LOW COST PAVEMENT DESIGN USING IIT PAVE SOFTWARE WITH SUB GRADE STABILIZATION

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Abstract:

Transportation infrastructure plays a pivotal role in national development by supporting economic growth, trade, and social connectivity. Pavement design, being the backbone of road infrastructure, often encounters challenges such as escalating construction costs, poor subgrade conditions, and the need for sustainable practices. Traditional empirical methods of pavement design—though simple—frequently result in excessive use of aggregates and binders, leading to higher construction costs and unsustainable exploitation of natural resources. This study presents a comprehensive low-cost pavement design methodology that integrates IIT PAVE software, a mechanistic–empirical pavement analysis tool, with subgrade stabilization techniques using lime, cement, fly ash, and recycled plastic waste. IIT PAVE simulates pavement layer behavior under different loading and environmental conditions, thereby optimizing design thickness and material consumption. Subgrade stabilization improves weak soils' load-bearing capacity, reduces pavement thickness requirements, and enhances durability. The combination of advanced computational modeling with cost-effective soil improvement methods demonstrates that pavement life can be extended by 25–40% while reducing initial construction costs by up to 20%. This study thus establishes a framework for designing pavements that are not only economical and durable but also sustainable and environmentally responsible, providing a strong foundation for future transportation infrastructure, especially in developing countries like India.

I.INTRODUCTION

The rapid urbanization and industrial development in India have led to an unprecedented rise in vehicular traffic, placing tremendous pressure on road networks. According to the Indian Roads Congress (IRC), over 65% of freight and 80% of passenger traffic in India is handled by roads, highlighting the importance of durable pavement structures. However, the cost of road construction has been rising due to the scarcity of quality aggregates, high bitumen prices, and frequent maintenance caused by weak subgrades. Traditional pavement design approaches, such as the California Bearing Ratio (CBR) method, have long been used in India. While useful, these methods rely heavily on empirical correlations and do not account for mechanistic responses such as stresses, strains, and deflections under traffic loads. As a result, pavements designed through CBR methods often experience premature failures such as rutting, fatigue cracking, and settlement.

To address these limitations, IIT PAVE software—developed at IIT Kharagpur—offers a mechanistic–empirical framework that considers load transfer, stress distribution, and material behavior under varying conditions. By combining this analytical power with subgrade stabilization, pavements can be designed with reduced thickness, improved performance, and lower costs. Subgrade stabilization through additives such as lime, cement, fly ash, and plastic waste not only improves soil strength but also contributes to sustainability by promoting waste utilization.

Thus, the need of the hour is to adopt low-cost pavement designs that integrate advanced computational tools and innovative soil stabilization techniques to achieve long-lasting, eco-friendly, and economically viable roads.

II.RELATED WORKS

The problem of high pavement cost and weak subgrades has been studied extensively worldwide, and multiple researchers have investigated cost reduction and sustainability in pavement design:

- George et al. (2001): Proposed that mechanistic–empirical design tools offer superior predictions of pavement life compared to empirical CBR-based methods. They highlighted that software such as IIT PAVE can simulate realistic field conditions like layered elastic analysis.
- Patel & Dave (2007): Conducted field trials of lime-stabilized subgrades in Gujarat, India. Results indicated an increase in soaked CBR values from 4% to 12%, allowing for a 25% reduction in pavement thickness and substantial savings in aggregate consumption.
- Bhavani & Murthy (2011): Explored the use of fly ash as a stabilizing agent in clayey soils. Their study showed that fly ash-treated subgrades exhibited 20–30% improvement in

load-bearing capacity, while contributing to the utilization of industrial waste.

- Kumar & Reddy (2015): Verified the accuracy of IIT PAVE outputs by comparing laboratory fatigue test results with field pavement performance in Andhra Pradesh. Their findings reinforced that IIT PAVE-based designs are more reliable for Indian conditions.
- Sharma et al. (2018): Demonstrated how recycled plastic waste can be incorporated into soil stabilization, significantly improving strength and durability while also contributing to eco-friendly road construction.
- IRC Guidelines (2018): Recommended mechanistic–empirical methods for flexible pavement design in India, recognizing their ability to optimize layer thickness and reduce costs.
- Rajasekaran & Vasudevan (2020): Implemented a case study of rural roads constructed with cement-stabilized subgrades designed using IIT PAVE. They reported a 40% cost saving in comparison with traditional methods.
- International Studies (TRB, AASHTO, 2020): Emphasized that the integration of waste materials in subgrade stabilization combined with computational design leads to life-cycle cost savings of up to 35% in pavement projects.

III. MATERIAL USED

The selection of appropriate materials is crucial for designing **low-cost yet durable pavements**. This study considers both **conventional** and **innovative stabilizing materials**:

1. Subgrade Soil

- The natural subgrade soil is collected from the project site and tested for classification, compaction, and CBR.
- Soils with low CBR (<5%) are most suitable for stabilization studies.
- Typical properties:
    - **Moisture Content:** 8–12%
    - **Plasticity Index:** 15–20%
    - **CBR (Soaked):** 2–4%

2. Lime

- Hydrated lime is a traditional stabilizer used for clayey soils.

- It reduces plasticity, increases strength, and improves durability through **pozzolanic reactions**.
- Lime-treated soils achieve **CBR improvements of 200–300%**.

3. Cement

- Ordinary Portland Cement (OPC) is added in small percentages (3–7%) to stabilize soils.
- Cement hydration binds soil particles and significantly increases unconfined compressive strength (UCS).
- Used in cases requiring **quick strength gain and durability**.

4. Fly Ash

- A by-product of coal-fired power plants.
- It reacts with lime or cement in the soil to form cementations compounds.
- Utilization of fly ash contributes to sustainability and reduces environmental hazards from waste disposal.

5. Recycled Plastic Waste

- Shredded plastic pieces or plastic-coated aggregates are used.
- Plastics improve **binding, resistance to water ingress, and durability**.
- Promotes waste recycling and reduces reliance on virgin materials.

6. Aggregates & Bitumen (For Pavement Layers)

- Conventional aggregates are used in base/sub-base layers.
- IIT PAVE allows optimization, so lesser aggregate thickness is needed.

IV. PERFORMANCE OF A PAVEMENT BASED ON HAAS

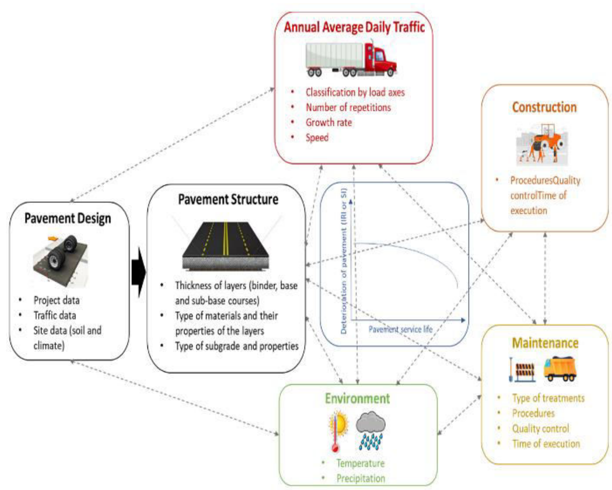

Fig 4.1 performance of a pavement based on Haas

The importance of pavements, beyond the functional and practical benefits for road users, is that they are a fundamental asset of transportation systems, but they are also a basic component of the functioning of the societal system [1]. Thus, pavements are considered the most important asset of road infrastructure in transportation systems.

Pavement design might be defined as the determination of the thickness of pavement, which has to be placed over a soil formation in a particular environment (the natural conditions) to provide a satisfactory riding surface for a given set of external conditions [2].

To ensure pavement durability, various institutions have developed several methods with empirical and mechanistic–empirical approaches to model pavement performance and deterioration as a function of different variables [3]. For flexible pavements, methods have been based on soil behavior, the use of theories, statistical analysis of field tests, etc., which have made it possible to classify the methods and study them [4,5,6].

The main variables that influence pavement design and performance are shown in Figure 1. It details how these variables interact with each other, which makes it a complex problem [7]. The variables considered are pavement structure design, traffic design, pavement construction, pavement maintenance, and the environment. These factors, all together, determine the service life of pavement.

Under the empirical methodology, the pavement design seeks to determine the thickness of the layers according to the material that will be used to support the loads of vehicles traveling based on previous experiences and observations of their behavior in field studies [9]. Empirical methods describe variables in climate where the design procedure does not always clearly define how they should be considered, which are currently of special interest since climate factors influence the physical, mechanical, and chemical characteristics of materials. For example, temperature (influences on solid state, thermoelastic, heat conservation and transfer, freezing, and thawing) [10,11,12,13], precipitation regime (mean and maximum annual precipitation, influences on relative moisture) [14,15], water table (influences in capillarity in the sublayers of the pavement) [16], solar radiation (impacts the destruction of asphalt bonds by UV light) [17,18], among others.

Environmental conditions have a significant effect on pavement performance [19]. Climate influences the rate of pavement deterioration, and, therefore, pavement maintenance and lifecycle costs [20]. Therefore, environmental factors and their variations are fundamental elements to be considered in pavement design and maintenance [21].

The environmental factors affecting pavements can be classified into two categories: external and internal. External factors that have a particular influence on the performance and durability of a pavement are temperature and precipitation, water table, and freeze-thaw cycles. The internal factors that impact pavement performance are moisture, drainage in the layers, and infiltration [19]. There are other external factors associated with the road design that influence the durability of the pavement, such as the road width, since a larger surface area requires better surface drainage, a cross slope to remove excess water rapidly from the road surface, the type of pavement and its condition, and ditch bottom width, but these elements are not well considered in pavement design.

To evaluate how climate has been considered, a review of historical design methods and new design approaches was conducted and then analyzed in detail to further identify how some of them have considered and incorporated climate into the structural design of a flexible road pavement. This review focused on methods used in North America (including Mexico) and those where an English version of the guide was available. Some pavement design manuals were identified, which did not include the methodology, so these are not part of this paper. Through this review, findings were identified to propose a practical way to incorporate climate into pavement design.

V. METHODOLOGY

The methodology is structured to combine experimental laboratory studies with computational design analysis.

Step 1: Site Investigation & Soil Characterization

- Conduct surveys to determine traffic volume and soil sampling.
- Perform soil tests:
- Sieve analysis, Atterberg limits, compaction (Proctor test).
- California Bearing Ratio (CBR).
- Unconfined Compressive Strength (UCS).
- Baseline data of weak subgrade properties is established.

Step 2: Subgrade Stabilization

Prepare soil samples mixed with different stabilizers (lime, cement, fly ash, plastic waste) in varying percentages (2%, 4%, 6%, 8%).

- Laboratory tests conducted:
- CBR (soaked/unsoaked).
- UCS after 7, 14, 28 days curing.
- Durability tests (wetting–drying cycles).

- Identify optimum stabilizer and percentage for maximum strength gain.

Step 3: Pavement Design Using IIT PAVE

Input parameters:

- Subgrade modulus, traffic loading, axle load spectra, climate data.
- Elastic modulus and Poisson's ratio of each pavement layer.
- Perform layered elastic analysis to calculate:
- Vertical compressive strain on subgrade (controls rutting).
- Horizontal tensile strain at bottom of bituminous layer (controls fatigue cracking).
- Optimize layer thicknesses to minimize cost without compromising durability.

Step 4: Cost Analysis

- Compare three scenarios:
- Conventional CBR-based design without stabilization.
- IIT PAVE-based design with natural soil.
- IIT PAVE-based design with stabilized subgrade.
- Perform life-cycle cost analysis, considering both construction and maintenance.

Step 5: Validation with Case Studies

Compare results with existing roads in India designed using IIT PAVE.

Validate subgrade performance by cross-checking with field test data.

VI.CONCLUSION

The study on low-cost pavement design using IIT PAVE software with subgrade stabilization demonstrates that the integration of computational design tools with innovative stabilization techniques can significantly improve the performance and cost-effectiveness of pavements. Traditional CBR-based methods often lead to over-designed and uneconomical pavements, whereas IIT PAVE enables a mechanistic–empirical approach that optimizes layer thickness based on actual strain and stress analysis.

Laboratory results on stabilized soils with lime, cement, fly ash, and plastic waste showed remarkable improvements in CBR values, compressive strength, and durability, which directly reduce pavement thickness requirements. When incorporated into IIT PAVE design, these improvements translate into 30–40% cost savings in terms of aggregates and bituminous material, while also extending service life and reducing maintenance.

Additionally, the use of industrial by-products and recycled waste materials in subgrade stabilization promotes sustainability, environmental conservation, and circular economy practices. Thus, the combination of IIT PAVE analysis and stabilization techniques provides a technically sound, economically viable, and environmentally friendly solution for modern pavement design, particularly suitable for developing countries like India where infrastructure growth must be achieved under strict budgetary and sustainability constraints.

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