Pavement Analysis and Design of Low-Volume Roads with Recycled Concrete Aggregate Bases treated with Bitumen-Emulsion

[1] B. Sudharshan Reddy[1], G.Sreenivasa Reddy[*], C. Sashidhar

[1] *Ph.D Scholar, Department of Civil Engineering, JNTUA,Anantapuramu & Asst. Professor in Narsimha Reddy Engineering College, Hyderabad,Telangana-India*
[2]*Department of Civil Engineering, KSRM College of Engg, Kadapa, Andhra Pradesh-India*
[3] *Department of Civil Engineering, JNTUA College of Engg, Anantapur, Andhra Pradesh-India*

* E-mail: sudharshan2055@gmail.com

Abstract:

Low-Volume Roads recorded highest share in the Indian road network. The annual length of rural roads constructed in India is approximately 7.2 lakh kilometers for the year of 2019-20 (As per Pradhan Mantri Gram Sadak Yojana). As the rate of road construction is increasing day-by-day, it is necessary to acquire the sufficient quantity of aggregates. To address this and avoid the use of Natural Aggregates, the Recycled Aggregates like Recycled Concrete Aggregates (RCA), Reclaimed Asphalt Pavement (RAP) material and Reclaimed Asphalt Shingles (RAS) are become familiar in pavement construction. The present study focused on the design and analysis of low-volume roads with aggregate bases treated Bitumen-Emulsion and sub-bases treated with cement. In prior to carry out the pavement analysis and design, the mechanical characteristics of bitumen-emulsion mixes with different proportions of RCA (25, 50 and 75%) are analyzed. The samples are prepared with various amounts (6 to 9%) of Bitumen-Emulsion Contents (BEC) and 1.5% cement. The prepared samples are evaluated for mechanical characteristics like Marshall Stability, Indirect Tensile Strength (ITS), Resilient Modulus (M_R), density and Tensile Strength Ratio (TSR). From the Marshall Stability-Test, the optimum BEC is determined and noted as 8% for the mixes with 25, 50 and 75% RCA contents. Later, the fatigue behavior is analyzed using Repeated Load Test. In addition to it, the sub-bases with 75% RCA and 2% cement are used in pavement analysis and design and corresponding characteristics are listed in this article. Finally, the pavement design and analysis are conducted for the pavements with bitumen-emulsion stabilized bases (BESB) having 75% RCA at optimum BEC for subgrade CBR of 5%. In overall, it is concluded that the Recycled Concrete Aggregates can be successfully utilized instead of Natural Aggregates in the bitumen-emulsion treated bases for construction of low-volume roads.

1 Background

The bitumen-stabilized materials (BSM) generally prepared with either bitumen-emulsion or foamed-bitumen. The behavior of BSMs is different from the cement treated mixes and conventional mixes. For BSMs, the ratio of residual bitumen and cement is restricted to 1 as per Asphalt Academy Technical Guidelines-2009 [1]. In this study the amount

cement is selected based on various specifications and studies in order to avoid the brittleness of the mixes [1-4]. These materials are evolved for reducing the consumption of natural aggregates by replacing them with recycled aggregates like RCA, RAP and RAS. To successfully utilizing the recycled aggregates, it is necessary to study the mechanical characteristics and analyze the stresses and strains induced.A previous study analyzed stresses and strains for different reductions in M_R using kenpave software [5]. The present study focused on the pavement analysis and design of low-volume roads by taking the reference sections as the pavement sections given in Indian Roads Congress: SP-72-2015 [6].

2 Research Methodology

In this study, the research approach composed of two stages. Firstly, the mechanical characteristics of bitumen-emulsion and cement treated mixes with RCA are studied. Secondly. the pavement design and analysis are conducted.

Firstly, a series of 145 bitumen-emulsion samples are produced and cured for 72hours at 40^{o}C to evaluate the corresponding mechanical characteristics. The sample matrix is shown in following table 1. Out of 145 sepcimens, 36 samples are tested for Marshall Stability and optimum BEC is determined for mixes with 25, 50 and 75% RCA. The Marshall Stability test is conducted at ambient temperature rather than 60^{o}C. Because, the cold mixes mostly preferred to test at ambient temperature unlike hot mix asphalt. ITS-test is conducted at a rate of loading 51mm/minute as per ASTM-D6391[7]. A set of 36 specimens are moisture-conditioned (24 hours) after 72 hours oven curing period and tested for determining wet-ITS. Next, the ratio of wet and dry-ITS is calculated and noted in terms of percentage as the Tensile Strength Ratio (TSR). The specimens prepared at optimum BEC are tested for evaluating the resilient modulus. The resilient modulus test is conducted as per ASTM-D4123 [8] for assumed poissons ratio of 0.35. Finally, the fatigue behavior of bitumen-emulsion mixes is evaluated using a repeated load test at different stress ratios (0.3, 0.5 and 0.8). In addition to it, the value of M_R for cement treated 75% RCA mixes are listed in the results and discussions.

Table 1. The specimen matrix for mechanical characterization

Test	**RCA-contents (%)**	**BEC (%)**	**Repeatability**	**Total**
Marshall Stability	25,50,75	6,7,8,9	3	36
dry-ITS	25,50,75	6,7,8,9	3	36
wet-ITS	25,50,75	6,7,8,9	3	36
Resilient Modulus	25,50,75	8	3	9
Fatigue Test	25,50,75	8	3	27

Secondly, the pavement design and analysis are carried out for the pavements with BESBs and cement treated sub-bases (CTSB). The design subgrade CBR of 5% and design traffic levels up to 2 msa (T-7, T-8 and T-9 as per IRC: SP-72-2015) are considered for pavement analysis. The pavement sections (corresponding to subgrade

class 3 and traffic categories T-7, T-8 and T-9) with unstabilized bases and subbases given in IRC: SP-72-2015 are considered as reference sections. For the reference sections, the vertical compressive strain on top of subgrade is calculated using KENPAVE software. These vertical compressive strains are considered as benchmark values for the present study. Finally, the pavement composition of low-volume roads with BESB and CTSB is finalized for corresponding traffic categories.

3 Results and Discussions

3.1 Mechanical Characterization

The specimens tested for mechanical characteristics are illustrated in following table 2. From, the results it is clear that the values of dry-ITS, wet-ITS and TSR are exceeding 125kPa, 50kPa and 50% respectively. Hence, the produced mixes can be successfully used for constructing the bases as per Asphalt Academy Technical Guidelines-2009. Pavement Analysis and Design. All the results of Bitumen-Emulsion mixes are shown corresponding to optimum BEC of 8%.

Table 2. The results of mechanical characteristics

	Bitumen-Emulsion Treated Mixes			**Cement Treated Mixes**
Characteristic	**RCA_25**	**RCA_50**	**RCA_75**	**RCA_75 at 2% cement**
Marshall Stability (kN)	14.8	11.3	11	-
dry-ITS (kPa)	185	164	154	113
wet-ITS (kPa)	142	111	98.4	-
TSR (%)	77	68	64	-
Resilient Modulus (MPa)	1291	1183	990	711
Fatigue life (N_f)	53000	22000	25000	9000

3.2 Pavement Analysis and Design

In order to design the pavement with BESB and CTSB, the vertical compressive strains on the top of the subgrade are computed using the KENPAVE software. In this, kenlayer interface is used for analysis of flexible pavements. Analysis of stresses and strains using Kenlayer involves in different stages. Firstly, the input data is entered through the LAYERINP option. In this study, the stresses and strains are computed for a dual wheel load of 80kN with center to center wheel-spacing of 310mm. The tire-pressure of 560kPa is adopted for determining the pavement-response. Two-point groups are considered for the pavement analysis and depicted a in figure 1.

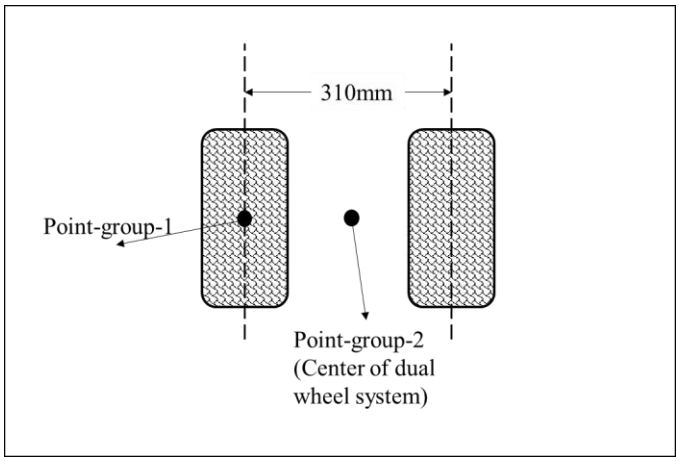

Figure 1. Dual Wheel Load System and point groups

The results of vertical compressive strains are depicted in following figure 2. From the results, the computed values of vertical compressive strain for reference section are 1453, 639 and 1038 micro-strains for traffic categories 7, 8 and 9 respectively. Similarly, the computed strain values for the present study are 643, 451 and 418micro-strains for traffic categories 7, 8 and 9 respectively. Hence, it can be concluded that the assumed pavement composition is finalized for construction of a low-volume roads with BESB and CTSB for corresponding traffic categories and subgrade CBR of 5%.

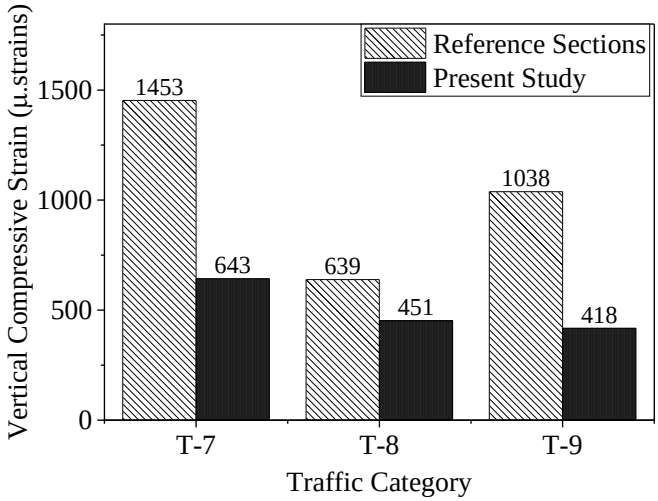

Figure 2. The vertical compressive strains on top of the subgrade

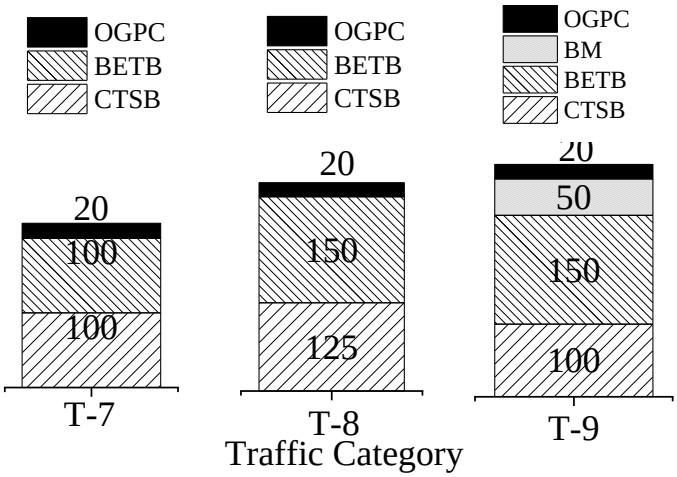

Figure 3. Pavement Composition for Bitumen-Emulsion Stabilized Pavements

From figure 3, it is observed that Bituminous Macadam is provided in traffic category (T-9) pavement section only as it provided in IRC: SP-72-2015. For bitumen emulsion stabilized pavement sections, the cement treated subbases (CTSB) is provided for all three traffic categories. The mix with 75% RCA with 2% cement is used in all three cases for construction of subbases. In all cases, it is observed that the Open Graded Pre-Mix Carpet is used as top layer. Generally, OGPC acts as a functional layer rather than structural layer. Hence, it is not considered in stress-strain analysis in kenpave.The overall thickness of different pavement sections is compared in the figure 4 for bitumen emulsion stabilized pavements.

From the figure 4, it can be observed that the overall thicknesses of the Bitumen-Emulsion stabilized pavement sections are 200, 275 and 300mm corresponding to the traffic categories 7, 8 and 9 respectively. These values are lesser than those of unstabilized and cement stabilized pavement composition given IRC: SP-72-2015.

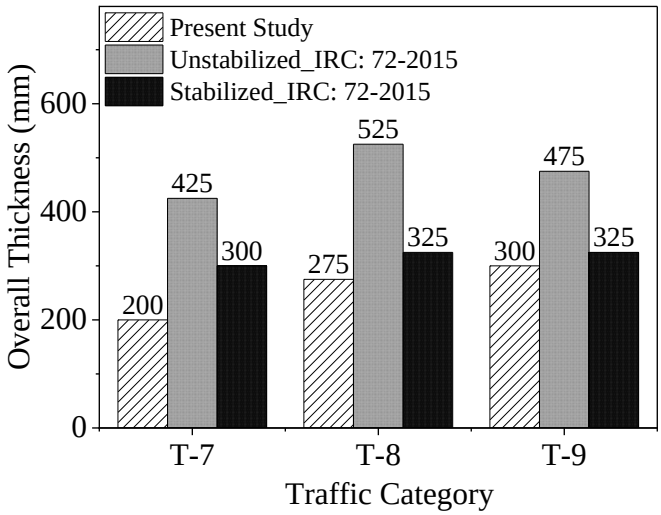

Figure 4. Overall thickness Comparison for Bitumen-Emulsion Stabilized Pavements

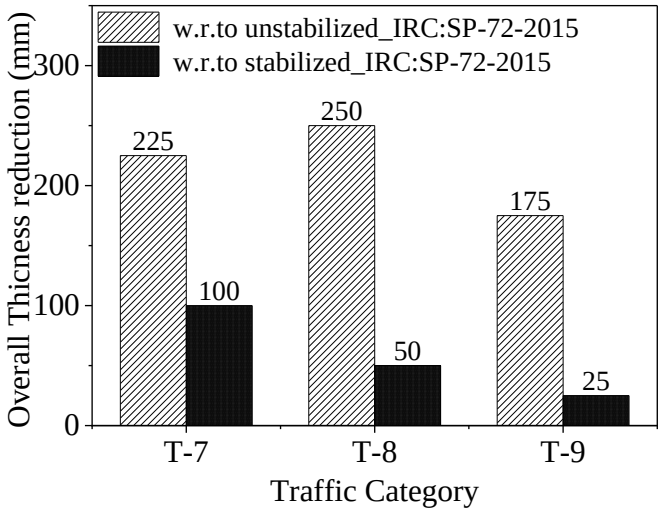

Figure 5. Thickness Reduction for Bitumen-Emulsion Stabilized Pavements

Similarly, the overall-thickness is reduced by 100, 50 and 25mm for bitumen- stabilized pavements with traffic categories 7, 8 and 9 respectively w.r.to cement stabilized pavement sections given in IRC: SP-72-2015. Similarly, the reduction in overall-thickness w.r.to unstabilized reference sections is 225, 250 and 175mm respectively for T-7, T-8 and T-9 traffic categories respectively (from figure 5).

4 Conclusions:

The following conclusions are drawn from the present study:

- The bitumen-emulsion treated bases with 75% RCA is recommended to construct the low-volume roads for design traffic lies in the range of 1msa to 2msa.
- The utilization of recycled concrete aggregates in the bitumen-emulsion treated bases, the obtained reduction in overall thickness as compared the reference sections are an amount 53, 48 and 37% for traffic categories 7, 8 and 9 respectively.
- Similarly, the overall-thickness is reduced by 100, 50 and 25mm for bitumen-stabilized pavements with traffic categories 7, 8 and 9 respectively w.r.to cement stabilized pavement sections given in IRC: SP-72-2015.

References

[1] Asphalt Academy. (2009). “Technical guideline: Bitumen stabilized materials. A guide for the design and construction of bitumen emulsion and foamed bitumen stabilized materials.”

[2] MS-19, A. Basic Asphalt Emulsion. "Manual series no. 19 (ms-19)." Asphalt Institute (1979).

[3] Congress, Indian Roads. "Use of Cold Mix Technology in Construction &Maintenance of Roads Using Bitumen Emulsion IRC: SP-100: 2014." In Indian Roads Congress, New Delhi. 2014

[4] Bessa, I. S., Almeida, L. R., Vasconcelos, K. L., & Bernucci, L. L. (2016). Design of cold recycled mixes with asphalt emulsion and Portland cement. *Canadian Journal of Civil Engineering*, *43*(9), 773-782.

[5] Li, C., Ashlock, J. C., Lin, S., &Vennapusa, P. K. (2018). In situ modulus reduction characteristics of stabilized pavement foundations by multichannel analysis of surface waves and falling weight deflectometer tests. *Construction and Building Materials*, *188*, 809-819.

[6] IRC SP 72-2005, Guidelines for the Design of Flexible pavements for Low Volume Rural Roads. Indian Road Congress, New Delhi.

[7] Standard, A. S. T. M. D6931 (2012), ". *Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures" ASTM International, West Conshohocken, PA*.

[8] Standard, A. S. T. M. D6931 (2012), ". *Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures" ASTM International, West Conshohocken, PA*.