INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

A Comparative Analysis of Flexible Pavement Design using IRC 37-2012 and IITPAVE Software

P Praveen Kumar[1]*, S Manjunatha[1], P B Gnanamurthy[2]

1 Assistant Professor, Department of Civil Engineering, Govt SKSJT Institute, Bangalore, 560001, Karnataka, India
2 Assistant Professor, Department of Civil Engineering, Govt Engineering College, Ramanagara, 562159, Karnataka, India

OPEN ACCESS

Received: 01-10-2023

Accepted: 05-10-2023

Published: 14-11-2023

Citation: Kumar PP, Manjunatha S, Gnanamurthy PB (2023) A Comparative Analysis of Flexible Pavement Design using IRC 37-2012 and IITPAVE Software. Indian Journal of Science and Technology 16(43): 3875-3883. https://doi.org/10.17485/IJST/v16i43.2479

* **Corresponding author**.

praveenkumarputtappa@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: To conduct a comparative analysis of pavement design methodologies adopted by the Indian Road Congress (IRC) 37-2012, based on the empirical method and mechanistic-empirical approach adopted by the IITPAVE software. **Methods:** The present research is carried out to design pavement crust thickness and calculate the strain values in pavement by adopting IRC 37-2012. Pavement crust thickness is designed based on real-time traffic and soil data collected for a stretch of road in Tamil Nadu, India. The allowable horizontal tensile strain and vertical compressive strains are estimated by the empirical equations proposed by IRC 37-2012 and the mechanistic-empirical method by IITPAVE software. A comparison of both design methodologies is made to check for their safety. **Findings:** Based on the soil data and traffic data from the stretch of road, the California Bearing Ratio (CBR) of the soil sample and design traffic in terms of million standard axles (msa) were computed to arrive at a total pavement crust thickness of 575 mm by adopting IRC 37-2012. The obtained values of allowable horizontal tensile strain at the bottom of the bituminous layer from IRC 37-2012 and the actual strain values from IITPAVE software are 301.73×10^{-6} and 270.4×10^{-6} respectively. Similarly, the allowable vertical compressive strain on the top of the subgrade soil surface and the actual strain values from IRC 37-2012 and IITPAVE software are 583.98×10^{-6} and 381.6×10^{-6} respectively. The analysis of the research shows that the actual compressive and vertical strain values obtained from IITPAVE are within the allowable strain values as per the code provisions of IRC 37-2012, making the design safe. **Novelty:** The novelty of the study lies in its approach to distinguishing itself by focusing on real-time data collection, analysis, and design of pavement. Furthermore, the design is checked for safety by using the latest available software.

Keywords: Pavement Design; IRC 372012; IITPAVE; Tensile Strain; Compressive Strain; Safe Design

1 Introduction

The flexible pavement design depends on several important factors, such as material characteristics, soil properties, traffic conditions, wheel load, contact pressure, climatic conditions, and environmental conditions, etc. [1,2]. The design should focus on the most economical and effective use of the existing subgrade materials to optimize their performance. Countries all over the world adopt different methodologies and criteria for the design of flexible pavement [3]. In India, generally, flexible pavements are designed based on the guidelines suggested by the Indian Road Congress (IRC). The design guidelines, principles, and methodologies adopted in IRC 37-2012, are applicable to all the new highways constructed in India, such as National Highways (NH), State Highways (SH), and Major District Roads (MDR).The pavement crust consists of different layers made of non-bituminous and bituminous layers. Non-bituminous layers consist of subgrade and sub bases, and bituminous layers consist of base course and surface course layers. The guidelines strongly recommend that the design of bituminous mixes, which is an integral part of pavement design to consider some of the important factors such as California Bearing ratio (CBR), Modulus of Elasticity (E) of the soil and bitumen, traffic, wheel load, axle load, tyre pressure, contact pressure, etc, [4]. The incorrect estimation and input of data in the analysis and design lead to early pavement failures or distress, which causes discomfort to the vehicular user simultaneously increasing the vehicular and road maintenance costs. Cracking, ravelling, shovelling, potholes, edge breaks, rutting, etc., are some of the common forms of failure or distress formed on the surface of the pavement [5,6]. The IRC 37-2012 highlights various reasons for early failure in the pavement surface and considers excessive strain and deformation in the pavement surface as the main factors responsible for it. The code and previous research findings also consider the development of horizontal tensile strain at the bottom of the bituminous layer and vertical compressive strain at the top of the subgrade layers, which are crucial parameters to limit cracking and rutting in the bituminous and non-bituminous layers of pavement [7,8]. Due to the load repetitions, tensile strains are developed at the bottom of the bituminous layer, over a period, they propagate to the top layers, which are due to fatigue, and the failure is known as fatigue failure. Similarly, the bituminous pavement surface undergoes rutting due to deformation in the subgrade and other non-bituminous layers to take on a deformed shape, and the failure is known as rutting failure [9]. The IRC 37-2012 adopts an empirical design methodology for pavement design by suggesting an equation to estimate both fatigue and rutting failures. IITPAVE software was developed by the Indian Institute of Technology, Kharagpur to analyse the stresses, strains, and deflections caused at different locations on the pavement surface. The most important input parameters in the IITPAVE software are the modulus of elasticity (E) of the material, Poisson's ratio, and thickness of the pavement. On successful running of the software with the input of relevant data, results are obtained as an output, showing the critical horizontal tensile strain and vertical compressive strain values at various locations of pavement layers. Many research studies are carried out using the IITPAVE, KENPAVE [10], MXROADS, AASHTOW, PAVERS, PAVEXPRESS, etc. [11], each using different input parameters for the design of pavement. Every software has some advantages and disadvantages [12]. Some of the disadvantages of using software other than IITPAVE can be listed as follows: they may not perfectly fit the Indian road design and standards, there are compatibility issues with the software and, more importantly, they are very expensive. All these drawbacks can be overcome by choosing IITPAVE, with a feel of a "Made in India" concept; hence, the present research uses IITPAVE in the design due to the fact that it is tailor-made to adhere to the Indian pavement design guidelines and standards, ensures the specific needs and requirements of road construction projects, is user-friendly, and is available free of charge. However, like any software, all the aforementioned software has disadvantages with respect to updates and maintenance to stay connected with changing design standards and practices [13].

In general, the majority of the research is carried out in India, and elsewhere it is limited to laboratory or experimental investigations [14,15]. Very few research works are based on real-time applications, data collection, analysis, design, etc., and the present research is one of them [16]. The present research distinguishes itself by focusing on the real-time data collection, analysis, and design for a stretch of road. The results obtained in this research are considered unique since they are based on specific project road data and cannot be directly compared with previous research findings. This uniqueness adds value to the study and is readily implemented in actual road construction. The main objective of the present research is to design the pavement crust thickness based on IRC 37-2012. The input data and details for the design of pavement are collected from the project road situated in a coastal village near Tirunelveli district, Tamil Nadu, India. The various data, such as type of soil, classification of soil, type and classification of traffic, traffic count, etc., are collected to arrive at the California Bearing Ratio (CBR), design traffic in terms of million standard axles (msa), and other important parameters. In addition, the allowable horizontal tensile strain at the bottom of the bituminous layer and the vertical compressive strain at the top of the subgrade layers are found by using the equations as suggested in IRC 37-2012. Furthermore, the pavement design is carried out by using IITPAVE software to compute the actual horizontal and vertical strain in the pavement layers. Finally, comparisons were made to check the actual and allowable strain values obtained from IITPAVE and IRC 37-2012 to ensure a "safe design".

2 Methodology

2.1 General

The methodologies adopted in the design of flexible pavement by IRC 37-2012 are empirical methods, and in IITPAVE software, they are mechanistic-empirical methods. The following data were collected from the coastal village, namely, Chettikulam, Tirunelveli District, Tamil Nadu, India, which connects the places from Kanyakumari (K) to Trivandrum (T). The location of the project site is shown in Figure 1.

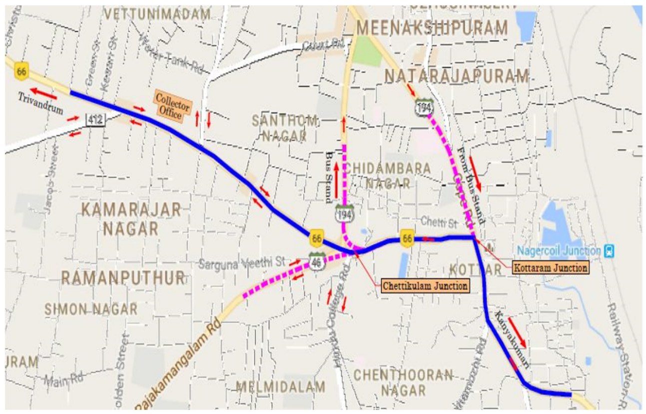

Fig 1. Location of Project Site on Google Map

2.2 Data Collection

Classified Volume Count Surveys: The different classes or types of vehicles travelling on the road at the project site were carried out manually by counting the number of vehicles travelling on the project site in both directions of the road for a time of 24 hours.

Axle Load Survey : The axle load survey was carried out on normal working days, continuously for 24 hours on the project road. The axle load survey is carried out for vehicles whose gross weight is more than 3.0 tonnes, by using two portable axle load pads to measure the weight of all axles of vehicles travelling on the project road. All the traffic surveys and data collection were done in both directions, i.e., the traffic moving from Kanyakumari to Trivandrum (K-T) and from Trivandrum to Kanyakumari (T-K).

Intersection Turning Movement Survey: At the intersections, a manual turning volume count of vehicles was carried out for a period of 12 hours, covering morning and evening peaks, in order to assess the current turning movement and to plan for junction improvement.

Subgrade Soil Investigation: A subgrade soil sample of approximately 20kg was collected from the test pit along the project road and tested in the laboratory. Some of the tests performed were grain size distribution, liquid limit, plastic limit, and soaked California Bearing Ratio (CBR) tests. The CBR is one of the important tests performed on the soil, which determines the total pavement thickness.

2.3 Flexible Pavement Design by IRC 37-2012

The data collected from the traffic details are used to estimate the design traffic in terms of million standard axles (msa). The design traffic is estimated using Equation(1) as suggested in IRC 37-2012.

$$N = \frac{365\left[(1+r)^n - 1\right]}{r} A \times D \times F$$

Where

N = Cumulative number of standard axles to be catered for in the design in msa.

A = Initial traffic in the year of completion of construction in terms of the number of Commercial Vehicles per Day (CVPD).

D = Lane distribution factor

F = Vehicle Damage Factor (VDF).

n = Design life in years

r = Annual growth rate of commercial vehicles in decimal

The traffic in the year of completion is estimated using the following formula: $A = P\,(1 + r)^{x}$

Where P = The number of commercial vehicles as per the last count. x = Number of years between the last count and the year of completion of construction.

Based on the estimated design traffic in terms of million standard axles (msa) and the CBR value of the soil sample, pavement crust thickness is adopted as per the design catalogue given in IRC 37-2012. The pavement design catalogue applicable to the present research is shown in Figure 2.

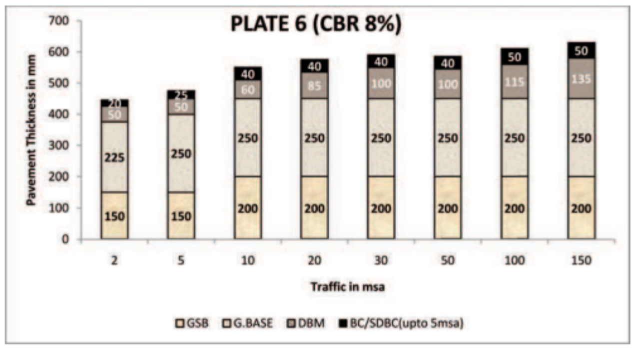

Fig 2. Pavement Design Catalogue for CBR 8% as Per IRC 37-2012

2.4 Fatigue Failure Criteria

The pavements are designed to fit the fatigue model as suggested in IRC 37-2012. The relationship between the CBR and resilient modulus are given in Equations (2) and (3). The code suggests the fitting of fatigue and rutting failure models. In the first case, computed strains in 80 percent of the actual data were higher than the limiting strains predicted by the model, termed the 80% reliability level, and in the second case, corresponding to 90% reliability values for the traffic, are shown in Equations (4) and (5) respectively.

$$M_R = 10 \times CBR \qquad \text{For CBR} < 5\% \tag{2}$$

$$M_R = 17.6 \times CBR^{0.64} \text{ For CBR} > 5\% \tag{3}$$

Where

M_R= Resilient modulus of subgrade soil,

CBR= California bearing ratio of soil sample.

$$N_f = 2.21 \times 10^{-04} \times (1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \tag{4}$$

$$N_f = 0.711 \times 10^{-04} \times (1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \tag{5}$$

Where

N_f= Fatigue life in number of standard axles

ε_t= Maximum tensile strain at the bottom of the bituminous layer

M_R= Resilient modulus of bituminous layer

2.5 Rutting Failure Criteria

The rutting is the permanent deformation usually occurring longitudinally along the wheel path of the vehicle. This is also caused by shear deformation under heavy traffic loads and higher temperatures. Similar to the fatigue models, rutting models were predicted for 80% and 90% reliability levels and are given in Equations (6) and (7) respectively.

$$N = 4.1656 \times 10^{-08} \times [1/\varepsilon_v]^{4.5337} \quad (6)$$

$$N = 1.41 \times 10^{-08} \times [1/\varepsilon_v]^{4.5337} \quad (7)$$

Where

N= Number of cumulative standard axles

ε_v= Vertical strain in the subgrade

2.6 Design Analysis of Pavement by IITPAVE

The design of the flexible pavement carried out using IRC 37-2012 is analysed using the IITPAVE software, which uses the mechanistic-empirical approach. The various data, such as layer thickness, Poisson's ratio, resilient modulus of the materials, wheel load, tyre pressure, and distance between the wheels, are given as input parameters to calculate critical stress and strains at the different locations of the pavement layer. Horizontal tensile strain at the bottom of the bituminous layers and vertical compressive strain at the top of the subgrade layers are considered critical parameters to limit the development of cracking and rutting in the bituminous and non-bituminous layers of pavement. The allowable tensile and compressive strains at the critical locations of the pavement are estimated using the empirical equations mentioned in the IRC 37- 2012 guidelines and are compared with the actual tensile and compressive strains as computed by IITPAVE software. If the actual tensile and compressive strain values are lower than the allowable strain values, then the design is considered 'Safe'.

3 Results and Discussion

The traffic survey, soil survey, and other data were collected from the project site. The values or counts on the number of vehicles, type, and class of vehicles obtained from the survey data are suitably converted to get the equivalent unit, namely, Passenger Car Unit (PCU). The survey data and the converted PCU units are shown in Table 1.

Out of the above number of vehicles travelling on the project site, only the commercial vehicles, which were carrying more than 3.0 tonne capacity, were considered for the analysis of design. The loads carried by the vehicles are individually measured at the project site using portable axle load pads (weighing pads). The different types of vehicles and the number of vehicles considered for the pavement design are shown in Table 2.

3.1 Calculation of Design Traffic in Million Standard Axle (msa)

The design traffic in terms of msa is calculated as shown below:

Type of carriageway= 2lanes.

Number of commercial vehicles (P) =818

Annual average traffic growth rate (r) =5%

Traffic in the year of completion, A=P (1+r) ^{n}

=818(1+0.05$)^{2}$

= 901 CVPD (Commercial Vehicles per Day)

Vehicle Damage Factor=3.5

CBR of the soil sample= 8.0%

Lane distribution factor=0.5

All the above-mentioned values are substituted in Equation (1) to get the design traffic in msa, and the obtained value of design traffic is 19 msa.

3.2 Design of Pavement Crust Thickness

The soil collected from the project site was subjected to various tests in the laboratory, such as grain size distribution, liquid limit, plastic limit, and CBR tests. The CBR value of the soil obtained was 8.0%. Using the pavement catalogue charts suggested

Table 1. Traffic Survey Details and Equivalent Passenger Car unit (PCU)

Type of Vehicle		Project Road Direction		Total Number of Vehicles
		Kanyakumari to Trivandrum (K-T)	Trivandrum to Kanyakumari (T-K)	
Passenger Vehicles				
Two Wheelers		7036	5941	12977
Auto Rickshaw		1171	1007	2178
Car/Jeep/Van		2474	2245	4719
Bus	Mini Bus	63	52	115
	School Bus	141	145	286
	Government Bus	667	615	1282
	Private Bus	152	125	277
Toll Exempted Vehicles	Government Car/Jeep/Van	26	23	49
	Ambulance	15	12	27
	Government Trucks	2	1	3
Goods Vehicles				
Mini Light commercial Vehicle (LCV)		475	457	932
Light Commercial Vehicles (LCV)		212	198	410
Two Axle Truck		100	96	196
Three Axle Truck		43	41	84
Multi Axle Vehicles		7	5	12
Tractor		4	5	9
Tractor-trailers		3	1	4
Slow Moving Vehicles				
Cycle		13	14	27
Cycle Rickshaw		0	0	0
Animal Drawn Vehicles		0	0	0
Total Number of Vehicles		12604	10944	23548
Total Passenger Car Unit (PCU)		12820	11303	24123

Table 2. Number of Commercial Vehicles Considered for the Design

Type of Vehicles	Number of Vehicles
LCV	129
Two axle Trucks	54
Three axle Trucks	27
Multi axle Trucks	3
Bus	605
Total Vehicles	**818**

in IRC 37-2012 and as shown in Figure 2, the pavement crust thickness for the project site was obtained by considering a design traffic of 19 msa (rounded off to 20 msa) and a CBR value of 8.0%. The total thickness and the thicknesses of different layers of pavement are shown in Table 3.

3.3 Calculation of Resilient Modulus of Elasticity (M_R)

Since the obtained value of CBR of the soil sample was 8.0%, Equation (3) is applicable for the present design. The resilient modulus of elasticity of subgrade soil is found by substituting the relevant data, and the obtained value of M_R is 66.60 MPa.

Table 3. Design Pavement thickness based on IRC37-2012 for 8.0% CBR Value

Type of Layer	Name of Layer	Thickness of Layer (mm)
Bituminous Layers	Bituminous Concrete (BC)	40
	Dense Bituminous Macadam (DBM)	85
Non-Bituminous Layers	Granular Base Course	250
	Granular Sub Base course	200
Total Pavement Thickness		575

3.4 Determination of Horizontal Tensile Strain (Fatigue Model)

The horizontal tensile strain at the bottom of the bituminous layer is estimated using Equation (4) for 80% reliability by substituting the values as mentioned below:

N_f = Fatigue life, 19msa (value obtained from the traffic survey of the project road)

E_t = Maximum tensile strain

M_R = Resilient modulus, 1700 MPa (for Viscosity Grade (VG) 30 bitumen at 35^0C, as per IRC 37-2012)

$E_t = 3.01735 \times 10^{-04}$

The strain value represented as Et = 301.735x 10-06

3.5 Determination of Vertical Compressive Strain (Rutting Model)

The vertical compressive strain at the bottom of the subgrade layer is estimated using Equation (6) for 80% reliability by substituting the values as mentioned below:

Where,

N = cumulative standard axles, 19msa

E_v = Vertical strain

$E_v = 5.83985 \times 10^{-4}$

The strain value represented as $E_v = 583.985 \times 10^{-6}$

3.6 Results of Pavement Analysis Obtained from IITPAVE

The various data as outlined in the methodology are entered into the IITPAVE software, and the obtained results are shown in Figures 3 and 4, respectively. The results of the horizontal tensile strain and vertical compressive stain values obtained from IRC 37-2012 and IITPAVE are shown in Table 4, respectively.

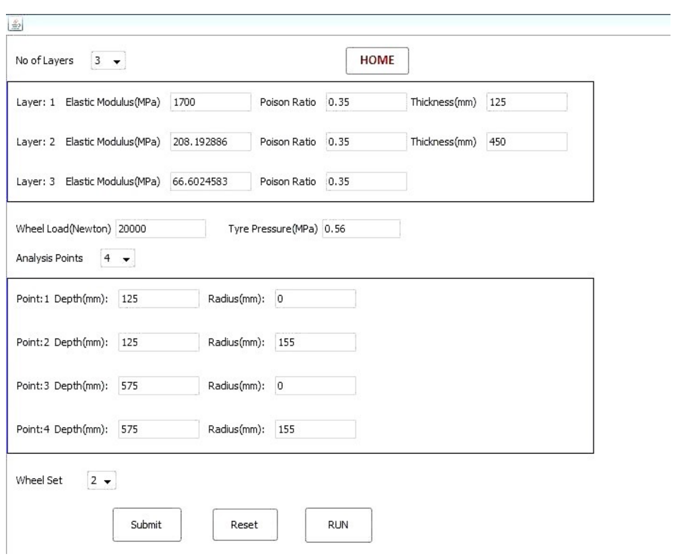

Fig 3. Input of Data in IITPAVE Software

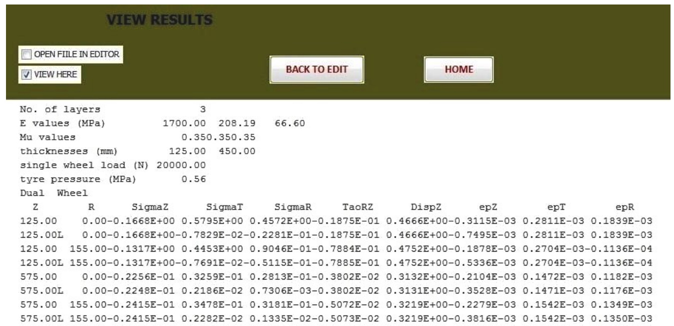

Fig 4. Output in IITPAVE Software

Table 4. Comparison of Horizontal Tensile and Vertical Compressive Strain Values obtained from IRC 37-2012 and IITPAVE Software

Type of Strain	Allowable Strain Values from IRC 37-2012	Actual Strain Values from IIT-PAVE Software	Remarks
Horizontal Tensile Strain	301.735 x 10^{-06}	270.4 x 10^{-6}	Safe
Vertical Compressive Strain	583.985 x10^{-6}	381.6 x 10^{-6}	Safe

From Table 4, it is observed that the actual horizontal tensile strain and vertical compressive strain values obtained from IITPAVE on the surface of bituminous and subgrade layers of pavement are less than the allowable strain values obtained from IRC 37-2012. This shows that the designed pavement thickness of 575 mm is safe enough to carry a traffic load of 19 msa during its service life.

Notably, most of the previous research adopted either an empirical or mechanistic- empirical method for the analysis of pavement design, whereas the present research study adopts both methodologies. The comparative analysis of different parameters of pavement design, namely, the thickness of pavement, tensile strain, and compressive strain values obtained in the present research, with the findings of other research based on mechanistic-empirical methods, shows a reasonable degree of convergence. The pavement thickness of 575 mm obtained in the research can be readily implemented in actual road construction. Overall, the present research provides a more direct solution suitable for real-world applications based on IRC37-2012 and IITPAVE methodologies.

4 Conclusion

The following are the conclusions drawn from the real-time research:

- The laboratory investigation of the soil sample yielded California Bearing Ratio of the soil sample was 8.0%, and the computation of the traffic survey details yielded the design traffic as 19 msa.
- Based on IRC37-2012, the pavement crust thickness is designed based on the CBR value and design traffic. A total pavement thickness of 575 mm is obtained with a pavement composition of Bituminous concrete (BC) of 40 mm, Dense Bituminous Macadam (DBM) of 85 mm, Granular Base Course of 250 mm, and Granular Sub Course (GSB) of 200 mm.
- Based on IRC 37-2012, the horizontal tensile strain at the bottom of the bituminous layer, based on the fatigue model, is computed, and the obtained value is 301.735 x 10-06.
- Based on IRC 37-2012, the vertical compressive strain at the top of the subgrade layer, based on the rutting model, is computed, and the obtained value is 583.985 x 10-6.
- The computation of the horizontal tensile and vertical compressive strain from the IITPAVE software yielded values of 270.4 x 10-6and 381.6 x 10-6respectively.
- On comparing the results obtained from IRC 37-2012 and IITPAVE software, the actual stain values are less than the allowable strain values in the pavement. This shows that the design pavement thickness of 575 mm is safe enough to carry the design traffic.
- The analysis of the pavement design from IRC 37-2012 and IITPAVE ensures a safe design.
- Since the present research is based on real-time data, the obtained value of pavement thickness can be readily adopted in actual road construction. In addition, it serves as a template for designing the pavement under similar conditions.

- The design also paves the way for economical pavement cross-section, as it is based on both empirical and mechanistic-empirical methods. This approach leads to cost-effective road construction.
- After the implementation of the design, continuous monitoring and evaluation of its performance are recommended, simultaneously addressing the issues of sustainability and environmental impact assessment. This helps to address the unforeseen challenges in road construction projects.

Acknowledgement

The authors greatly acknowledge the contributions of M/s India International Infrastructure Engineers Pvt. Ltd., Bangalore, and Ms. Rajeshwari Madihalli, Postgraduate student of M Tech (Highway Technology) at Government Sri Krishnarajendra Silver Jubilee Technological Institute, Bangalore.

References

1) Karimi MN, Mallick RB. Flexible Pavement Instrumentation: A State-of-the-Art Review. *Journal of Transportation Engineering*. 2023;149(2). Available from: https://doi.org/10.1061/JPEODX.PVENG-1175.
2) Hassani A, Taghipoor M, Karimi MM. A state of the art of semi-flexible pavements: Introduction, design, and performance. *Construction and Building Materials*. 2020;253:119196. Available from: https://doi.org/10.1016/j.conbuildmat.2020.119196.
3) Lin T, Ishikawa T, Maruyama K, Tokoro T. Pavement design method in Japan with consideration of climate effect and principal stress axis rotation. *Transportation Geotechnics*. 2021;28:100552. Available from: https://doi.org/10.1016/j.trgeo.2021.100552.
4) IRC: 37. Tentative guidelines for design of flexible pavements. Indian Road Congress. New Delhi, India. New Delhi, India. Indian Road Congress. .
5) Hafezzadeh R, Autelitano F, Giuliani F. Asphalt-based cold patches for repairing road potholes – An overview. *Construction and Building Materials*. 2021;306:124870. Available from: https://doi.org/10.1016/j.conbuildmat.2021.124870.
6) Shaikh SG, Wadekar AP. Systematic Evaluation and Analysis of Bituminous Road Pavement Failure. *Journal of Physics: Conference Series*. 2021;1964(7):072016. Available from: https://doi.org/10.1088/1742-6596/1964/7/072016.
7) Yadav D, Khode BV, Ghodmare S. Temperature Variation of Pavement Design In India. *SSRN Electronic Journal*. 2022;7. Available from: https://doi.org/10.2139/ssrn.4136538.
8) Kumar ANM, Kumar PP. Analysis of flexible pavement using IITPAVE software and economic analysis of the project using HDM-4 software. *International Journal for Research in Applied Science & Engineering Technology*. 2020;8(5):2651–2657. Available from: https://doi.org/10.22214/ijraset.2020.5443.
9) Ling M, Zhang J, Fuentes L, Walubita LF, Lytton RL. A mechanistic framework for tensile fatigue resistance of asphalt mixtures. *International Journal of Fatigue*. 2021;151:106345. Available from: https://doi.org/10.1016/j.ijfatigue.2021.106345.
10) Sahis MK, Biswas PP. Optimization of Bituminous Pavement Thickness using Mechanistic-Empirical Strain-Based Design Approach. *Civil Engineering Journal*. 2021;7(5):804–815. Available from: https://doi.org/10.28991/cej-2021-03091691.
11) Maqbali LA, Ragab O. A Review of Software in Flexible Pavement Design. *Sustainability in Environment*. 2021;6(2):27. Available from: https://doi.org/10.22158/se.v6n2p27.
12) Mensahn ES, Wada SA, Lugeiyamu L. Roadway pavement design methods, Structural approaches and relevant computer algorithms: A critical. *International Journal of Transportation Engineering and Technology*. 2022;8(1):13–23. Available from: https://doi.org/10.11648/j.ijtet.20220801.12.
13) El-Ashwah AS, El-Badawy SM, Gabr AR. A Simplified Mechanistic-Empirical Flexible Pavement Design Method for Moderate to Hot Climate Regions. *Sustainability*. 2019;13(19):10760. Available from: https://doi.org/10.3390/su131910760.
14) Gonfa LG, Quezon ET, Geremew A. experimental study on application of marble waste as conventional aggregate for base course materials. *Journal of Civil Engineering*. 2020;11(2):144–163. Available from: https://doi.org/10.1016/j.matpr.2022.09.065.
15) Kumar K, Saraswat S, Arora R, Singh V, Dharmveer, Mishra L, et al. Experimental investigation on fly ash as sand replacement in flexible pavement: A case study. *Materials Today: Proceedings*. 2022;69:387–391. Available from: https://doi.org/10.1016/j.matpr.2022.09.065.
16) Kumar A, Digvijay, Kumar R, Prabhat, Khan S, Kumar S. Analysis of Flexible Pavement using IIT-PAVE Software. *European Chemical Bulletin*. 2023;12(4). Available from: https://doi.org/10.48047/ecb/2023.12.si4.1280.