COMPREHENSIVE REVIEW OF DESIGN METHODS FOR FLEXIBLE AND RIGID PAVEMENTS: A COST ANALYSIS APPROACH

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ABSTRACT
Pavements are essential for ensuring smooth, safe, and organized traffic flow. They are categorized into flexible and rigid types. Flexible pavements, which have low flexural strength, adjust to loads with flexibility. In contrast, rigid pavements possess significant flexural strength and rigidity. Flexible pavements are often favored over concrete roads due to their ability to be reinforced and enhanced as traffic increases, along with the ease of milling and recycling their surfaces for repairs. They also require less initial investment and maintenance. Although rigid pavements are more expensive, they demand less maintenance and have a longer design life. This review article , we present the approach for cost estimation with various methodology .For rigid pavement, the Indian Road Congress (IRC) method is used. The design method yielding the maximum thickness is chosen for constructing the flexible pavement.

I. INTRODUCTION
Designing pavements that are both durable and cost-effective is paramount for ensuring the longevity and functionality of transportation infrastructure. In this comprehensive review, we delve into the various design methods employed for both flexible and rigid pavements, focusing particularly on their cost implications.

Flexible pavements, characterized by their layered structure and ability to distribute loads, offer a versatile solution for accommodating diverse traffic loads. Common design methods for flexible pavements include the Group Index (GI), California Bearing Ratio (CBR), and American Association of State Highway and Transportation Officials (AASHTO) methods [1][2]. These methods vary in their approach to pavement design, considering factors such as soil properties, traffic conditions, and environmental factors to determine pavement thickness and composition.

On the other hand, rigid pavements, constructed with a single layer of concrete, offer durability and strength suitable for heavy traffic areas. Design methods for rigid pavements, such as the AASHTO method, aim to provide sufficient thickness and reinforcement to withstand heavy loads and resist cracking [2]. Despite their durability, rigid pavements may be more susceptible to cracking due to temperature changes and concrete shrinkage, leading to potential maintenance costs over time.

In this review, we explore the advantages and limitations of each design method for both flexible and rigid pavements. Additionally, we analyze the cost-effectiveness of these methods, considering factors such as initial construction costs, maintenance requirements, and lifecycle costs. By conducting a cost analysis approach, we aim to provide insights into the economic implications of choosing different design methods for pavement construction projects.

Furthermore, we examine recent advancements and innovations in pavement design technology, such as mechanistic-empirical design methods and sustainable materials, and their impact on project costs and long-term performance [3][4]. These advancements offer opportunities to optimize pavement designs for enhanced durability, reduced maintenance costs, and improved sustainability, aligning with the goals of cost-effective infrastructure development.

Based on the structural behavior, pavements are generally classified into the following three categories:

1) Flexible pavement

2) Rigid pavement

3) Semi-rigid pavement.

Flexible pavements, with their layered construction and ability to distribute loads, offer a cost-effective and relatively simple solution for accommodating various traffic loads. Rigid pavements, constructed with concrete, provide durability and strength suitable for heavy traffic areas, despite being prone to cracking. Semi-rigid pavements strike a balance between flexibility and stiffness, offering enhanced durability and load-bearing capacity. Each pavement type has its advantages and maintenance requirements, making them suitable for different applications based on traffic conditions and environmental factors [1][2].

1. Flexible Pavement

Flexible pavements are constructed with multiple layers of materials, including a bituminous surface layer, base, and sub-base layers. These pavements can accommodate various traffic loads and are characterized by their ability to distribute loads over a wide area. They are composed of materials like asphalt concrete and are designed to flex under loading, hence the term "flexible." This flexibility allows them to withstand the stresses imposed by traffic and environmental factors, such as temperature changes and soil movement. Flexible pavements are known for their relatively simple construction process, cost-effectiveness, and ease of maintenance. However, they may require periodic resurfacing and maintenance to address wear and tear [1].

2. Rigid Pavement

Rigid pavements are constructed with a single layer of concrete, which provides stiffness and support to the structure. These pavements are less flexible compared to their flexible counterparts and are typically used for highways, airports, and industrial areas where heavy loads are expected. Rigid pavements are known for their durability, strength, and ability to distribute heavy loads without significant deformation. They require fewer layers compared to flexible pavements, which simplifies the construction process. However, rigid pavements are more susceptible to cracking due to temperature changes and concrete shrinkage. Despite this, they generally require less maintenance over their lifespan [1].

3. Semi-Rigid Pavement

Semi-rigid pavements, also known as composite pavements, combine characteristics of both flexible and rigid pavements. They typically consist of a layer of asphalt concrete over a layer of cement-treated or lean concrete base. Semi-rigid pavements offer a balance between flexibility and stiffness, providing adequate support while allowing some degree of movement to accommodate thermal expansion and contraction. These pavements are commonly used in urban areas, intersections, and heavy traffic zones. They offer advantages such as improved durability, reduced cracking, and enhanced load-bearing capacity compared to flexible pavements. However, they may require more maintenance than rigid pavements due to the potential for joint deterioration and surface distress [2].

II. LITRATURE OF REVIEW

Muddada poojitha1, B.Praveen babu2, et al.,(2016) :The paper explores traditional design methods for rigid and flexible pavements, emphasizing their cost analysis. Flexible pavements, preferred for their adaptability and recyclability, offer lower initial and maintenance costs compared to concrete roads. It suggests the California Bearing Ratio (CBR) method, specified by IRC 37-2001, as the most appropriate for flexible pavements on black cotton soil subgrades. Flexible pavements are more cost-effective for lower traffic volumes, lasting about 15 years with higher maintenance costs. In contrast, rigid pavements have a longer lifespan of approximately 40 years with lower maintenance expenses, despite higher initial costs [1].

I.Rohini1, V.Arularasi2 et al,. (2016) this article covers the pavement layers, prescribed limits by the Ministry of State Transportation, and raw material sources for constructing 4 lanes on NH-18 between Kadapa and Kurnool. The project road spans 188.752 km, designed as a single construction package on a Build Operate and Transfer (BOT) basis under NHAI's direction. The alignment includes 177 km of plain terrain and 15.2 km of rolling and mountainous terrain. The project enhances vehicle speed efficiency and transportation facilities. The highway's cross-section design is comparable to NH-18's design.

Panchadi Manoj Kumar, B.Praveen babu et al,. (2016) Over the past decade, the country has experienced a significant rise in vehicle numbers and axle loads, which has overstressed the road network, causing early failures. To determine if a pavement has functional or structural deficiencies, it's essential to consider the type of deterioration. Structural failures occur due to conditions that negatively impact the pavement's load-bearing capacity. Factors such as insufficient thickness, cracking, distortion, and disintegration contribute to structural deficiencies.

Saurabh Jain, Dr. Y. P. Joshi, S. S. Goliya et al,. (2013) presented about :Highway and pavement design significantly impact DPR projects, affecting vehicle operating costs and travel time, thus influencing economic feasibility. This paper reviews traditional design methods for rigid and flexible pavements, comparing their costs. Flexible pavements are favored for their adaptability and lower initial and maintenance costs, although rigid pavements require less maintenance over a longer lifespan. The CBR method per IRC 37-2001 is recommended for flexible pavements on black cotton soil, providing cost-effective results. While flexible pavements last about 15 years with high maintenance costs, rigid pavements last around 40 years with lower maintenance costs, despite higher initial investment.

Shital H. Jadhav, Shital H. Ingle, Rajpal G. Kumawat et al,. (2016) this represented: Highway planning and pavement design are crucial in daily life. , we determine the thickness of flexible pavement by comparing various design methods, including the Group Index (GI), California Bearing Ratio (CBR), and Indian Road Congress (IRC) methods. The method resulting in the maximum thickness is chosen for construction. Our study shows that flexible pavement thickness depends primarily on wheel load; higher wheel loads require greater thickness. Among the methods, IRC is found to be more suitable for road construction due to its better consideration of strength, span, and other factors compared to GI and CBR methods.

Sai Phani Raghu Veer, Siddharth Gupte, Jayesh Juremalani et al,.(2018) Geometric design of highways involves planning the visible features such as cross-sectional elements, sight distances, alignments, curves, and superelevations. In India, increasing population and traffic volumes, coupled with insufficient government funding for infrastructure, necessitate careful initial planning of geometric elements to avoid costly post-construction modifications. This paper reviews past work on highway geometric design, emphasizing efficient and safe traffic flow at reasonable costs. Key objectives include optimizing traffic movement and safety, adhering to AASHTO and IRC guidelines, and using MX Road and ArcGIS software for design and alignment optimization. Special attention is needed for superelevation, pavement widening on curves, shoulder width, median width, and sight distance to enhance safety and reduce fuel consumption.

After review various article the observation and finding on highlight critical insights into highway and pavement design as below.

Cost Analysis of Pavement Types: Flexible pavements, favored for their adaptability and recyclability, have lower initial and maintenance costs, particularly suitable for lower traffic volumes, lasting about 15 years. In contrast, rigid pavements, though having higher initial costs, offer a lifespan of about 40 years with lower maintenance costs.

CBR Method: The California Bearing Ratio (CBR) method per IRC 37-2001 is recommended for designing flexible pavements, especially on black cotton soil subgrades, due to its cost-effectiveness.

NH-18 Project Design: The NH-18 project from Kadapa to Kurnool illustrates the effective planning and construction of a 188.752 km road under NHAI's BOT model. The alignment includes plain, rolling, and mountainous terrains, enhancing vehicle speed and transportation efficiency.

Pavement Deterioration: Increasing vehicle numbers and axle loads cause early road failures. Identifying structural deficiencies such as insufficient thickness, cracking, and disintegration is crucial for maintaining pavement integrity.

Economic Feasibility: The impact of highway design on vehicle operating costs and travel time underscores the economic feasibility of DPR projects. Flexible pavements, despite higher maintenance costs, are preferred for their initial low cost, while rigid pavements offer long-term benefits with less frequent maintenance.

Thickness Determination: The study comparing design methods like GI, CBR, and IRC methods concludes that IRC is most suitable for flexible pavement construction due to its comprehensive consideration of strength and span.

Geometric Design: Proper geometric design, including cross-sectional elements, sight distances, and curves, is essential for safe and efficient traffic flow. Initial planning is vital to avoid costly modifications later.

III. METHODOLOGY

Collection of materials: Red Soil

Red soil, also known as Terra Rossa, is characterized by its reddish color due to the presence of ferric oxide. It is siliceous and aluminous, containing free quartz as sand, and is generally loamy but can range from sandy to clayey. Red soil is rich in potassium but deficient in lime, phosphate, manganese, nitrogen, humus, and potash. It covers significant areas in India, such as Uttar Pradesh, Odisha, and southern parts of the Deccan Plateau, occupying roughly 2 lakh square kilometers. These soils are typically poor, flinty, and porous, making them suitable for crops like bajra on highlands.

Properties of red soil :

1. **Color**: Red soils are named for their red color, which is due to the high content of iron oxide [2].
2. **Texture**: The texture of red soils can vary from clayey to sandy loam. They are generally derived from the weathering of ancient crystalline and metamorphic rocks [5].
3. **Fertility**: Red soils are typically less fertile as they lack nitrogen, phosphorus, and organic matter [6].
4. **Acidity**: These soils often have high exchangeable acidity and low pH, making them somewhat acidic [5].
5. **Mineral Content**: They are rich in iron and potassium but have a low cation exchange capacity, indicating limited nutrient-holding capacity [1].
6. **Drainage**: Red soils are typically well-drained due to their porous nature, which also makes them prone to erosion [2].

These properties make red soils suitable for certain types of agriculture, although their fertility often requires enhancement through the addition of fertilizers and organic matter.

a) Atterberg's Limit

Atterberg Limits are a basic measure of the critical water contents of a fine-grained soil. These limits help to classify soils based on their plasticity characteristics. The three limits are the liquid limit, plastic limit, and shrinkage limit. The liquid limit is the water content at which soil changes from a plastic state to a liquid state [5]. The plastic limit is the water content at which soil changes from a plastic state to a semi-solid state [2].

b) Sieve Analysis

Sieve analysis is a method used to determine the particle size distribution of a granular material. This process involves passing the soil through a series of sieves with progressively smaller openings. The amount of material retained on each sieve is weighed to determine the gradation of the soil particles [6]. Sieve analysis is critical in soil classification and helps in understanding soil behavior under different loading conditions. It provides a complete particle-size distribution curve when combined with Atterberg limits for fine-grained soils [6].

c) Specific Gravity

Specific gravity of soil is the ratio of the density of the soil solids to the density of water. It is a dimensionless quantity that is used in various soil mechanics calculations, such as determining the void ratio and porosity of soils. Specific gravity is determined using a pycnometer or a specific gravity bottle. This property is essential for identifying the mineralogical composition of soils. It helps in understanding the soil's behavior and stability under different moisture conditions [1].

d) Compaction Test

The compaction test is used to determine the optimal moisture content at which a soil type will become most dense and achieve its maximum dry density. It involves compacting soil samples at various moisture contents and measuring the corresponding densities. This test is essential for constructing foundations, embankments, and other structures where soil stability is crucial. The Proctor compaction test and the Modified Proctor test are the most commonly used methods. The results help engineers design and construct more stable and durable structures.

e) Unconfined Compression Strength Test

The unconfined compression strength test measures the shear strength of cohesive soils. It involves compressing a cylindrical soil sample until failure occurs without any lateral confinement. The test determines the maximum axial compressive stress that a soil sample can withstand. It is a quick and straightforward test used for soil strength assessment, especially in the field. The results are crucial for designing foundations and other structures that rely on soil strength [3].

Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic, and liquid. In each state, the consistency and behavior of a soil are different, and consequently, so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg limits can be used to distinguish between silt and clay, and to differentiate between various types of silts and clays. The liquid limit is the water content at which soil changes from a plastic to a liquid state, while the plastic limit is the water content at which soil transitions from a plastic to a semi-solid state [3]

Liquid limit:

The liquid limit of soil refers to the minimum water content at which the soil transitions into a liquid state, while still maintaining a small amount of shearing strength against flow. This property is crucial in geotechnical engineering for understanding soil behavior and its consistency under different moisture conditions.

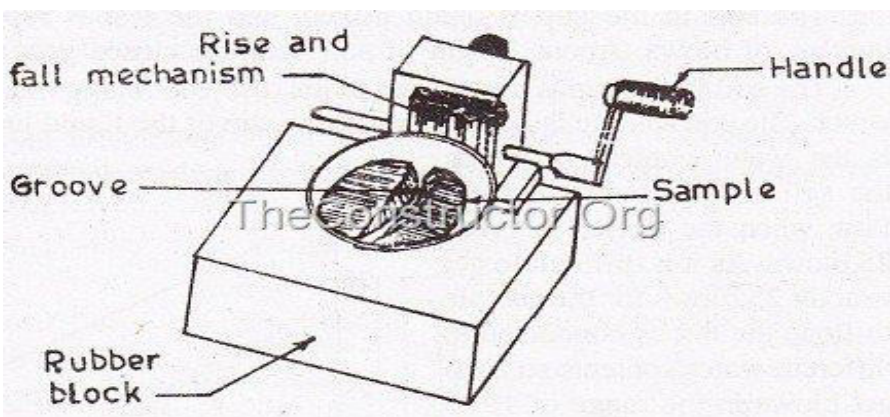

Fig.1 *Liquid Limit Apparatus*

The plastic limit

The plastic limit indicates the moisture percentage at which soil transitions, decreasing in wetness, from a plastic to a semi-solid state, or increasing in wetness, from semi-solid to plastic. This limit defines the lower boundary of the plastic state. It is the moisture content where a soil thread can be rolled into a 3 mm diameter without breaking, but starts to crumble under hand pressure. Slight moisture increase above this limit disrupts soil cohesion and shear strength [4].

Fig.2 *Plastic Limit Apparatus*

A sieve analysis

A sieve analysis assesses particle size distribution in granular materials, crucial for material functionality, and is applicable to a wide range of substances, making it a commonly used method. A sieve analysis, also called a gradation test, assesses the particle size distribution of granular materials like sands, crushed rock, clays, and coal. This distribution impacts material performance across diverse applications. The method is versatile, applicable to organic and non-organic substances, capable of analyzing particle sizes to precise thresholds. Its simplicity and effectiveness have made it a standard practice in various industries for particle size analysis.

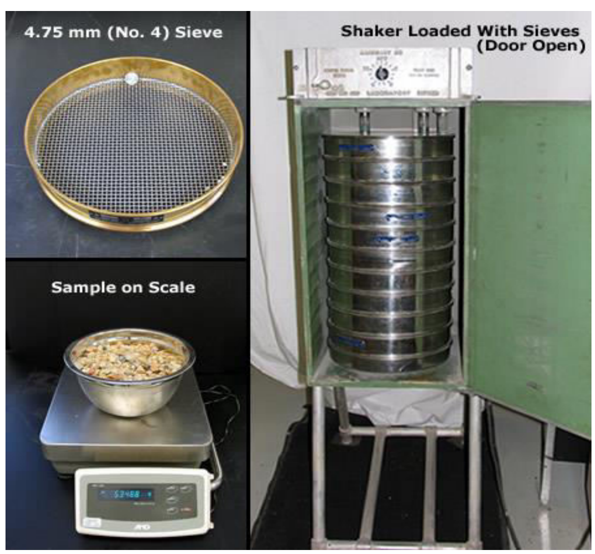

Fig 3.*Sieve Analysis Apparatus*

Compaction test

Compaction can be generally defined as the densification of soil by the removal of air and rearrangement of soil particles through the addition of mechanical energy. The energy exerted by compaction forces the soil to fill available voids, and the additional frictional forces between the soil particles improves the mechanical properties of the soil.

The degree of compaction of a soil can be measured by its dry unit weight, γ_d. When water is added to the soil, it functions as a softening agent on the soil particles, causing them to slide between one another more easily. At first, the dry unit weight after compaction increases as the moisture content (ω) increases, but after the optimum moisture content (ω_{opt}) percentage is exceeded, any added water will result in a reduction in dry unit weight because the pore water pressure will be pushing the soil particles apart, decreasing the friction between them.

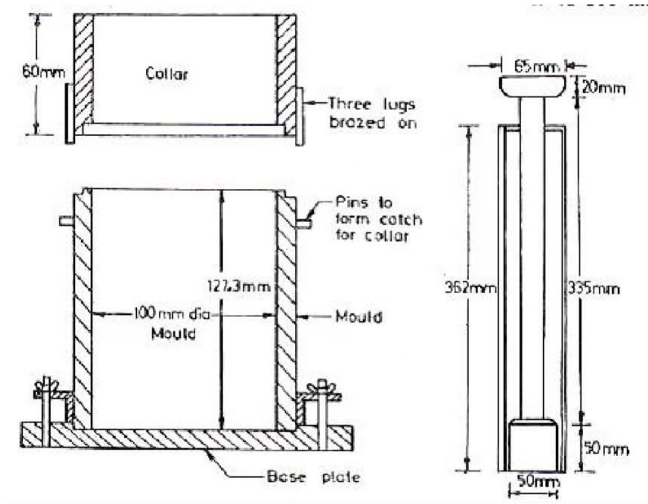

***Fig 4** Compaction Test Apparatus*

Unconfined compression test

The unconfined compression test is by far the most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The method is used primarily for saturated, cohesive soils recovered from thin-walled sampling tubes. The unconfined compression test is inappropriate for dry sands or crumbly clays because the materials would fall apart without some land of lateral confinement.

In the unconfined compression test, we assume that no pore water is lost from the sample during set-up or during the shearing process. A saturated sample will thus remain saturated during the test with no change in the sample volume, water content, or void ratio.

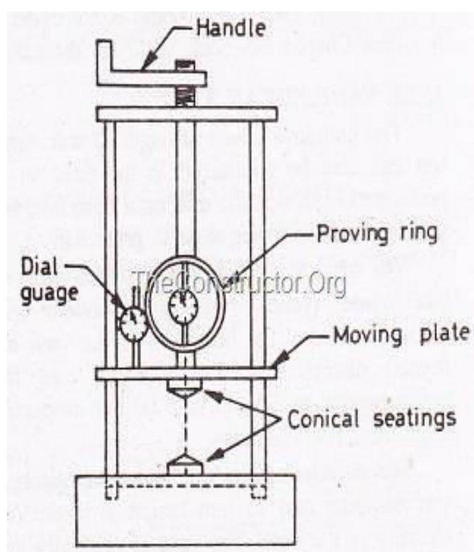

Fig 5. Unconfined Compression Test Apparatus

California bearing ratio

The California Bearing Ratio(CBR) test is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. It was developed by the California Division of Highways as a method of classifying and evaluating soil- sub grade and base course materials for flexible pavements.

CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute.

The loads for 2.5mm and 5mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value.

Table 1 Standard Load Values for CBR Test

Penetration(mm)	Standard Load(kg)	Unit Standard Load(kg/cm^2)
2.5	1370	70
5	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

IV. DESIGN OF FLEXIBLE PAVEMENTS

Group index method

In order to classify the fine grained soils within one group and for judging their suitability as sub grade material, an indexing system has been introduced in HRB classification which is termed as Group Index. Group Index is function of percentage material passing 200 mesh sieve (0.074mm), liquid limit and plasticity index of soil and is given by equation: (0.074mm) . Liquid limit and plasticity index of soil and is given by equation:

GI=0.2a+0.005ac+0.01bd

Here,

a=that portion of material passing 0.074mm sieve, greater than 35 And not exceeding 75 %

b=that portion of material passing 0.074mm sieve, greater than 15

And not exceeding 35%

c = that value of liquid limit in excess of 40 and less than 60

d = that value of plasticity index exceeding 10 and not more than 30

Or

GI= (F-35) 0.2+0.05(WL -40) +0.01(F-15) (IP-10)

DATA:

F =66%

WL=55%

IP =31%

GI = (F-35)0.2+0.05(WL -40)+0.01(F-15)(IP-10)

=17.35

So Pavement Thickness =700mm

Thickness of Surface Course =35mm

Thickness of DBM =145mm

Thickness of Base Course=200mm

Thickness of Sub Base=320mm.

California Resistance Value Method

F.m Hakeem and R.M.Carmany in 1948 provided design method based on stabilometer R- value and cohesiometer Computer- value.Based on performance data it was established by Hveem and Car many that pavements thickness varies directly with R value and logarithm of load repetitions. It varies inversely with fifth root of Computer value. The expression for pavement thickness is given by the empirical equation.

T=K (TI) (90-R)/C1/5

Here T=total thickness of pavement, cm

K=numerical constant=0.166

TI=traffic index

R=stabilometer resistance value

C =Cohesiometer value

The annual value of equivalent wheel load (EWL) here is the accumulated sum of the products of the constant and the number of axle loads .The various constant for the different number of axles in group are given below

Table.2 *EWL constant*

Number of axles	EWL Constant(Yearly basis)
2	330
3	1070
4	2460
5	4620
6	3040

DATA

K =0.166, TI =9.66, R = 44, C =61

Pavements thickness is given by the empirical equation:-

T=K(TI)(90-R)/C1/5

Calculation:

TI = 1.35(EWL)0.11

TI=1.35(32729750)0.11

TI=9.66

T=K(TI)(90-RC)/C1/5

T=0.166(9.66)(90-44)611/5

T=730 mm

So Pavement Thickness =730mm

Thickness of Surface Course =35mm

Thickness of DBM =145mm

Thickness of Base Course=210mm

Thickness of Sub Base=340mm

California Bearing Ratio Method

The following sub sections describe the various variables and parameters involved in design of flexible pavement of road as per IRC 37 - 2001.

Traffic- CV/Day Annual traffic census 24 X 7

For structural design, commercial vehicles are considered. Thus vehicle of gross weight more than 8 tonnes load are considered in design. This is arrived at from classified volume count.

Wheel loads

Urban traffic is heterogeneous. There is a wide spectrum of axle loads plying on these roads. For design purpose it is simplified in terms of cumulative number of standard axle (8160 kg) to be carried by the pavement during the design life. This is expressed in terms of million standard axles or msa.

Design Traffic

Computation of design Traffic In terms of cumulative number of standard axle to be carried by the pavement during design life.

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

Where,

N = The cumulative number of standard axles to be catered for in design in terms of million standard axles - msa.

A = Initial traffic in the year of completion of construction duly modified as shown below.

D = Lane distribution factor

F = Vehicle damage factor, VDF

n = Design life in years

r = Annual growth rate of commercial vehicles {this can be taken as 7.5% if no data is available}

Table 3 *Penetration and determination of CBR*

S.No	Penetration Y (mm)	Standard load Value (p)(kgf)	Proving Ring Dial Gauge Reading (R)	Plunger Load on (Pt)=R x f =R x 1.282 (kgf)
1	0		0	0
2	0.5		10	12.82
3	1.0		18	23.07
4	2.0		33	42.30
5	2.5	1370	54	69.22
6	3.5		63	80.76
7	4.0		71	91.02
8	5.0	2055	78	99.99
9	7.5		85	108.97
10	10.0		91	116.66
11	12.5		102	130.76

Data

1. Length of Road= 3.45/00 km
2. Traffic intensity as worked out =1001 CV/D Average
3. Growth rate of traffic (assumed) = 7.5%
4. Total Period of Construction =4 months
5. Design C.B.R. of Sub grade Soil=5.00%
6. Design Period of the Road= 10 Years
7. Initial Traffic in the Year of Completion of Construction

A = P x (1 +r) x

Where:

A = Traffic in the year of completion of construction CV/ Day

P = Traffic at last Count April 2013

r = Annual growth rate of traffic

x = Number of years between the last census and the year of completion of construction

A =1001 x (1 + 0.075) x1 1076 CV / Day

(As per Clause 3.3.4.4 Table 1 of IRC -37 -2001)

8. Vehicle Damage Factor =3.5Standard Axle per CV
9. Design Calculation

Initial traffic in design lane = Initial traffic x Distribution factor

= 1076 x 0.75 = 807.05 CVPD

N = [365 x {(1+r) x - 1} x A x F] / r

=365 x [{(807(1 +0.075)^10-1}x3.5]/0.075 = 14.58 msa

Say 15.00 msa

10.Total Pavement Thickness for design C.B.R. = 660 mm

(As per Plate - 2 of IRC-37-2001)

The thickness of individual component layers of flexible pavement by CBR method is given below:

So pavement thickness =660mm

Thickness of surface course =40mm

Thickness of DBM =70mm

Thickness of base course=250mm

Thickness of sub base=300mm.

V. CONCLUSION

In this article, the focus is on integrating advanced geometric and pavement design techniques for a road, Adhering to IRC specifications ensures the road's safety and efficiency in both geometric and pavement aspects. The design primarily utilizes the Group Index (GI) and California Bearing Ratio (CBR) methods for flexible pavement design, omitting more complex methods due to time and scope constraints. Estimation efforts also include quantifying the earthwork required for the flexible pavement. Additionally, the cost analysis highlights that the Triaxial method is more expensive compared to GI, California Resistance Value, and CBR methods.

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