REVIEW ON COMPARATIVE STUDY OF PARTIAL REPLACEMENT OF RIGID PAVEMENT WITH STONE AND A MIX OF LIME WITH LOCAL MATERIALS IN THE CORE PART & IT'S ECONOMIC ANALYSIS

Mr. Manoj Khadka, Research Scholar, Parul University,
Ankita Sharma, Assistant Professor, Parul University &
Prapti Lalpuriya, Assistant Professor, Parul University

ABSTRACT

This study explores two methods for improving road pavements in the hilly regions of Nepal using locally available materials. The first method involves replacing parts of rigid pavement with a mix of lime and local soil, while the second uses crushed stone or cobblestones instead of RCC (Reinforced Cement Concrete) pavement, both of which are more cost-effective and suited to the terrain. Hence, the study assesses the practicality and cost-effectiveness of replacing traditional rigid pavements by using a mix of lime with local hilly soil and stone soling in separate methods in Nepal's hill regions. It also evaluates the mechanical properties, durability, and load-bearing capacity of these modified pavements, comparing them to conventional rigid pavements [1]. The research combines principles from flexible and block pavement design to investigate the potential of stone soling as an affordable alternative, considering factors like construction, maintenance, and long-term durability [2]. It also examines the possibility of partially replacing rigid pavements with lime-treated, locally sourced granular materials, following flexible pavement design guidelines [3]. The goal is to explore whether stone soling and lime-treated local materials can serve as affordable and durable alternatives to traditional rigid pavements. To address issues like damage from the road edges to the centre, the study suggests creating a rigid outer boundary and filling voids with stone soling, lime, and local materials, which could improve durability and reduce future maintenance costs [4]. In the field, the California Bearing Ratio (CBR) value is determined using a Dynamic Cone Penetrometer (DCP), especially for sub-grade layers. This ensures the pavement is strong enough to handle the expected loads [5,20]. Research and lab experiments are used to find the compressive strength and Young's modulus of stone soling pavement [8,28]. Various lab tests, including the CBR and plasticity tests, assess the strength of a mix of lime and locally available materials. These tests assess the material's performance [6,7]. All of those Laboratory tests are conducted to evaluate the properties of the usage materials, and the results are compared with standard norms to recommend the best materials for construction [21]. An economic analysis looks at the cost-effectiveness of using local materials and their long-term benefits [9]. Early results suggest that using stone and lime improves the pavement's strength and reduces costs by using local materials, leading to more sustainable and economical pavement solutions [12].

Key words: Hilly regions of Nepal, Lime and local soil, Crushed stone, Cobblestones, Cost-effectiveness, Durability, California Bearing Ratio (CBR), Economic analysis

I. Introduction

The hilly regions of Nepal face considerable challenges in road construction and maintenance due to their rugged terrain, limited access, and socioeconomic constraints [10]. Highway pavements are essential structures that distribute vehicle loads to the underlying subgrade while providing a smooth, durable surface with acceptable riding quality, skid resistance, and noise control. Pavements are typically classified into two types: flexible and rigid [11]. One promising area of research involves using stone for strength and durability and lime for enhancing soil properties and performance [1]. Lime has long been used as a binder in road construction, with its use dating back to ancient civilizations. In modern applications, lime stabilizes local aggregates and soils, improving the strength, durability, and moisture resistance of road pavements. Derived from limestone, a sedimentary rock rich in calcium and magnesium carbonates, lime is abundant, cost-effective, and often sourced locally, which helps reduce transportation costs. Lime stabilization improves the properties of both clayey and granular soils, making them more suitable for road construction. This is particularly valuable in regions like Nepal, where mountainous terrain and variable soil types pose significant challenges [3,13]. Stone soling, an ancient road construction technique, continues to be relevant today, especially in challenging terrains like the hilly regions of Nepal. Historically used by civilizations such as the Romans, stone soling creates durable road surfaces using locally available materials. In Nepal, where transportation costs for imported materials are high, stone soling presents an economical and sustainable alternative, reducing both construction and maintenance expenses. By utilizing local stones, stone soling supports community engagement and environmental sustainability while offering resilience against harsh weather and difficult terrain. This study investigates the potential of stone soling as a cost-effective and adaptable solution for road construction in Nepal's mountainous areas, emphasizing its economic and practical benefits [14,18]. Traditional rigid pavements, typically made of concrete, are often uneconomical due to high material and maintenance costs, particularly in areas with low traffic volumes [15]. Other traditional pavement materials, such as gravel wearing courses and otta seal practices, commonly used in rural areas, also incur high maintenance expenses [16].

II. Literature

Lime in Road Construction

Lime treatment is an advanced technology used to improve the strength and stiffness of natural soils. It reduces the plasticity index of soils, enhances compaction properties, and increases bearing capacity. Long-term benefits include improved compressive strength, California Bearing Ratio (CBR), and resistance to frost, making it ideal for road construction, particularly in areas with poor soil conditions. [3,7]

Stone Pavement

In Nepal's hilly regions, stone pavements like crushed stone and cobblestones are used for road construction to improve connectivity and accessibility. Crushed stone provides a durable, weather-resistant surface for heavy traffic, while cobblestones offer aesthetic appeal and good traction but require more maintenance. Stone-paving techniques involve layers of sub-base, cushion materials, and sealing to create durable roads. While cobblestone roads date back to Roman times, they are still used in cities across Europe, the US, and parts of Africa and Asia today, appreciated for their durability, historical value, and aesthetic qualities.[18]

Block Pavement

Block pavement, using tightly fitted pavers on a flexible base, has roots in Roman roads. The modern version, concrete block pavements (CBP), started in the Netherlands in the late 1940s to replace clay brick streets. It quickly spread to Germany and Western Europe as an effective solution for both pedestrians and vehicles. The U.S. Army Corps of Engineers developed a design method combining the California Bearing Ratio method with block thickness for better performance, though further improvements are needed [23,30]. Concrete block pavements are flexible, distributing stress across interlocking blocks, and require frictional interlock and rigid edge restraints. They typically have three or four layers, with thickness varying by use: 40mm for footpaths, 50mm for driveways, 60mm for normal areas, and 80mm for service roads. According to BS 7533-2, pavement design requirements vary based on traffic load and usage. For heavy traffic areas (Category I), a site-specific design is required. Medium traffic areas (Category II) need thicker sub-bases and paving blocks, depending on CBR values. Light traffic or pedestrian areas (Categories IIIa, IIIb, IV) have lower requirements with thinner materials. Specific guidelines are provided for car parks, footways, private drives, and pedestrian zones. The laying pattern affects stability and load-bearing, with herringbone patterns (45° or 90°) being best for heavy traffic, while stretcher bond suits medium traffic. Parquet or stack bonds are unsuitable for vehicular use [24].

Interlocking Concrete Block pavement

The IRC: SP:63-2018 guidelines provide the design and construction standards for interlocking concrete block pavements, specifying block thickness based on traffic type: 60 mm for light, 80 mm for medium, and 100-120 mm for heavy traffic. Blocks must have uniform thickness within ±2 mm and length/width tolerance of ±2-3 mm. The design focuses on material quality, cement strength, and dimensional accuracy for optimal performance. For general use, blocks should have a compressive strength of at least 30 MPa, with 40-50 MPa for commercial traffic. Maintenance is minimal, mainly involving joint sand checks and block replacement [25]. Interlocking concrete pavement (ICP), developed from Roman roads and refined in the 1940s, provides durable, flexible, and low-maintenance surfaces resistant to freeze-thaw cycles, abrasion, and cracking. Interlocking Concrete Block Pavement (ICBP) uses modular blocks for quick, cost-effective installation, with performance influenced by block shape, size, thickness, and laying pattern [31].

Study on the Problem of Edge-to-Center Road Damage

In hilly regions like Nepal, road edges deteriorate due to landslides, erosion, poor drainage, heavy traffic, and weak road design. Water from drainage issues weakens the foundation, while heavy vehicles put extra stress on the edges. Tracy's Law, "If you lose the edge, you lose the road," highlights the importance of maintaining road edges for stability. These challenges affect road safety, durability, and maintenance, especially on narrow, poorly constructed roads in tough terrains [4,17].

Determining Young's Modulus and Compressive Strength of Stones and Rocks in the Hilly Region of Nepal

The mechanical properties of rocks in Nepal's hilly regions, such as Young's Modulus and compressive strength, vary significantly based on rock type, geological conditions, and tectonic influences. Research emphasizes the need for localized studies to assess the suitability of specific rocks for engineering applications. The process involves reviewing secondary research to identify rock types and using related studies to estimate values for Young's Modulus and compressive strength in the hilly region [8,21].

Study Life Cycle Cost Analysis (LCCA) for Flexible vs. Rigid Pavements

LCCA is a method used to evaluate and compare the long-term cost efficiency of different investment options to identify the most cost-effective maintenance strategy. Life Cycle Cost Analysis (LCCA) evaluates the long-term economic feasibility of pavement designs by comparing flexible and rigid pavements. The formula for calculating the Net Present Value (NPV) is:

$$\text{NPV}=\sum \frac{(\textbf{initial cost} \times (\textbf{1+growth rate})^{m}}{(\textbf{1+discount rate})^{m}}$$

Where the growth rate is 7%, and the discount rate is 15%. Flexible pavements require overlays every 5 years, (m=multiple periods), while rigid pavements do not, with maintenance costs based on Roads and Highways Department reports [19].

Methodology

The study area selected for this research focuses on a hilly or mountainous road in Nepal [10].

Environmental data, such as temperature and rainfall, were collected, along with local material samples for the necessary laboratory tests [9].

Traffic evaluation used seven-day commercial vehicle counts for design analysis, following IRC:9 guidelines for average daily traffic.

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The in-situ CBR of the subgrade soil can also be determined quickly from the Dynamic Cone Penetrometer (60º cone) tests using the following relationship (ASTMD 6951).

Log10 CBR = 2.465 - 1.12 Log10 N or equivalently: CBR%=$10^{[2.465-1.12\text{Log10}(N)]}$

where N is the rate of cone penetration in mm/blow [5].

The California Bearing Ratio (CBR) test, as per IRC norms, evaluates the load-bearing capacity of road materials like lime-treated local soil, stone dust, and granular substances. Soil properties such as liquid limit, plastic limit, and plasticity index are tested for the base and sub-base, particularly for lime-treated soil, as they indicate moisture content and material cohesion [7].

For stone soling, tests like compressive strength, specific gravity, water absorption, Aggregate Impact Value (AIV), and Los Angeles Abrasion Test (LAA) determine the material's strength, durability, and resistance to wear and impact, ensuring suitability for construction [21].

The RC (Indian Roads Congress) Westergaard method is used for rigid pavement design. It optimizes material usage while ensuring the pavement can handle traffic loads and environmental conditions, maintaining structural integrity [9].

Lime mixed with local materials is used in the base pavement design, following the flexible pavement approach and IRC CBR method. This technique improves subgrade strength, stability, and load-bearing capacity [22].

A cost analysis is conducted for three pavement options; rigid pavement, rigid pavement replaced with stone soling, and rigid pavement replaced with lime-mixed local granular material using the unit rate method [9]. Life cycle costs are evaluated using the Net Present Value (NPV) method. A comparison of the total costs for all three pavement options is then presented, highlighting the most cost-effective solution [19].

Calculation and plotting all lab experiments results, the traffic evaluation, design calculations, and cost analysis for stone soling pavements, lime-treated local materials as a base structure, rigid pavements, and the outer rigid RCC boundary, along with a comparative cost study of these options, will be performed using Excel spreadsheets for all designs, evaluations, cost analyses, and comparisons [26]. Necessary drawing of the related drawings (Cross-Section, Plan, Elevation) is done by AutoCAD Software [27].

III. Conclusion

This study investigates cost-effective and sustainable alternatives to traditional rigid pavements in the hilly regions of Nepal by utilizing locally available materials such as lime and stone. The research explores two methods: mixing lime with local soil to partially replace rigid pavements and using stone soling instead of RCC pavements for partial replacement. Both approaches aim to improve strength, durability, and load-bearing capacity while reducing construction and maintenance costs. The study also highlights the importance of creating a rigid outer boundary and filling voids with local materials to enhance pavement longevity. Early results suggest these methods can provide more affordable, durable, and environmentally sustainable solutions for Nepal's road infrastructure.

IV. Future Scope

This study opens several avenues for future research and development in the field of road construction using local materials in hilly regions of Nepal. Expanding the study to other hilly areas of Nepal or similar regions to see if the results apply elsewhere. Future testing of lime combinations with local materials will identify the best mix for cost, strength, and durability, while studying the long-term performance of roads under varying weather and traffic conditions. Exploring new technologies, like geosynthetics, to improve road stability, drainage, and erosion control. Further Study how using local materials can create jobs, save costs, and boost local economies. Developing Road designs that can be adapted to different regions with varying local materials. Studying how policies and regulations can support the use of local materials in road building, including potential incentives for sustainable practices It includes advanced material testing, cost analysis, and community engagement to align road designs with local needs.

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