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"EXPERIMENTAL AND COST EVALUATION OF FLEXIBLE PAVEMENT INCORPORATING CTSB AND CTB AS ALTERNATIVE PAVEMENT LAYERS"

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ABSTRACT

Treated Base (CTB) as alternative layers in flexible pavement construction. The proposed pavement structure consists of 40 mm Bituminous Concrete (BC), 60 mm Dense Bituminous Macadam (DBM), 100 mm CTB, 100 mm AIL, and 200 mm CTSB, resulting in a total pavement thickness of 500 mm. The performance of CTSB was experimentally evaluated and compared with conventional Granular Sub-Base (GSB) based on compaction characteristics, soaked California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). The CTSB mix containing 2% OPC-53 cement and ANT stabilizer achieved a soaked CBR of 75%, compared with 35% for GSB, while the 7-day and 28-day UCS values were 2.10 MPa and 2.85 MPa, respectively. The Optimum Moisture Content (OMC) increased from 5.20% for GSB to 6.80% for CTSB, while the Maximum Dry Density (MDD) remained comparable at 2.15 g/cc. The use of CTSB also enabled a reduction in sub-base thickness from 300 mm to 200 mm, representing approximately 33.33% reduction in thickness. The findings indicate that the proposed CTSB–AIL–CTB pavement system can provide improved load-bearing capacity, stiffness, and structural efficiency compared with conventional granular pavement layers. The study demonstrates the potential of cement-treated pavement layers for developing thinner and structurally efficient flexible pavement systems.

KEYWORDS: Cement Treated Sub-Base (CTSB), Cement Treated Base (CTB), Aggregate Interlocking Layer (AIL), Granular Sub-Base (GSB), Flexible Pavement, Soaked CBR, Unconfined Compressive Strength, Pavement Thickness.

INTRODUCTION

Flexible pavement is one of the most widely adopted pavement systems for road infrastructure because of its adaptability, ease of construction, and ability to distribute traffic loads through a layered structure. A conventional flexible pavement generally consists of bituminous surfacing, granular base and sub-base layers, such as Wet Mix Macadam (WMM) and Granular Sub-Base (GSB), supported by the prepared subgrade. The performance of such pavement depends significantly on the strength, stiffness, drainage characteristics, compaction, and durability of its individual layers. With the continuous growth of traffic volume, increased axle loading, limited availability of high-quality aggregates, and rising construction costs, there is a growing requirement for pavement systems that can provide adequate structural performance while reducing material consumption and overall construction expenditure.

Conventional granular pavement layers require considerable quantities of natural aggregates. The extraction, crushing, processing, transportation, and placement of these materials contribute significantly to pavement construction cost and environmental impacts. Furthermore, in regions where suitable aggregates are located far from construction sites, transportation becomes a major component of the total cost. These limitations have encouraged researchers and highway agencies to investigate stabilized pavement materials that can provide higher strength and stiffness with relatively smaller layer thicknesses. Cement stabilization is one such approach in which cement is incorporated into granular or soil materials to produce bound pavement layers with improved engineering properties.

Cement-Treated Sub-Base (CTSB) is a stabilized sub-base material produced by mixing suitable granular material with a controlled quantity of cement and water. The addition of cement improves the load-bearing capacity, stiffness, resistance to moisture, and durability of the layer compared with an untreated granular sub-base. Similarly, Cement-Treated Base (CTB) is a cement-stabilized base material designed to provide a stronger and stiffer structural layer beneath the bituminous courses. The improved mechanical properties of CTSB and CTB enable them to distribute traffic-induced stresses more effectively and potentially reduce the required thickness of conventional granular layers.

The use of CTSB and CTB can therefore provide both technical and economic advantages in flexible pavement construction. Higher stiffness and strength may allow a reduction in pavement layer thickness, resulting in lower quantities of aggregates, reduced hauling requirements, and potentially lower construction costs. However, the addition of cement introduces an additional material and processing cost. Therefore, the economic benefit of cement-treated pavement cannot be assessed simply by comparing the cost of individual materials; it requires a systematic comparison of the complete pavement structure, material quantities, layer thicknesses, construction requirements, and unit rates. This makes combined experimental and cost evaluation essential for determining whether CTSB and CTB are practical alternatives to conventional pavement layers.

From an experimental perspective, the engineering performance of cement-treated materials can be evaluated through parameters such as moisture-density relationship, optimum moisture content (OMC), maximum dry density (MDD), soaked California Bearing Ratio (CBR), and unconfined compressive strength (UCS). These properties provide an indication of compaction behavior, bearing capacity, stiffness, and resistance to deformation. The results can subsequently be used to assess the suitability of CTSB and CTB as structural pavement layers. A comparative assessment with conventional GSB and WMM can provide a better understanding of the improvement achieved through cement stabilization.

In addition to engineering performance, cost evaluation is an important consideration in pavement design and construction. A pavement alternative with higher strength may not necessarily be economical if the cost of cement and stabilization operations offsets the savings obtained from reduced aggregate quantities and layer thickness. Hence, a comprehensive economic evaluation should consider the quantities of cement, aggregates, water, transportation, mixing, laying, compaction, and other relevant construction activities. The cost per unit area and cost per kilometre can then be compared between the conventional and proposed pavement systems.

Therefore, the present study focuses on the experimental and cost evaluation of a flexible pavement incorporating CTSB and CTB as alternative pavement layers. The study investigates the engineering characteristics of cement-treated materials through laboratory testing and compares their performance with conventional pavement materials. Based on the obtained strength and bearing-capacity characteristics, the feasibility of adopting CTSB and CTB in the pavement structure is evaluated. A detailed cost comparison is also carried out by considering material quantities, layer thicknesses, cement consumption, and construction-related costs. The study ultimately aims to determine whether the proposed CTSB–CTB pavement system can provide a technically satisfactory and economically viable alternative to conventional flexible pavement construction.

Literature Review

Danish Farooq et al (2025) cement Treated Base (CTB) is a stabilized pavement base layer in which a controlled proportion of cement is thoroughly mixed with selected aggregates and water to produce a strong, durable, and relatively rigid layer capable of distributing traffic loads effectively to the underlying subgrade. The use of CTB is particularly important in modern pavement construction because conventional granular base materials often require large quantities of good-quality aggregates, whose production involves activities such as quarrying, drilling, blasting, crushing, screening, and transportation, thereby increasing construction cost, energy consumption, and environmental impacts. Moreover, conventional untreated granular layers may experience excessive deformation, rutting, and loss of strength when subjected to heavy traffic, repeated axle loading, moisture variations, and adverse climatic conditions. The main objective of the study is therefore to investigate the feasibility of using CTB as an alternative pavement base layer for improving the load-bearing capacity, structural performance, and durability of roads while maintaining an economical construction cost. In the experimental investigation, different percentages of cement are mixed with the selected aggregate material, and laboratory tests such as the Modified Proctor Compaction Test and Unconfined Compressive Strength (UCS) test are conducted to determine the optimum moisture content, maximum dry density, and strength characteristics of the cement-treated material. The results indicate that a cement content of approximately 3.5% provides optimum strength, demonstrating its suitability for applications where high load-bearing capacity is required. On the other hand, the 4% cement content produces the minimum rutting, indicating better resistance to permanent deformation and making it more suitable for roads subjected to heavy traffic and high axle loads. The study also indicates that cracking behavior in CTB is affected by both cement content and curing conditions because increasing cement content generally increases stiffness and strength but may also increase shrinkage-related cracking if not properly controlled. Proper moisture control, compaction, cement proportioning, and curing are therefore essential for achieving satisfactory CTB performance. From an economic perspective, CTB can reduce dependence on high-quality virgin aggregates and, when locally available materials are appropriately stabilized with cement, can reduce transportation and overall construction costs. Although CTB has certain limitations, particularly its susceptibility to shrinkage and reflective cracking and the requirement for careful construction and curing practices, its high compressive strength, improved stiffness, resistance to rutting, durability, and ability to utilize marginal or locally available materials make it a practical alternative to conventional untreated base layers. Overall, the findings of the study and previous research indicate that CTB can be an effective, economical, and robust pavement base solution, particularly for roads exposed to high traffic volumes, heavy axle loads, weak subgrade conditions, and demanding environmental conditions, provided that the cement content, aggregate characteristics, moisture, compaction, and curing are properly designed and controlled.

Guthrie et al. (2024) studied the strengthening of clayey soils using aggregate blending and cement stabilization. The research focused on improving the engineering characteristics of clayey soils by modifying their particle-size distribution through aggregate blending and enhancing their strength through cement stabilization. The combined treatment provides an effective approach for improving materials that may otherwise be unsuitable for pavement construction. The study highlights the potential of using locally available marginal soils after appropriate modification and stabilization, which can reduce dependence on high-quality natural aggregates and improve the load-bearing performance of pavement foundation layers. The findings are relevant to the present study because they support the use of stabilized and engineered materials as alternatives to conventional granular pavement layers.

METHODOLOGY

The proposed flexible pavement structure consists of a total pavement thickness of 500 mm and incorporates Cement Treated Sub-Base (CTSB), Aggregate Interlocking Layer (AIL), and Cement Treated Base (CTB) as alternative pavement layers. The upper bituminous portion comprises a 40 mm thick Bituminous Concrete (BC) wearing course over a 60 mm thick Dense Bituminous Macadam (DBM) binder course. Beneath the bituminous layers, a 100 mm thick Cement Treated Base (CTB) layer is provided to enhance structural capacity and load distribution, followed by a 100 mm thick Aggregate Interlocking Layer (AIL) to provide effective aggregate interlock and additional load distribution. The bottom structural layer consists of a 200 mm thick Cement Treated Sub-Base (CTSB), which provides improved stiffness, strength, and support to the pavement system. Thus, the proposed pavement crust is 40 mm BC + 60 mm DBM + 100 mm CTB + 100 mm AIL + 200 mm CTSB = 500 mm total thickness, resting directly over the prepared subgrade.

Mix Design of CTSB and CTB

The mix design of CTSB (Cement Treated Sub-Base) and CTB (Cement Treated Base) is carried out to determine the optimum proportion of granular material, cement and water required to achieve the specified strength, density, durability. Initially, the aggregates are selected and their grading is checked against the specified gradation limits. Different trial cement contents are then prepared, generally with varying percentages of cement, and the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are determined for each trial mix. Test specimens are prepared at the required compaction level and cured for the specified period, after which their Unconfined Compressive Strength (UCS) or other specified strength parameters are determined.

Table 1 Quantity of Cement Treated Sub-Base (CTSB) Mix Design with 'ANT' Stabilizer.

S. No.	Description	Grade	Units	Quantity
1	STAR Cement	OPC-53	%	2.00
2	ANT Stabilizer	-	ml/cum	50.00
3	Proposed CTSB layer thickness	-	mm	200.0
4	Rate of spray cement	OPC-53	kg/sqm	8.43
5	Rate of spray cement	OPC-53	kg/cum	42.16

RESULTS AND DISCUSSION

The test results of GSB and CTSB were compared to evaluate the improvement in the engineering and strength characteristics of the pavement sub-base material. GSB is an untreated granular material whose strength is mainly dependent on aggregate gradation, particle interlocking, moisture content, and compaction. In contrast, CTSB is a cement-treated material in which the addition of cement improves the bonding between the aggregate particles and consequently increases the strength and stiffness of the layer.

The results indicate that the CTSB mixture exhibited improved strength characteristics compared with conventional GSB. The development of cementitious bonds within the CTSB matrix resulted in increased resistance to deformation and improved load-carrying capacity. The strength of CTSB was evaluated primarily through Unconfined Compressive Strength (UCS), whereas the performance of GSB was mainly assessed using CBR and compaction characteristics.

Therefore, based on the laboratory results, CTSB can be considered a stronger and stiffer alternative to conventional GSB. The use of CTSB may reduce deformation and improve the structural capacity and overall performance of the pavement sub-base, subject to compliance with the applicable design specifications and construction requirements.

Table 2 Comparative Laboratory Results of GSB and CTSB.

Parameter	GSB	CTSB
Layer Thickness (mm)	300	200
OMC (%)	5.20	6.80
MDD (g/cc)	2.18	2.15
Soaked CBR (%)	35.0	75.0
7-Day UCS (MPa)	—	2.10
28-Day UCS (MPa)	—	2.85

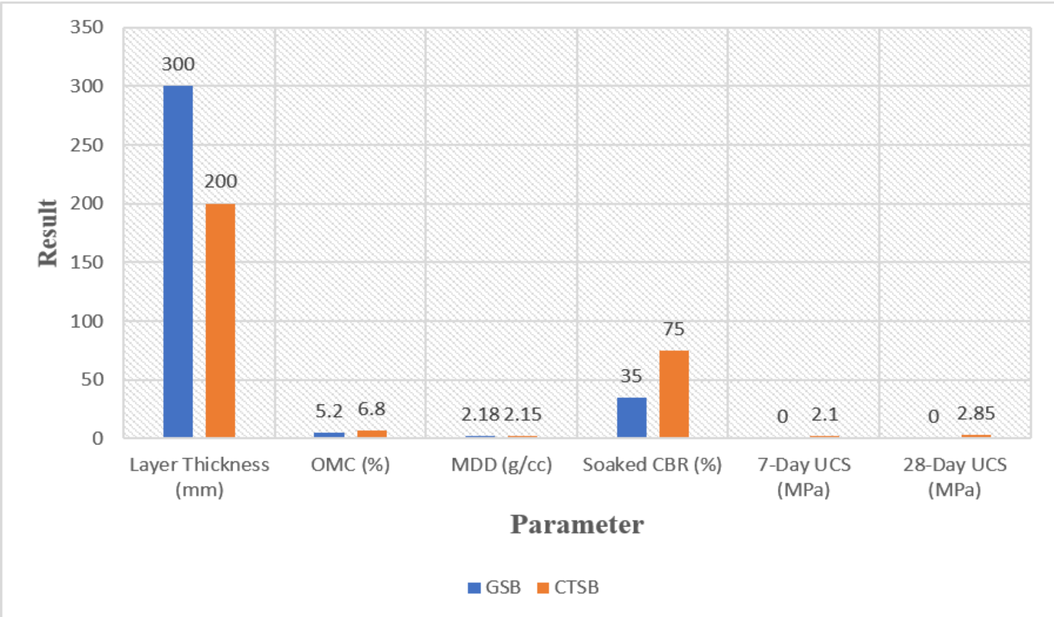

Figure 1 Comparative Laboratory Results of GSB and CTSB.

The comparative analysis of conventional Granular Sub-Base (GSB) and Cement Treated Sub-Base (CTSB) was carried out to evaluate the improvement in the engineering and strength characteristics of the pavement sub-base layer. The laboratory results indicate that the conventional GSB was designed with a layer thickness of 300 mm, whereas the proposed CTSB layer has a thickness of 200 mm. Thus, the CTSB layer thickness is reduced by 100 mm, representing a reduction of approximately 33.33% compared with the GSB layer.

CONCLUSION

Based on the experimental investigation and comparative evaluation, it can be concluded that Cement Treated Sub-Base (CTSB) provides significantly improved engineering and strength characteristics compared with conventional Granular Sub-Base (GSB). The CTSB prepared with 2% OPC-53 cement and ANT stabilizer achieved a soaked CBR of 75% compared with 35% for GSB, while the 7-day and 28-day UCS values reached 2.10 MPa and 2.85 MPa, respectively, indicating the development of adequate cementitious strength with curing. The proposed pavement structure comprising 40 mm BC + 60 mm DBM + 100 mm CTB + 100 mm AIL + 200 mm CTSB results in a total pavement thickness of 500 mm, with the CTSB layer thickness reduced from 300 mm to 200 mm, representing a reduction of approximately 33.33%. Although the OMC increased from 5.20% for GSB to 6.80% for CTSB, the MDD remained relatively comparable at 2.15 g/cc. Overall, the results demonstrate that CTSB, in combination with CTB and AIL, has good potential as an alternative to conventional granular pavement layers by improving load-bearing capacity, stiffness, and resistance to deformation while reducing pavement layer thickness. The proposed pavement system therefore offers a technically promising and structurally efficient alternative for flexible pavement construction, subject to further field validation, durability assessment, and detailed cost evaluation.

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