IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 9, Issue 3, June- July, 2021
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Pavement Design for Low Volume Roads Cement Treated Recycled Concrete Aggregate Bases

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Abstract

Generally, cement-treated bases are the non-conventional pavement layers used for improving the mechanical characteristics of base and sub-base courses. The present study focused on the design and analysis of the pavement with cement-treated bases made of Recycled Concrete Aggregates (RCA). The mechanical characteristics of the cement-treated recycled concrete aggregate mixes with 75% and 100% RCA are explored in the current study. The mixes with 2% and 4% cement are used as either a base or a sub-base for pavement design and analysis. To investigate the stresses and strains analysis and subgrade California Bearing Ratio (CBR) of 6% and 1 to 2 million standard axles (msa) of design traffic are considered. The reference pavement sections are considered corresponding to subgrade class-III and a total of 3 traffic categories ranging from T-7 to T-9 are considered as per the IRC: SP-72-2015. Initially, the Resilient Moduli (M_R) of the pavement layers for corresponding reference sections are calculated. Using the above-calculated M_R values, thicknesses and Poisson's ratio of 0.35 is considered corresponding to the granular layers. The allowable stresses and strains are estimated by using the KENPAVE software. By taking these stresses and strains as the benchmark, the pavement design and analysis was carried out. From the obtained results, it is concluded that the Cement Treated Mixes with 75% RCA and 100% RCA can be recommended for the base sub-base layer materials especially for Low Volume Roads (LVRs)

Keywords: Cement Treated Bases (CTB); Recycled Concrete Aggregates (RCA); Strains; KENPAVE;

1. Introduction

There are several essential points to be considered while evolving suitable and economical designs for the LVRs roads in India. First and foremost is the aspect of practical implement ability of the recommended designs within the available resources and level of expertise in rural areas, availability of equipment/plant for construction and maintenance as well as the level of quality control that can be effectively exercised. To the extent possible, the use of locally available innovative or marginal materials as such or after suitable processing has to be maximized in the immense interest of the economy. The design life to be taken for purposes of pavement design should neither be too short of requiring expensive up-gradation at close intervals nor should it be so long as to require prohibitively high cost of initial construction. Pavement design forms an integral part of the detailed engineering study. The economic benefit accrued to society directly depends on the performance of the pavement. The design of pavement by following the guidelines and specifications given IRC: SP: 72-2015. In practice, CTBs was first brought back in 1935 in order to improve the roadbed for State Highway 41 at Johnsonville. Even though the idea of stabilizing the soils and pavement materials is present over a century, at present, thousands of kilometers of treated bases with cement are put in to practice in developing and developed countries. Presently, in India, a considerable amount of research work is being done on CTBs to enhance its utilization in all the high and low volume roads. Generally, CTB is composed of 2 layers, in which the upper layer has less thermal expansion as compared to the lower layer (Scullion et al. (1998). The CTB can also be reinforced with fibers in order to improve tensile and toughness properties (Mohammed et al. (2000)). Lim et al. (2003) performed an experimental study to calculate the modulus of elasticity and compressive strength of CTAB materials.

2. Experimental Program

In the current research paper, the pavement design is based on specifications given in IRC: SP-72-2015 for the flexible pavement design of LVRs. The pavement composition of LVRs for subgrade CBR 5% and traffic volume in the range of 1-2 msa is considered. The pavement design followed a different step by step procedure. Firstly, the resilient moduli of the pavement layers are calculated for the composition given in IRC: SP-72-2015. Secondly, the approximate thickness of different layers is determined based on Odemark's method of equivalent thickness for both cement stabilized and emulsion stabilized low volume flexible pavements. Thirdly, the stress-strain analysis was carried out using KENPAVE software for optimizing the thickness of each layer. Finally, the pavement composition is fixed based on corresponding vertical stress and strains as calculated using the software. The better mechanical characteristics and their magnitudes are the prerequisites for the pavement analysis and design. The mechanical characteristics and their magnitudes are listed subsequently. Figure1.The flow chart for pavement analysis and design of LVRs.

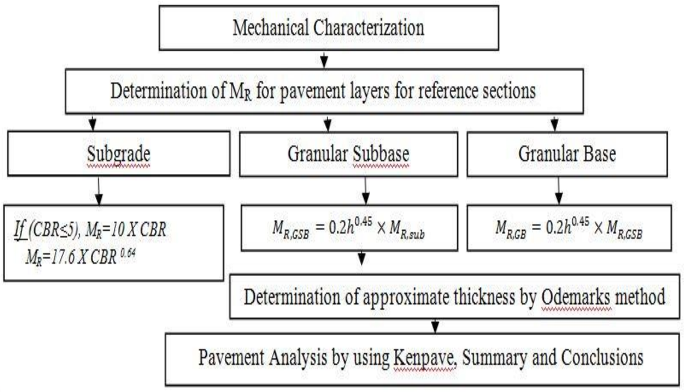

Figure 1. The methodology adopted for Pavement Analysis and Design of base

2.1 Mechanical Characterization

The cement-treated mixes with RCA are evaluated in terms of dry-density, unconfined compressive strength (UCS), Indirect Tensile Strength (ITS), fatigue resistance, resilient modulus (M_R) and durability. The results are shown in the following Table 1.

Table 0 Summary of mechanical characterization Cement Treated Mixes with RCA

Mechanical Characteristic	**75% RCA**		**100% RCA**	
	2%C	**4%C**	**2%C**	**4%C**
Maximum Dry Density (MDD) in g/cc	2.12	2.14	2.06	2.07
Unconfined Compressive Strength (UCS) in MPa	-	1.1	-	0.7
Indirect Tensile Strength (ITS) in kPa	113	272	103	143
Number of failures causing fatigue failure (N_f)	27500	8200	26200	6100
Resilient Modulus (M_R) in MPa	711	1148	718	1157
UCS after dry& wet cycles in MPa	-	3.7	-	2.6

2.2 Reference sections

The study adopted the pavement sections with granular layers corresponding to the subgrade class of III as per IRC: SP-72-2015. The layer and overall thicknesses are mentioned below (Table 2). The Open Graded Pre-Mix Carpet (OGPC) is provided as the top layer to provide the smooth movement of the vehicle and act as a dust palliative layer. It is only a functional layer. Hence it is not considered in the pavement design and analysis.

Table 2 Unstabilized Pavement Composition for CBR=5 (IRC: SP-72-2015)

CBR= 5	Traffic Category (msa)		
	T-7	T-8	T-9

	(6,00,000-1,000,000)	(1,000,000-1,500,000)	(>1,500,000-2,000,000
OGPC	20	20	20
BM	-	-	50
WBM-III	75	75	0
GB CBR>100	150	150	225
GSB	100	200	200
ISG	100	100	-
Total Thickness (mm)	425	525	475

2.3 Determination of Resilient Modulus

The resilient moduli of subgrade, granular sub-base and granular base are calculated as follows, and obtained values are listed in table 3.

STEP-I: Resilient Modulus of Subgrade ($M_{R,\ subgrade}$)

The resilient modulus of the subgrade is calculated using the empirical equations given below:

$$M_{R,subgrade} = 10 \times CBR \text{ for } CBR \leq 5\% \quad (1)$$

$$M_{R,subgrade} = 10 \times M_R = 17.6 \times CBR^{0.64} \text{ for } CBR > 5\% \quad (1)$$

STEP-II: Resilient modulus of granular subbase ($M_{R,\ GSB}$)

The resilient modulus of granular subbase is calculated as follows:

$$M_{R,GSB} = 0.2 \times h^{0.45} \times M_{R,subgrade} \quad (2)$$

Where. h= thickness of granular subbase (GSB) in mm

STEP-III: Resilient modulus of the granular base ($M_{R,\ GSB}$)

The resilient modulus of granular subbase is calculated as follows:

$$M_{R,GB} = 0.2 \times h^{0.45} \times M_{R,GSB} \quad (3)$$

Where. h= thickness of the granular base (GB) in mm

Table 3 Resilient Modulus Matrix for unstabilized pavement layers (IRC: SP-72-2015)

CBR 5%	Traffic Category		
	T-7	T-8	T-9
BM	-	-	600
WBM-III	335.822	458.746	0
GB CBR>100	240.603	328.673	248.299
GSB	126.191	172.383	108.508
ISG	79.432	79.432	-
Subgrade	50	50	50

The resilient modulus of cement stabilized RCA bases, and subbases are determined as explained in earlier under 2.3 heading. The values of M_R cement-treated bases with the composition of 100RCA_4C and 75RCA_4C are taken as 718MPa and

1148MPa, respectively. Similarly, the value of M_R for cement-treated subbase (75RCA_2C) is taken as 711MPa for the design of flexible pavements. The values of M_R for WBM-III and Bituminous Macadam layers are taken as 450MPa and 600MPa, respectively (IRC: 37-2018).

2.4 Determination of thicknesses by Odemarks Method

The equivalent thickness of the bases is determined based on Odemark's method. The values of the relative stiffness of the different mixes are equated with obtaining the equivalent thickness of the different combination of the mixes.

$$l_2 = l_1$$

$$\frac{E_2 \times h_e^3}{12k(1-\mu_1^2)} = \frac{E_1 \times h_1^3}{12k(1-\mu_1^2)}$$

$$h_e^3 = \frac{E_1}{E_2} \times h_1^3$$

$$h_{e_{1-2}} = \left(\frac{E_1}{E_2} \times h_1^3\right)^{1/3}$$

Table 4 The proposed pavement composition for Cement Stabilized Roads

CBR 5%	Traffic Category					
	T-7		T-8		T-9	
	Thickness (mm)	M_R (MPa)	Thickness (mm)	M_R (MPa)	Thickness (mm)	M_R (MPa)
OGPC	20	-	20	-	20	-
BM	0	-	0	-	50	600
WBM-III as CRAL	75	450	75	450	75	450
CTB	125	718	125	1148	100	718
CTSB	-	-	150	711	-	-
GSB	100	79.4	-	-	100	79.4
Total Thickness (mm)	**300**		**350**		**325**	

2.5 Pavement analysis by KENPAVE

The KENPAVE software has two parts, i.e., Kenlayer and Kenslab. Kenlayer deals with stress analysis of flexible pavements, whereas Kenslab deals with rigid pavements. In this study, KENLAYER is used for stress analysis of flexible pavements. Stress analysis using KENLAYER involves entering the input data and extracting the results in text documents.

The required input data for stress analysis is mentioned below:

- Nature of layers such as linear, non-linear, viscous, viscoelastic
- No. of layers, vertical coordinates at which response is required
- Layer details such as thickness poisons ratio and Moduli of corresponding layers
- Load details such as type of axle, contact radius, contact pressure, the distance between wheels and axles and point groups at which response is needed

The poisons ratio is taken 0.35 for granular and bituminous layers while 0.25 is taken for cementitious mixes. Later, the file is saved after entering the required data and options KENLAYER and LGRAPH are used for extracting the results of displacements, stresses and strains.

Table.5 Stress Analysis for Traffic Category T7 (6,00,000-1,000,000)

Point Group	Vert. Coordinate (cm)	Vert. Displacement (cm)	Vert. Stress (kPa)/ Strain (με)
1	7.5	0.16673	487.89, 1048.00
	22.5	0.14739	198.18, 1194.00

	32.5	0.13312	119.38, 1294.00
	42.5	0.11868	83.15, 1314.00
2	7.5	0.17199	407.58, 743.70
	22.5	0.15485	204.68, 1222.00
	32.5	0.13961	130.05, 1419.00
	42.5	0.12368	90.90, **1453.00**

Table.6 Stress Analysis for Traffic Category T8 ((1,000,000-1,500,000)

Point Group	Vert. Coordinate (cm)	Vert. Displacement (cm)	Vert. Stress (kPa)/ Strain (με)
1	7.5	0.09184	70.70, 17.05
	22.5	0.09005	54.69, 178.20
	42.5	0.08416	37.27, 328.00
	52.5	0.07942	32.21, 466.40
2	7.5	0.10748	102.75, 34.16
	22.5	0.10476	77.40, 264.90
	42.5	0.09633	50.11, 463.70
	52.5	0.08978	42.36, **638.80**

Table 7 Stress Analysis for Traffic Category T9 (>1,500,000-2,000,000)

Point Group	Vert. Coordinate (cm)	Vert. Displacement (cm)	Vert. Stress (kPa)/ Strain (με)
1	5	0.15244	530.43, 589.10
	27.5	0.12596	149.22, 968.80
	47.5	0.10421	66.05, 917.30
2	5	0.15546	431.63, 351.60
	27.5	0.13182	160.18, **1038.00**
	47.5	0.10799	71.83, 1010.00

It is observed that the maximum vertical compressive strains are observed at point group 2, i.e. centre of dual wheel system. The maximum observed vertical strains are 1453.00, 638.80, 1038.00με for traffic categories T-7, 8 and 9, respectively (Unstabilized Pavement sections are given in IRC: SP-72-2015). These values are taken as benchmarks for design of cement; emulsion stabilized pavements. (Table 5, 6 and 7)

Table 8 Stress and strain results for Cement Stabilized Roads for T-7 (Author's Study)

Point Group	Vert. Coordinate (cm)	Vert. Displacement (cm)	Vert. Stress (kPa)/ Strain (με)
1	7.5	0.10855	69.46, 7.10
	20	0.10745	54.14, 151.20
	30	0.10165	47.74, 593.60
2	7.5	0.13089	100.72, 11.55
	20	0.12925	76.32, 227.30
	30	0.12087	66.28, **854.50**

Table 9 Stress and strain results for Cement Stabilized Roads for T-8 (Author's Study)

Point Group	Vert. Coordinate (cm)	Vert. Displacement (cm)	Vert. Stress (kPa)/ Strain (με)
1	7.5	0.10857	510.82, 523.10
	20	0.10529	224.84, 247.60
	35	0.10088	59.54, 320.00
2	7.5	0.11128	418.38, 358.90
	20	0.10864	214.75, 235.60
	35	0.10405	63.81, **348.60**

Table 10 Stress and strain results for Cement Stabilized Roads for T-9 (Author's Study)

Point Group	Vertical coordinate (cm)	Vertical Displacement	Vertical Stress (kPa)/ Strain (με)
1	7.5	0.10331	71.72, -48.80
	12.5	0.10312	62.05, 71.40
	22.5	0.10208	49.51, 147.70
	32.5	0.09611	43.39, 586.40
2	7.5	0.12295	104.33, 68.97
	12.5	0.12265	88.88, 107.90
	22.5	0.12111	68.94, 219.60
	32.5	0.11271	59.39, **821.00**

The results of cement stabilized pavements are shown in Tables from 8 to 10 for traffic categories T-7, 8 and 9 respectively. The maximum observed vertical strains are 854.50, 348.60 and 821.00με for traffic categories T-7, 8 and 9, respectively (Unstabilized Pavement sections are given in IRC: SP-72-2015). These values are less than benchmark-values. Hence, the pavement composition can be taken the construction of low volume roads for traffic categories T-7, 8 and 9.

3. Summary of Results for Pavement Design and Analysis

It can be seen that the Crack Relief Aggregate Layer, i.e., WBM-III is provided above the CTB in all compositions (Fig. 2). It is also observed that Bituminous macadam is provided in T-9 traffic category pavement section only as it provided in IRC: SP-72-2015. For traffic category T-7 and T-9, the mix with 100% RCA with 4% cement is used for constructing the base layers. Cement stabilized sub-bases are not provided in T-7 and T-9 categories. However, the cement stabilized base and subbase are provided in T-8 categories. 75% RCA mixes with 2%, 4% of cement are used in construction sub-bases and bases respectively in traffic categories. The overall thickness of different pavement sections is compared for cement stabilized pavements from Figure 3.

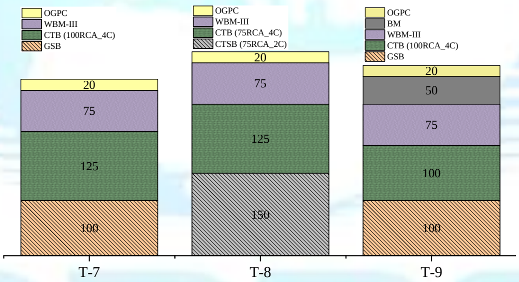

Figure 2 Pavement composition for cement stabilized pavements

In all the cases, it is observed that the Open Graded Pre-Mix Carpet is used as the top layer. Generally, OGPC acts as a functional layer rather than the structural layer. Hence, it is not considered in stress-strain analysis in KENPAVE.

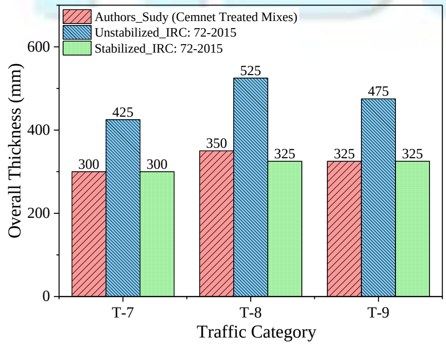

Figure 3. Comparison of pavement thicknesses for cement treated pavements

From Figure 3, it can be observed that the overall thicknesses of the cement stabilized pavement sections are 300, 350 and 325mm corresponding to the traffic categories 7, 8 and 9, respectively. These values are lesser than those of unstabilized pavement composition, but not lesser than those of cement stabilized pavement composition given in IRC: SP-72-2015.

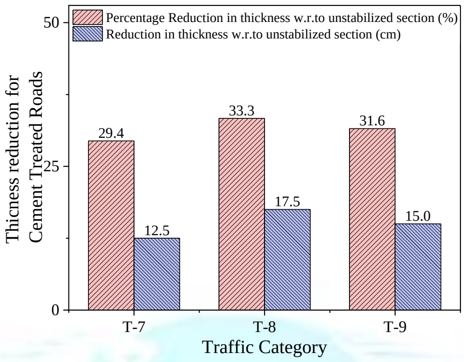

Figure 4. Thickness reduction for cement stabilized pavements

Similarly, the achieved reduction in overall-thickness is 52.9, 47.6 and 36.8% for cement stabilized pavements with traffic categories 7, 8 and 9, respectively. The overall-thickness is reduced by an amount of 22.5, 25 and 17.5cm, respectively for T-7, T-8 and T-9 traffic categories respectively (Figure 4).

4. Summary and Conclusions

In the current research paper, the pavement design is based on specifications given in IRC: SP-72-2015 for the flexible pavement design of LVRs. The pavement composition of LVRs for subgrade CBR 5% and traffic volume in the range of 1-2 msa is considered this study analyzed the stresses and strains of the pavements with Cement Treated RCA bases/subbases. A set of following conclusions can be drawn from this analysis.

- It is concluded that the cement-treated bases with 4% cement can be prepared by entirely replacing the natural aggregates with recycled concrete aggregate.
- The subbases can be successfully constructed with 75% recycled concrete aggregates for traffic lies in the range of 1 to 1.5msa for low volume roads.
- The use of cement-treated bases/subbases with RCA produces a reduction in thickness
- The overall-thickness is reduced by an amount of 22.5, 25 and 17.5cm, for T-7, T-8 and T-9 traffic categories respectively.

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