in Table 5 and 6. The summery of Life cycle cost analysis is given in Table 7.

Table 4 Crust Composition

TWT Pavement	Flexible Pavement with CTB	Conventional Flexible Pavement
CTB = 200 mm PQC (M30) = 150 mm	CTSB = 200 mm CTB = 170 mm SAMI Layer BC = 50 mm	GSB = 150+100 mm WBM = 250 mm BM = 70 mm BC = 40 mm

Table 5 Construction and Maintenance Life Cycle Cost Analysis

Year	Scope	Construction/ Maintenance Cost in lakh/km			Net Present Value in lakh/km		
		TWT Pavement	Flexible Pavement with CTB	Conventional Flexible Pavement	TWT Pavement	Flexible Pavement with CTB	Conventional Flexible Pavement
1	Construction	60.803	42.071	47.367	60.803	42.071	47.367
2	--	--	--	--	--	--	--
3	Maintenance	--	0.770	0.484	--	0.620	0.389
4	Maintenance	--	0.810	0.509	--	0.607	0.381
5	Maintenance	0.160	17.865	14.374	0.111	12.444	10.012
6	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--
8	Maintenance	--	0.983	0.617	--	0.551	0.346
9	Maintenance	--	1.030	0.646	--	0.537	0.337
10	Maintenance	0.778	22.750	31.717	0.377	11.038	15.389
11	--	--	--	--	--	--	--
12	--	--	--	--	--	--	--
13	Maintenance	--	1.256	0.788	--	0.490	0.308
14	Maintenance	--	1.315	0.826	--	0.478	0.300
15	Maintenance	0.260	29.030	23.358	0.087	9.811	7.894
16	--	--	--	--	--	--	--

17	--	--	--	--	--	--	--
18	Maintenance	--	1.601	1.005	--	0.435	0.273
19	Maintenance	--	1.681	1.055	--	0.425	0.267
20	--	--	--	--	--	--	--
	Total	**62.001**	**121.168**	**122.751**	**61.380**	**79.511**	**83.267**

Table 6 Vehicle Operating Life Cyle Cost Analysis

Year	Traffic Growth Rate @ 5%	TWT Pavement			Flexible Pavement with CTB			Conventional Flexible Pavement		
		VOC Roughness 2000	VOC In lakh	NPV-VOC In lakh	VOC Roughness 2500	VOC In lakh	NPV-VOC In lakh	VOC Roughness 3000	VOC In lakh	NPV-VOC In lakh
1	300	28.28	30.966	30.966	28.87	31.612	31.612	29.46	32.258	32.258
2	315	29.69	34.140	31.758	30.31	34.852	32.421	30.93	35.565	33.083
3	331	31.18	37.668	32.595	31.83	38.454	33.275	32.48	39.240	33.955
4	348	32.74	41.583	33.472	33.42	42.450	34.171	34.10	43.318	34.869
5	365	34.37	45.795	34.291	35.09	46.750	35.007	35.81	47.706	35.722
6	383	36.09	50.456	35.145	36.85	51.509	35.879	37.60	52.561	36.612
7	402	37.90	55.607	36.031	38.69	56.767	36.783	39.48	57.927	37.535
8	422	39.79	61.292	36.944	40.62	62.571	37.715	41.45	63.850	38.486
9	443	41.78	67.560	37.881	42.65	68.969	38.671	43.53	70.379	39.461
10	465	43.87	74.461	38.837	44.79	76.014	39.647	45.70	77.567	40.458

11	488	46.07	82.051	39.810	47.03	83.763	40.641	47.99	85.474	41.471
12	512	48.37	90.390	40.797	49.38	92.276	41.648	50.39	94.162	42.499
13	538	50.79	99.730	41.872	51.85	101.810	42.745	52.91	103.891	43.619
14	565	53.33	109.971	42.950	54.44	112.266	43.846	55.55	114.560	44.742
15	593	55.99	121.192	44.031	57.16	123.721	44.949	58.33	126.249	45.868
16	623	58.79	133.690	45.182	60.02	136.479	46.125	61.25	139.268	47.068
17	654	61.73	147.359	46.327	63.02	150.434	47.294	64.31	153.508	48.261
18	687	64.82	162.535	47.533	66.17	165.926	48.525	67.52	169.316	49.517
19	721	68.06	179.107	48.726	69.48	182.844	49.742	70.90	186.581	50.759
20	757	71.46	197.453	49.969	72.95	201.572	51.011	74.44	205.692	52.054
		Total		795.12			811.717			828.30

Table 7 Life Cycle Cost Analysis Summery

Sr No	Type of Pavement	Life Cycle Direct Cost Lakh/km	Life Cycle Road User Cost Lakh/km	Total Life Cycle Cost Lakh/km	% Saving in Life Cycle Cost
1	TWT CTB+PQC	61.38	795.13	856.51	6.04
2	Flexible with CTB	79.51	811.72	891.23	2.23
3	Conventional Flexible	83.27	828.31	911.57	--

8. Conclusion

Two trial field stretches are constructed with CTB using CIPR technique. Thin White Topping has been provided as wearing course, The construction of rural roads with CTB using CIPR technique is effective and environment friendly solution.

The performance evaluation rating after two years construction is good. Surface cracking, pot holes, rutting or any defects are not observed. The riding comfort for TWT pavement is good. The recurring maintenance cost of TWT pavement is very less.

There is saving of 6.04 % in TWT pavement 2.23 % saving in flexible pavement with CTB as compare to conventional flexible pavement. life cycle cost.

References

[1] Wu, Z., & Mahdi, M. (2015). Roller Compacted Concrete over Soil Cement under Accelerated Loading. Airfield and Highway Pavements 2015. Presented at the Airfield and Highway Pavements 2015. https://doi.org/10.1061/9780784479216.038

[2] Dr. V. Ramachandra (2011), White Topping: An Excellent Solution for pavement Rehabilitation. NBM & CW.

[3] Skanda Kumar B. N., S. R, Bhavan V. (2014) Performance Evaluation of Thin White Topping, International Journal of Research in Engineering and Technology, Vol-3.

[4] IRC:37 (2018), Guidelines for Design of Flexible Pavements, (Fourth Revision), Indian Road Congress.

[5] IRC: SP: 76 (2015), Guidelines for Conventional and Thin White Topping, (First Revision), Indian Road Congress.

[6] IRC SP 62 (2014), Guidelines For Design and Construction Of Cement Concrete Pavements For Low Volume Roads, Indian Road Congress.

[7] IRC SP 30 (2019), Manual on Economic Evaluation of Highway Projects in India. Indian Road Congress

[8] S K Bagui (2012), Pavement Design for Rural Low Volume Roads Using Cement and Lime treatment base, Jorden Journal of Civil Engineering, Volume 6.