International Journal of Recent Research and Review, Vol. XVII, Issue 2, June 2024
ISSN 2277 – 8322

EVALUATING THE ECONOMIC EFFICIENCY OF PAVEMENT DESIGN METHODOLOGIES

Sovik Jain[1], Deepak Mathur[2]
Department of Civil Engineering (Transportation),
Kautilya Institute of Technology & Engineering, Jaipur
[1]sovikjain17698@gmail.com, [2]mathurdeepak1507@gmail.com

Abstract: The development of a robust road network is pivotal for fostering balanced economic growth within a nation, connecting urban hubs with rural areas and commercial centers. This study investigates most economical method of design of flexible pavements in Jaipur compared different methods like Group Index (GI), California Bearing Ratio (CBR), and Indian Roads Congress (IRC) methods, this research expands the analysis by incorporating the Mechanistic-Empirical (IIT Pave) method.

Focusing on a specific road project – a stretch connecting Sitapura and Chaksu in Jaipur, India. The findings reveal significant variations in pavement thickness across the methods. The IRC method results in the thickest pavement, followed by the CBR and GI methods. The IIT Pave method yield the thinnest pavements. Construction cost analysis demonstrates that the IIT-PAVE method offers the most economical design, while the IRC method proves to be the least economical. A cost analysis of the IIT-Pave method for flexible pavement compared to rigid pavement construction revealed that the IIT-Pave method offers approximately 50% lower material costs.

Keyword: IRC, CBR, IIT-PAVE, Group Index, Flexible Pavement, Rigid Pavement.

1. Introduction

1.1 General

Importance of Roads

Transportation is the backbone of modern life, and highway engineering plays a vital role in designing and building efficient road systems.

Economic Development: Roads facilitate the movement of goods and services, enabling trade and commerce to flourish. Efficient transportation networks connect businesses to markets, raw materials to factories, and finished products to consumers.

Social Benefits: Roads connect communities, allowing people to access essential services like healthcare, education, and employment opportunities.

Accessibility and Emergency Response: Good road infrastructure ensures timely access to emergency services like ambulances, fire trucks, and police vehicles. This can save lives and minimize damage during disasters.

Regional Development: Roads promote balanced regional development by opening up remote areas for economic activity and tourism.

National Security: A well-maintained road network is crucial for national security.

1.2 Objectives of the Study

- Design a flexible pavement structure using each of the four methods: Group Index, CBR, IRC and IIT-PAVE methods.
- Evaluate the pavement thickness obtained from each method.
- Compare the material quantities required for each design option.
- Estimate the construction costs associated with each pavement design.
- Comparison of cost of material used in flexible pavement and rigid pavement.

2. Literature Review

Baskaran et. al. (2023) [1] investigation reveal that India prioritizes expanding its road network, primarily using flexible pavements for low to medium traffic roads. This study investigates the influence of California Bearing Ratio (CBR) on flexible pavement design for a specific road link in Tirunelveli City with bituminous surfacing on a granular base and sub-base. Effective subgrade CBR values of 9% to 15% are considered. Traffic data is collected using an automated vehicle classifier system

Ventakcharyulu&Viswanandh (2021) [2] investigation reveal that with growing traffic demands, inadequate road infrastructure creates discomfort and safety hazards. This study tackles the improvement of KKY District Road (Karimnagar KamareddyYellareddy), currently plagued by unevenness from heavy vehicles.

Pospelov et. al. (2021) [3] tackles the challenges of building roads in permafrost regions, specifically Russia's Arctic. The harsh climate drives up construction costs and limits access, especially for heavy equipment. The research analyzes how costs vary across different climate zones within Russia.

El-Ashwah et. al. (2021) [4] This study tackles the complexities of flexible pavement design by proposing a streamlined Mechanistic-Empirical (M-E) method named "ME-PAVE." Inspired by established guidelines, ME-PAVE simplifies the process by using only two key temperatures to adjust asphalt properties for rutting and fatigue analysis, eliminating the need for extensive hourly climate data.

Dokku et al (2020) [5] study proposes a new model for rut depth in bituminous layers of pavements. It leverages rut depth data from AASHTOWare Pavement ME Design software and incorporates factors like traffic volume (annual average daily truck traffic - AADTT), vehicle speed, and bituminous layer thickness.

Research Gap

- There's a limited comparison of different pavement design methods (e.g., ME vs. CBR) to identify optimal approaches for various scenarios.
- The review doesn't delve into how new technologies (e.g., self-healing materials, advanced sensors) might impact future pavement design and construction.

3.Study area, data collection & theory

General

Given Jaipur's captivating blend of geography and transportation systems, this thesis focuses on a specific area within the city (Fig.3.1). The chosen location is a road stretch connecting Sitapura and Chaksu (as illustrated in Fig. 3.2).

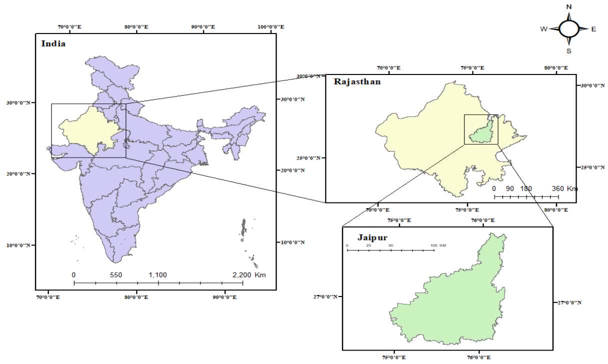

Fig. Location map of the study area

Ideal Pavement Requirements

The theoretical underpinnings of pavement design translate into a set of desired characteristics for an ideal pavement. These characteristics represent the goals that engineers strive to achieve when designing and constructing pavements. Here's a breakdown of these key functionalities:

- **Structural Strength and Load Distribution:** The pavement must be thick enough to distribute the weight (wheel load stresses) from traffic across a larger area. **Durability and Resilience:** The pavement needs to be structurally strong to withstand various stresses – traffic loads, environmental factors (temperature variations, moisture), and even occasional overloads.
- **Skid Resistance:** A safe pavement provides adequate friction to prevent vehicles from skidding, especially during wet or icy conditions.
- **Ride Quality and Comfort:** A smooth and even pavement surface is essential for user comfort, especially at high speeds.
- **Noise Reduction:** Ideally, pavements should generate minimal noise from traffic..
- **Dust Control:** A dust-proof surface is crucial for maintaining good visibility and traffic safety. Proper material selection, surface treatments, and regular maintenance can help minimize dust generation.
- **Imperviousness:** A watertight pavement prevents water infiltration into the lower layers.
- **Cost-Effectiveness:** While achieving the desired functionalities is essential, pavements should also be cost-effective.

4 methodology

4.1 General

This study proposes a comprehensive comparison of four prominent design methods for flexible pavements and rigid pavement:

(1) Group Index (GI) Method (2)California Bearing Ratio (CBR) Method

(3) Indian Roads Congress (IRC) Method (4)Mechanistic Empirical Method

4.2 Factors to be considered in pavement design

Design wheel load, Subgrade soil, Design life ,Climatic factor

Pavement component materials, Environment factors

Drainage ,Road geometry

4.2.1 Design Wheel Load

In the pavement design the following wheel load factor are considered:

- Maximum wheel load
- Contact pressure
- Equivalent single wheel load (ESWL)
- Repetition of loads

4.3 Group Index (GI) Method

The Group Index (GI) method is a widely used empirical approach for designing flexible pavements. It offers a relatively simple and straightforward way to determine the required pavement thickness based on the physical properties of the subgrade soil (Huang et. al. 2009).

The GI value is given as in Eq.

GI = 0.2a + 0.005ac + 0.01bd ………..(4.1)

Where, a = F – 35, b = F – 15, c = W_L – 40 and d = I_P – 20. F is percentage of fraction of soil passed through 75 μm, W_L is liquid limit and I_P is plastic index (W_L – W_P).

Table 4.1 Categories wise volume of traffic is divided

Sr. No.	Traffic Volume (Commercial Vehicle)	No. of Vehicle per day
1	Very Low	Less than 50
2	Low	50 to 250
3	Medium	250 to 500
4	Heavy	500 to 750
5	Very Heavy	Over 750

Table 4.2 Types of Subgrades

Sr. No.	GI Value	Types of Subgrades
1	0 to 1	Excellent
2	2 to 4	Good
3	5 to 9	Fair
4	10 to 20	Poor

4.4 California Bearing Ratio Method

The California Bearing Ratio (CBR) method is an empirical approach for designing flexible pavements. It relies on the CBR value, a measure of the strength and bearing capacity of subgrade and pavement materials, to determine the required thickness of each pavement layer (Choudhary et. al. 2014).

Calculate the CBR value using the following formula in Eq. 4.4 and 4.5.

$CBR_{2.5} = \frac{P_{2.5}}{1370} \times 100$ …………….(4.4)

$CBR_{5.0} = \frac{P_{5.0}}{2055} \times 100$……………….(4.5)

Select the higher value obtained from the two calculations as the final CBR of the soil subgrade specimen.

- The total thickness of the pavement can be calculated using Eq. 4.6.

$T = \sqrt{\frac{1.75P}{CBR\%} - \frac{P}{\pi p}}$…………………….(4.6)

Where, P maximum wheel load, p is contact pressure or tyre pressure.

Table 4.3 Traffic Classification as per IRC:37-2012

Curve	No. of commercial vehicles per day exceeding 3 tonne laden weight
A	0-15
B	15-45
C	45-150
D	150-450

E	450-1500
F	1500-4500
G	More than 4500

4.5 Indian Road Congress (IRC) Method

The thickness of pavement is determined by considering the California Bearing Ratio (CBR) of the subgrade and the total number of repetitions of standard axle loads.According to IRC:37-2012, the design of flexible pavement should be based on the cumulative number of standard axle load repetitions expected over the pavement's design life, rather than being solely dependent on the number of commercial vehicles per day.The cumulative number of standard axle load repetition throughout the design life of road is calculated by using Eq.4.7.

$$N_S = \left(\frac{365\ ADF\ [(1+r)^n - 1]}{r}\right) \ldots\ldots\ldots\ldots..(4.7)$$

4.6 Mechanistic Empirical Method

In this research, pavement lifespan is determined using a mechanistic-empirical approach. This method considers the pavement to have reached its end-of-life when either fatigue cracking covers 20% of the surface area or rutting reaches a critical depth of 20 millimeters, whichever occurs first (IRC:37-2018). IIT-PAVE, a software program based on mechanistic-empirical principles, is employed to analyze pavement responses and predict performance. This software utilizes a multi-layer theory to simulate the structural behavior of flexible pavements.

Table 4.6 Indicative value of VDF

Initial Traffic Volume in Terms of CVPD	Terrain	
	Rolling/Plain	**Hilly**
0-150	1.7	0.6
150-1500	3.9	1.7
>1500	5.0	2.8

Source: IRC:37-2018

4.7 Resilient Modulus of Bituminous Mix

IRC:37-2018 emphasizes using actual properties of the field-designed DBM/BM mix for pavement design. These properties must comply with the maximum limits specified in Table 4.8 for the chosen mix type (unmodified binder DBM/BM) and an average annual pavement temperature of 35°C.

Table 4.7 Summary of Bituminous Layer

Sr. No.	Traffic Level	Surface Course		Base/Binder Course	
		Mix Type	**Bitumen Type**	**Mix Type**	**Bitumen Type**
1	>50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB5.	Crumb rubber modified bitumen		
		BC	With modified bitumen		
2	20-50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	Modified bitumen or VG40		
3	<20 msa	BC/SDBC/PMC/MSS/ Surface Dressing (besides SMA, GGRB and BC with modified binders)	VG40 or VG30	DBM/BM	VG40 or VG30

5: RESULT & DISCUSSION

5.1 General

In this we will discuss the calculation and its results of four methods: Group Index method, CBR method, IRC method and Mechanistic Empirical (IIT Pave) method of flexible pavement design.

5.2 Design of Flexible Pavement using Group Index Method

5.2.1 Determining the liquid limit using Casagrande method

liquid limit of the soil at 25 number blow is 47%.

W_L = 47%

5.2.2 Calculation of thickness

The value of Group Index can be calculated using Eq.4.3 which can be show below,

GI = 0.2a + 0.005ac + 0.01bd

GI = 10.605

T = 60 cm

5.3 Design of Flexible Pavement using CBR Method

5.3.1 Determine the CBR value

The result of the CBR test on subgrade can be seen in table 5.2. From the fig.5.2, the load corresponding to 2.5mm and 5.0mm penetration is 64 kg and 110 kg respectively.

- **Calculate the CBR value corresponding to 2.5mm penetration.**

$CBR_{2.5} = \frac{P_{2.5}}{P_S} \times 100$ $CBR_{2.5} = \frac{64}{1370} \times 100 = 4.67\%$

$CBR_{2.5}$ = 4.67%

- **Calculate the CBR value corresponding to 5.0mm penetration.**

$CBR_{5.0} = \frac{P_{5.0}}{P_S} \times 100$ $CBR_{5.0} = \frac{110}{2055} \times 100$

$CBR_{5.0}$ = 5.35%

The CBR value is maximum of above two values, therefore

CBR = 5.35%

5.3.2 Calculation of thickness of pavement

As per the IRC: 37-2012, Maximum wheel load consider for design if data is not available is 5100 kg.

The average commercial vehicles per day at Sitapura and Chaksu is 1578 and 1667 respectively. For the design purpose let's we consider maximum of above two value, therefore maximum commercial vehicle per day exceeding 3 tonne laden weight is 1667.

The present traffic (P) = 1667,Consider growth rate (r) = 7.5% ,Design life (n) = 20 years

The future traffic

$F = P(1+r)^n$, $F = 1667\ (1 + 0.075)^{20}$

F = 7081

T = 62 cm

Similarly, the thickness of pavement is calculated upto sub-base and base and it come to 34cm and 11cm respectively.

Thickness of surface course (T_s) = 11cm ,Thickness of base course (T_b) = 34-11 = 23 cm

Thickness of sub-base course (T_{sb}) = 62-34 = 28 cm

5.4 Design of Flexible Pavement using IRC Method

- Traffic Flow (A) = 1667 CVPD, Growth rate of traffic (r) = 7.5%
- Design life (n) =20 years, Vehicle damage factor (F) = 2.5 as per the IRC:37 is taken if data is not available.
- Lane distribution factor (D) = 0.75 (our road is dual carriage way two lane road)

5.4.1 Calculation of Standard axle load (N_s)

$N_S = \left(\frac{365\ ADF\ [(1+r)^n - 1]}{r}\right)$

N_S = 49msa i.e. million standard axles

5.5 Design of Flexible Pavement using Mechanistic Empirical Method

Calculation of resilient modulus of subgrade (Support) soil

CBR = 5.35% > 5% therefore using Eq.4.17

$M_{RS} = 17.6 \times (CBR)^{0.64}$ $M_{RS} = 17.6 \times (5.35)^{0.64}$

M_{RS} = 51.48 MPa

Calculation of resilient modulus of granular subgrade

$M_{R\text{-}granular} = 0.2 \times h^{0.45} \times M_{RS},$ $M_{R\text{-}granular} = 0.2 \times (280)^{0.45} \times 51.48$

$M_{R\text{-}granular}$ = 130 MPa

5.5.1 Computation of allowable horizontal tensile strain at the bottom of bituminous layer

ε_t = 0.0001790 or 179× 10^{-6}

5.5.2 Computation of allowable compressive vertical strain on subgrade

From Eq. 4.14 for 90% reliability

$N_R = 4.1656 \times 10^{-8} \times [\frac{1}{\varepsilon_V}]^{4.5337}$

$\boldsymbol{\varepsilon_V = 474.12 \times 10^{-6}}$

Table 5.1 Input of data in IIT Pave Software

Sr. No.	**Parameters**	**Values**			
1	**No. of layers**	4			
2	**Layers**	SC	BC	SBC	SGC
	E value (MPa)	3000	800	130	51.48
	Thickness (mm)	100	160	250	-
	Poison Ratio	0.35	0.35	0.35	0.35
3	**Tyre Pressure (MPa)**	0.56			
4	**Dual Wheel (N)**	20000			

Table 5.2 Summary of IIT PAVE design

1	Cumulative Standard Axle (MSA)	Design life	49 MSA
2	Effective Subgrade CBR%	-	5.35%
3	Thickness of layers	Bituminous	100 mm
		RAP with Emulsion	160 mm
		GSB	250 mm
4	MR of Subgrade	-	51.48 MPa
5	MR of Rap Stabilised with Emulsion SS2		800 MPa
6	MR of Bituminous Layer	(DBM + BC)	3000 MPa
7	Percentage of air Void	V_a	3.5 %
8	Percentage of bitumen	V_{be}	11.5 %
9	-	M	0.371
10	-	C	2.350
Fatigue Model			
11	Allowable Horizontal Strain	ε_t	0.179×10^{-3}
Rutting Model			
13	Allowable Vertical Strain	ε_V	0.474×10^{-3}
		BC	40 mm
		DBM	60 mm
Computation of strain using IIT PAVE			
14	Horizontal Tensile Strain	Safe	0.108×10^{-3}
15	Vertical Strain	Safe	0.412×10^{-3}

5.6 Comparison of thickness of various layer calculated by different flexible pavement methods

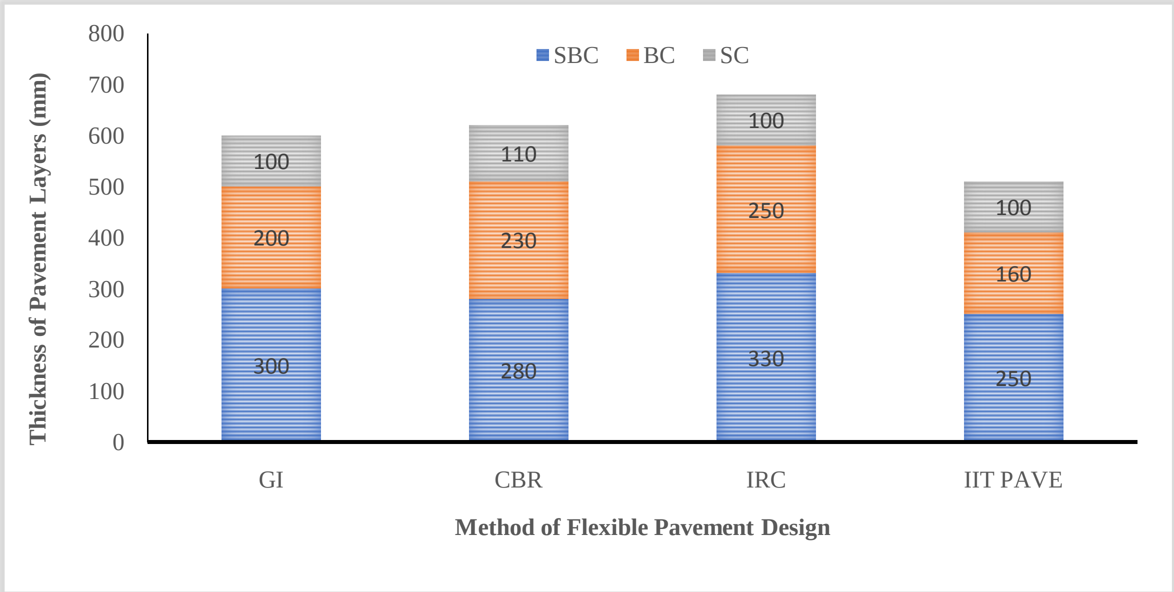

Fig. 5.1 Thickness of Pavement Layers by different Methods

5.7 Comparison of various methods by material cost

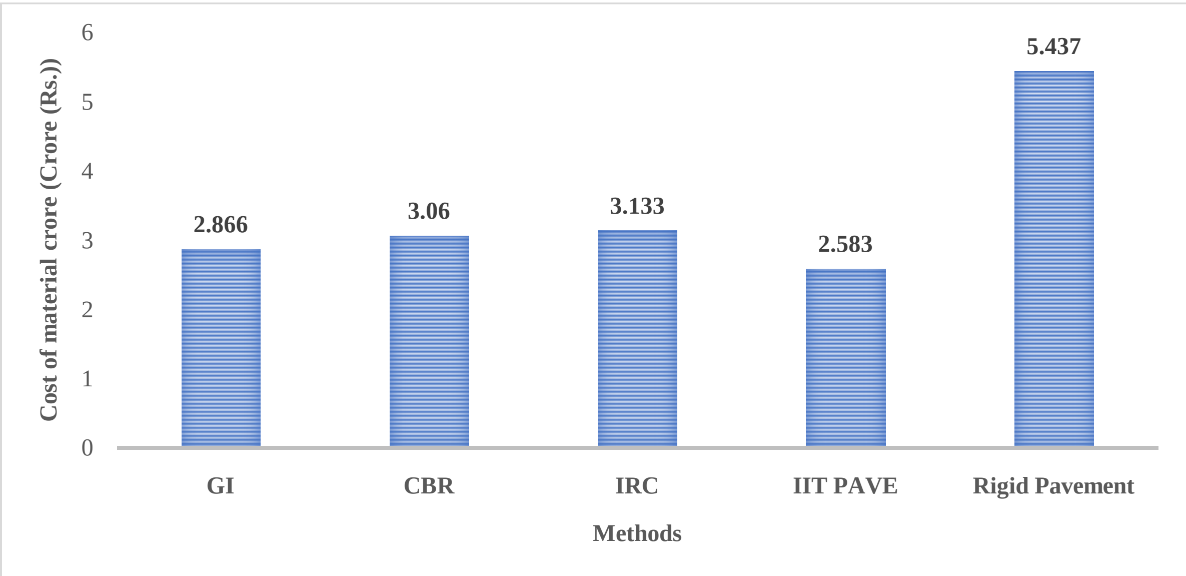

Fig. 5.2 Cost of material for flexible and rigid pavement of 1KM road

CONCLUSION

This study compared four design methods for flexible pavements on a road section connecting Sitapura and Chaksu in Jaipur, India. The analysis focused on Group Index (GI), California Bearing Ratio (CBR), Indian Roads Congress (IRC) and IIT-PAVE methods.

The results revealed that IIT Pave emerged as the most sophisticated approach, considering traffic patterns, material properties, and environmental factors in detail.

A cost analysis of the IIT-Pave method for flexible pavement compared to rigid pavement construction revealed that the IIT-Pave method offers approximately 50% lower material costs.

FUTURE SCOPES

- Future research could explore the long-term performance implications of using each design method for this specific road section..
- Conducting a sensitivity analysis could help understand how variations in traffic volume, subgrade strength, and material costs affect the optimal design method.
- Research into novel materials like high-modulus asphalt (EME2) that can lead to thinner, stronger pavements and self-healing asphalt that repairs minor cracks automatically.
- Designing pavements that are more resilient to extreme weather conditions.

REFERENCES

1. Baskaran, V., Subash, R. C., Sankar, V. S., & Blessy, K. (2024). The influence of CBR value on the cost of optimal flexible pavement design. Sustainability, Agri, Food and Environmental Research, 12.
2. VenkatCharyulu, S., &Viswanadh, G. K. (2021). Flexible pavement design of district road. In E3S Web of Conferences (Vol. 309, p. 01210). EDP Sciences.
3. Pospelov, P., Korochkin, A., &Evtyukov, S. (2021). Pavement design and construction in the Arctic climate. Transportation Research Procedia, 57, 489-494.
4. El-Ashwah, A. S., El-Badawy, S. M., & Gabr, A. R. (2021). A simplified mechanistic-empirical flexible pavement design method for moderate to hot climate regions. *Sustainability*, *13*(19), 10760.
5. Dokku, B., Savio, D., Nivitha, M. R., & Krishnan, J. M. (2020). Development of rutting model for Indian highways based on rut depth simulations from AASHTOWare pavement ME design software. Journal of Transportation Engineering, Part B: Pavements, 146(2), 04020013.
6. Code, I. S. IS 2720 (Part 5)–1985. Determination of liquid limit and plastic limit (second revision).
7. Congress, I. R. (2012). Tentative guidelines for the design of flexible pavements. In Indian Road Congress (p. 108).
8. Corley-Lay, J., Jadoun, F. M., Mastin, J. N., & Kim, Y. R. (2010). Comparison of flexible pavement distresses monitored by North Carolina department of transportation and long-term pavement performance program. Transportation research record, 2153(1), 91-96.
9. Huang, J. F., Wu, S. P., Ma, L. X., & Liu, Z. F. (2009, July). Material selection and design for moisture damage of HMA pavement. In Materials Science Forum (Vol. 614, pp. 269-274). Trans Tech Publications Ltd.
10. Integrated schedules of rates 2022: Rajasthan Urban Infrastructure Development Project (RUIDP).
11. IRC:37-2001 Guidelines for the design of Flexible Pavements.
12. IRC:37-2012 Tentative guidelines for the design of Flexible Pavements.
13. IRC:37-2018 Guidelines for the design of Flexible Pavements.
14. IS:2720 (Part II)-1973: Indian Standard Methods of Test for Soils