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In-depth Evaluation of the CBR Method in Flexible Pavement Design

Piyush Kumar Rai[1,*], Kamalpreet Kaur[2], Lovepreet Kaur[2]

Abstract

The California Bearing Ratio (CBR) value of the subgrade is a crucial parameter utilized in the design of flexible pavements, as recommended by the Indian Roads Congress (IRC). The choice of materials used in constructing the pavement can significantly influence its overall design and performance. Pavements play an essential role in ensuring traffic flows smoothly, safely, and efficiently. Generally, pavements are categorized into two types: flexible and rigid. Flexible pavements possess low flexural strength and exhibit a flexible structural behavior under load. In contrast, rigid pavements are characterized by their high flexural strength and rigidity. Many existing roads, which are designed based on empirical guidelines, often fail to withstand heavy wheel loads, leading to their gradual deterioration over time. To address this issue, various engineering parameters must be meticulously determined through rigorous experiments. Soil samples are collected along the proposed road alignment to assess soil properties such as consistency limits, particle size distribution (sieve analysis), and CBR values. These parameters are then used to design the appropriate pavement thickness for flexible pavements. Additionally, the road alignment is meticulously designed and established using precise surveying and leveling techniques. In this study, the total length of the road being designed and analyzed is 257 m. California Bearing Ratio tests were conducted in the laboratory to obtain accurate and reliable data for the pavement design. This comprehensive approach ensures the pavement structure can adequately support the anticipated traffic loads, thereby enhancing the road's longevity and performance.

Keywords: CBR, pavement, IRC, flexible, road, road construction, pavements

INTRODUCTION

For the economical and efficient construction of highways, it is essential to accurately design the thickness of pavements to accommodate various traffic conditions and sub-grades. Pavement design is a relatively new science, especially in India, where road crusts were previously designed based on a mix of rational data and the experience of the road engineer. This often led to the use of arbitrary pavement thicknesses, causing costly failures and wastage, either due to insufficient pavement thickness or unnecessary expenses from overly thick pavements. Without proper design criteria, road construction was often uneconomical.

Therefore, a methodical approach to designing and calculating the crust thickness, based on traffic load estimation and sub-grade bearing capacity, is necessary for economical road construction [1–4].

The objectives and Requirements of Pavements Include:

- Ensuring the pavement surface is stable and non-yielding to allow heavy wheel loads to move with minimal rolling resistance.

*Author for Correspondence
Piyush Kumar Rai
E-mail: jayp7034@gmail.com

[1]Student, Department of Civil Engineering, Kurukshetra University, Kurukshetra, Haryana, India.
[2]Assistant Professor, Department of Civil Engineering, Kurukshetra University, Kurukshetra, Haryana, India

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- Maintaining an even longitudinal profile to enable safe and comfortable movement of fast vehicles at design speeds.
- Designing pavement layers that efficiently spread the stress from wheel loads over a larger area per unit depth of the layer.

Types of Pavements

Pavements can be classified into three main categories based on their structural behavior:

- Flexible Pavement;
- Rigid Pavement; and
- Semi-rigid Pavement.

Flexible Pavement

Flexible pavements are those that flex under load. Key characteristics include:

- Lack of flexural strength.
- Reflection of lower layer deformations.
- Vertical compressive stress transmission to lower layers through grain-to-grain transfer.
- Use of inferior, low-cost materials in lower layers due to lower stress magnitudes and no direct traffic load wear.

Rigid Pavement

Rigid pavements possess significant flexural rigidity. Key characteristics include:

- The presence of flexural strength.
- Load transfer through slab action, spreading the wheel load over a broader area beneath.
- The occurrence of flexural stresses caused by wheel loads and temperature fluctuations.
- The emergence of tensile stresses due to slab bending under the wheel load.
- Bridging of minor variations in the lower layer without deforming to its shape.

Semi-Rigid Pavement

Semi-rigid pavements incorporate bonded materials like pozzolanic concrete, lean concrete, or soil cement, which provide greater flexural strength than typical flexible pavements. However, these materials have low resistance to impact and abrasion, so they are often used with a flexible pavement surface layer [5].

FACTORS TO CONSIDER IN PAVEMENT DESIGN

Pavement design involves two main components:

1. The mix design of the materials used in each layer of the pavement.
2. The design of the thickness for the pavement and its component layers.

Key factors to consider in pavement design include:

- Design wheel load;
- Subgrade soil;
- Climatic conditions;
- Materials used in pavement components;
- Environmental factors; and
- Specific considerations for different types of pavements.

Design of Flexible Pavement

Designing a flexible pavement involves several key steps and considerations to ensure the pavement can support anticipated traffic loads and environmental conditions over its intended lifespan. Here is a comprehensive guide to the design process:

Traffic Analysis
- *Traffic Data Collection:* Gather data on the volume and types of vehicles expected to use the pavement.
- *Equivalent Single Axle Load (ESAL):* Convert different axle loads and configurations to a standard single axle load for uniformity in design.

Subgrade Evaluation
- *Soil Sampling and Testing:* Obtain soil samples from the site and conduct tests to determine properties such as soil classification, moisture content, and California Bearing Ratio (CBR).
- *Subgrade Improvement:* If the subgrade soil is weak, consider improving it through stabilization techniques like adding lime, cement, or geosynthetics.

Material Selection
- *Aggregate Base and Sub-base:* Choose high-quality aggregates with appropriate gradation and durability.
- *Bituminous Materials:* Select suitable bituminous binders and mix designs for the asphalt layers.

Pavement Layer Thickness Design
- *Design Methods:* Use empirical or mechanistic-empirical methods to determine the thickness of each pavement layer. Widely used methods for pavement design include the AASHTO Guide for Pavement Structure Design and the methodology developed by the Asphalt Institute.
- *Structural Number (SN):* Calculate the structural number required for the pavement based on traffic loading and subgrade strength.
- *Layer Coefficients:* Determine the thickness of each layer using layer coefficients that represent the strength contribution of each material.

Drainage Design
- *Surface Drainage:* Design the pavement surface to allow for efficient runoff of water.
- *Subsurface Drainage:* Include provisions for subsurface drainage to prevent water accumulation within the pavement layers and subgrade.

Construction Considerations
- *Quality Control:* Ensure proper material quality and construction practices to achieve the desired pavement performance.
- *Compaction:* Properly compact each layer to achieve the required density and strength.

Maintenance Planning
- *Routine Maintenance:* Plan for regular maintenance activities such as sealing cracks, patching potholes, and reapplying surface treatments.
- *Rehabilitation:* Include strategies for major rehabilitation activities, such as overlay or reconstruction, when the pavement reaches the end of its design life.

California Bearing Ratio Method

Most road pavements designed using the CBR (California Bearing Ratio) method rely on the CBR value of sub-grade soil, which is determined through laboratory tests. These tests are performed on either disturbed or remolded sub-grade soil, depending on whether the existing sub-grade is utilized without enhancement or a new sub-grade is built with specific properties, particularly focusing on compaction characteristics [6].

The California Bearing Ratio (CBR) value measures the load needed to achieve a specific penetration (usually 2.5 or 5 mm) of a standard plunger into the soil sample, compared to the load needed to achieve the same penetration into a standard stone aggregate sample. This measurement is expressed as a percentage [7].

CBR values range from 0 to 100%, with higher values indicating stronger soil. Lower density results in lower CBR values. The California Bearing Ratio (CBR) quantifies the penetration resistance of a pavement material compared to a standard reference value obtained from a crushed stone aggregate. The thickness of the pavement is then determined using charts that correspond to the CBR value [8].

LITERATURE REVIEW

Flexible pavements are often favored over cement concrete roads because they offer various advantages. They can be reinforced and upgraded progressively as traffic increases, and their surfaces can be milled and recycled for rehabilitation purposes. Additionally, flexible pavements typically require a lower initial investment and incur lower maintenance costs. Although rigid pavements are more costly, they require less maintenance and have a longer design period [9].

Traditional Design Methods for Both Rigid and Flexible Pavements, Along with Cost Analyses for Each Method

The effectiveness of flexible pavement on expansive soil sub-grade, utilizing gravel or fly ash as the sub-base course and reinforced with waste tire rubber. Laboratory tests indicate that the gravel sub-base outperforms the fly ash sub-base when combined with different amounts of waste tire rubber.

A Study to Assess the Potential of Bagasse Ash (BA) and Egg Shell Powder (ESP) in Stabilizing Soft and Expansive Soils

California Bearing Ratio (CBR) tests were performed on black cotton soil mixed with ESP and varying BA percentages ranging from 5 to 25% [9]. Results showed that the stabilized soil required a thinner pavement compared to virgin soil.

The CBR Value for Black Cotton Soil Stabilized with Quarry Dust, a by-product of Quarrying Activities

Quarry dust was added to the soil in varying percentages (10, 20, 30, and 40%), demonstrating its effectiveness in soil stabilization. After performing the experiments, the CBR value is increased 87.5% to black cotton soil and swelling pressure is decreased 88% [10].

The CBR Method for Designing the Flexible Pavement

In two different soil samples. The samples were clayey silt and Kopra and CBR test conducted on it. After obtaining results, the thickness of pavement was less while using Kopra compared to clayey silt, and it is also determined that, thickness of crust varied with the change in value of CBR. With higher value of CBR, the crust thickness is less [11].

CBR Test for Designing the Flexible Pavement with Using Black Cotton Soil as Base Material

They designed the pavement using lime and fly ash. The California Bearing Ratio (CBR) test, a penetration test used to evaluate the strength of subgrade soil, is essential in designing flexible pavements. A higher CBR value indicates better load-bearing capacity, which is particularly important when using challenging materials like black cotton soil as the base.

MATERIALS AND METHODS

Soil Samples

Three soil samples were collected from the site location for analysis. The main test performed on these samples was the California Bearing Ratio (CBR) test, devised by the California Division of Highways. This test assesses the stability of soil sub-grades and other flexible highway materials. The outcomes of the CBR test are used to establish the necessary pavement thickness for highways. The test can be carried out in a laboratory on a prepared specimen in a mold or directly in the field [12].

Procedure

Sample Preparation

- Take about 5 kg of oven-dried soil sample and mix it with the optimum moisture content.

- Compact the soil using either IS light compaction (3 layers, 55 blows each with a 2.6 kg Hammer) or IS heavy compaction (5 layers, 55 blows per layer using a 4.89 kg hammer).

Setting Up the Test

- Position the mold with the base plate under the penetration plunger of the loading machine and apply a 2.5 kg surcharge weight.
- Attach the dial gauge to measure the plunger's penetration values. Adjust the dial gauge of the proving ring and the penetration dial gauge [13].

Conducting the Test

- Record the load readings at penetration intervals of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0 mm.
- Note the proving ring calibration factor.

Plot the Load-Penetration Curve

Calculating the CBR Value

Identify the unit load values for 2.5 and 5.0 mm penetrations from the curve. Calculate the CBR value by expressing these load values as a percentage of the standard load values for the respective penetration levels. Typically, the CBR value at 2.5 mm penetration is used [14].

Observations from Admixture in Black Cotton Soil

Experiments with black cotton soil mixed with an admixture showed improvements in soil properties (Table 1):

Optimum moisture content improved by 11.1%.

Maximum dry density increased by 10.74%.

Free swell index improved by 13.74%.

CBR value is calculated by the formula:

$$\text{CBR} = \frac{\text{Load sustained by specimen at defined penetration level}}{\text{Load sustained by sustained crushed stone at same penetration level}} \times 100$$

RESULTS AND DISCUSSION

This section presents the results of CBR analysis laboratory experiments conducted under controlled conditions, followed by a discussion on the experimental findings. The work has been performed in laboratory CBR analysis, in the lab analysis was carried out on the experimental laboratory condition at Patna (Bihar), three soil samples were collected from site [15, 16].

Sample 1

- CBR at 2.5 mm penetration =9.08%
- Design traffic volume: 450 to 1500 vehicles/day.
- Pavement thickness for subgrade with 9.08% CBR is determined to be 30 cm using curve E.
- 30 cm of pavement material is necessary to cover the subgrade with a 9.08% CBR value.

Table 1. The Standard Load Values.

Penetration (mm)	Standard Load (kg)	Unit Standard Load (kg/cm^2)
2.5	1370	70
5.0	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

Sample 2

- CBR at 2.5 mm penetration =9.08%.
- Design traffic volume: 450 to 1500 vehicles/day.
- Pavement thickness for subgrade with 9.08% CBR is determined to be 30 cm using curve E.
- 30 cm of pavement material is necessary to cover the subgrade with a 9.08% CBR value.

Sample 3

- CBR at 2.5 mm penetration =9.31%.
- Design traffic volume: 450 to 1500 vehicles/day.
- Pavement thickness for subgrade with 9.31% CBR is determined to be 27 cm using curve E.
- 27 cm of pavement material is necessary to cover the subgrade with a 9.31% CBR value.

CONCLUSION

Based on the analyses of CBR experiments data and other ancillary data, the following conclusions are drawn: designing a flexible pavement involves a combination of traffic analysis, subgrade evaluation, material selection, thickness design, and proper drainage and construction practices. For safety, use the higher of the two CBR values obtained in each case. Accordingly, provide a sub-base layer with a thickness of 25 cm, a base course with a thickness of 15 cm, and a wearing course with a thickness of 7 cm, as recommended by the IRC curves.

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