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A Study on Stabilization of Pavement Subgrade Soil using Chemical Additive

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ABSTRACT

The subgrade is a critical component of flexible pavement systems, as its engineering properties significantly influence the strength, stability, serviceability, and durability of the pavement structure. This study investigates the stabilization of pavement subgrade soil using a chemical additive to improve its engineering performance. Soil samples collected from the selected location are treated with different proportions of the chemical additive, and their properties are evaluated through laboratory investigations. The chemical additive is incorporated into the soil at varying percentages of 0.1%, 0.2%, 0.3%, and 0.4% by weight of dry soil. The effectiveness of the additive is assessed by comparing the properties of untreated and treated soil samples. Laboratory tests including consistency limits, Modified Proctor compaction test, moisture–density relationship, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) are conducted to determine the changes in the engineering characteristics of the subgrade soil. The study focuses on evaluating the influence of the chemical additive on maximum dry density, optimum moisture content, shear strength, compressive strength, and bearing capacity of the soil. The experimental results are used to identify the optimum percentage of chemical additive that provides maximum improvement in the subgrade properties. The findings of this study are expected to demonstrate the suitability of chemical stabilization as an effective and economical technique for improving weak subgrade soils and enhancing the performance and service life of flexible pavement structures.

Keywords: Pavement Subgrade Soil, Soil Stabilization, Chemical Additives, Soil Strength, California Bearing Ratio (CBR), Atterberg Limits, Compaction, Bearing Capacity, Flexible Pavement, Subgrade Improvement.

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I. INTRODUCTION

Pavement performance largely depends on the strength and stability of the subgrade soil, as it provides the foundation for the pavement layers and carries the stresses transferred from traffic loads. Weak subgrade soils generally possess low bearing capacity, high plasticity, poor drainage characteristics, and considerable volume changes under varying moisture conditions. These problems can result in excessive settlement, rutting, cracking, and premature pavement failure. Therefore, improving the engineering properties of weak subgrade soil is an important requirement for constructing durable and economical pavements [4], [5].

Soil stabilization is one of the widely adopted techniques for improving the strength and performance of problematic subgrade soils. Conventional stabilization methods commonly involve the use of chemical additives such as lime, cement, fly ash, and other cementitious materials. These additives modify the physical and chemical characteristics of soil and can significantly improve its compaction, strength, stiffness, and resistance to moisture-induced deterioration. A review of calcium- and non-calcium-based stabilizers indicates that chemical stabilization can provide an effective approach for treating a wide range of problematic soils used in pavement construction [12]. Similarly, studies on expansive soils have demonstrated that chemical additives can reduce undesirable volume changes and improve the overall engineering behavior of treated soil [2], [11].

Among the various chemical additives, fly ash has received considerable attention because of its pozzolanic properties and potential to utilize an industrial by-product in pavement construction. Fly ash-based stabilization can improve the engineering properties of weak subgrade soils while also providing an opportunity for beneficial reuse of waste materials. Zimar et al. reported that coal fly ash has significant potential for pavement subgrade stabilization and highlighted its influence on strength development and long-term performance [1]. Experimental investigations have also shown that combinations of fly ash and cement can substantially modify the engineering characteristics of stabilized subgrade soil, making such mixtures suitable for pavement applications [3].

Lime is another widely used chemical stabilizer, particularly for clayey and expansive soils. The addition of lime can reduce plasticity, improve workability, alter the soil structure, and increase the strength of the treated material. Gidday and Mittal demonstrated that lime treatment can improve the characteristics of dispersive subgrade soils and enhance their suitability for pavement applications [8]. Lime has also been investigated in combination with other additives to control the behavior of expansive soils under repeated wetting and drying conditions [4]. Such stabilization is particularly useful in regions where subgrade soils experience significant moisture fluctuations.

Cementitious stabilization is also effective in improving very weak subgrade soils subjected to pavement loading. Cement-treated soils can develop improved stiffness and load-bearing capacity through cementation and strength development. Laboratory studies under cyclic loading have shown the potential of cementitious treatment for improving the performance of very weak subgrade materials [5]. Further research has evaluated cementitious stabilization as a sustainable pavement treatment and reported improvements in the performance of weak subgrade soils [14]. Lime–cement combinations have also been investigated for highway construction, with

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attention given to both geotechnical performance and environmental considerations [13].

Recent research has expanded chemical stabilization beyond conventional lime and cement by investigating secondary additives, geopolymer materials, cement kiln dust, and other alternative stabilizers. The use of secondary additives with fly ash-based stabilization has been investigated for improving soft subgrades and optimizing their engineering performance [6]. Similarly, metakaolin and fly ash-based geopolymers modified with lime and gypsum have been studied for stabilizing highly expansive sulfate-bearing soils [7]. These developments indicate that the selection and combination of chemical additives can be tailored according to the characteristics of the soil and the required pavement performance.

More recently, researchers have explored combined chemical–mechanical stabilization techniques to achieve greater improvements in expansive subgrade soils. Cement kiln dust combined with polypropylene fibers has been investigated for improving the stability and pavement performance of expansive subgrade materials [10]. Other studies have examined combinations of activated carbon, coir fiber, and lime for enhancing flexible pavement subgrade stability [15]. These approaches demonstrate the growing interest in developing stabilization methods that improve strength while also addressing durability, sustainability, and resource-utilization concerns.

Therefore, the present study focuses on the stabilization of pavement subgrade soil using chemical additives. The study aims to evaluate the changes in the physical and engineering properties of untreated and chemically treated soil and to determine the effectiveness of the selected additive in improving subgrade performance. Parameters such as plasticity characteristics, compaction properties, and California Bearing Ratio (CBR) can be used to assess the improvement achieved through stabilization. The findings can contribute to the development of a more stable and durable pavement subgrade while reducing problems associated with weak and expansive soils. The study also supports the broader objective of adopting effective and potentially sustainable chemical stabilization techniques for road construction [1], [2], [12].

LITERATURE SURVEY

G.W., Yeo, R., Sharp, K.G. (1995) Noise and vibration are of concern with many mechanical systems, including industrial machines, home appliances, vehicles, Noise and vibration can also be used as the source of signals for machinery diagnostics and health monitoring, although this topic will not be discussed here.4,5 Once noise and vibration sources have been identified, the noise and vibration of machinery can be reduced by the use of vibration isolation, barriers, sound-absorbing materials, Sound-absorbing materials have been used increasingly in the construction of aircraft, spacecraft and ships because of their low weight and effectiveness when used correctly. This trend is driven by demands for higher load capacity and reduced fuel consumption for cars, trucks and aerospace structures. This has been due mainly to both improve technology and public concern about noise in everyday life. Architects and acoustical engineers now have a wide choice of sound-absorbing materials that not only provide the desired acoustical properties, but also offer an extremely wide variety of colors, shapes, sizes, light reflectivity, fire ratings, and methods of attachment – to say nothing of the costs of purchase, installation, up keep

P. Taylor and M. Balat. (2011) Most of the porous sound-absorbing materials

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commercially available are fibrous. Fibrous materials are composed of a set of continuous filaments that trap air between them. They are produced in rolls or in slabs with different thermal, acoustical, and mechanical properties. Fibers can be classified as natural or synthetic (artificial). Natural fibers can be vegetable (cotton, kenaf, hemp, flax, wood, etc.), animal (wool, fur felt) or mineral (asbestos). Synthetic fibers can be cellulose (bamboo fiber, for example), mineral (fiberglass, mineral wool, glass wool, graphite, ceramic, etc.), or polymer (polyester, polypropylene, Kevlar, etc.). Synthetic fibrous materials made from minerals and polymers are used mostly for sound absorption and thermal isolation. However, since they are made from high-temperature extrusion and industrial processes based on synthetic chemicals, often from petrochemical sources, their carbon footprints are quite significant. Recently, the use of natural fibers in manufacturing sound absorbing materials has received much attention

Kim,S. Jung, and J. Kim. (2010) Natural fibers are essentially completely biodegradable and modern technical developments have made natural fiber processing more economical and environmentally friendly. These new methods may result in increased use of high-quality fiber at competitive prices for industrial purposes. The absorption properties of sound-absorbing materials made of these fibers can be similar to those made from minerals. These properties can be modified by pre-treatments such as drying, carbonizing, impregnation, and mineralization. In addition, natural fibers are also safer for human health compared with most mineral synthetic fibers, since they do not need precautions in handling. An important microscopic parameter of a fiber is its diameter. The fiber diameter is directly related to the sound-absorbing characteristics of the material. Table 1 shows a comparison of the average fiber diameters of several types of industrial fibers measured using electronic microscopy techniques. In general, the diameter of natural fibers tends to be larger than the diameter of synthetic fibers obtained by extrusion. some scanning-electron micro scope images of samples of hemp, cotton and polyester fibers. It is evident that natural fibers have more irregular shapes and variable diameters compared to synthetic fibers.

C.N.V. Satyanarayana Reddy and N.V (2004) Changes in the biosciences and their relations to society over the last decades provide a unique opportunity to examine whether or not such changes leave traces in the language we use to talk about them. In this article we examine metaphors used in English-speaking press coverage to conceptualize a new type of (interdisciplinary) bioscience: synthetic biology. Findings show that three central metaphors They exploit social and cultural knowledge about books, computers and engines and are linked to knowledge of three revolutions in science and society These three central metaphors are connected to each other through the concepts of reading/ writing, designing and mass production and they focus on science as a revolutionary process rather than on the end results or products of science. Overall, we observed the use of a complex bricolage of mixed metaphors and chains of metaphors that root synthetic biology in historical events and achievements, while at the same time extolling its promises for the future.

T. Gnanada Rao and C.N.V. (2014) Synthetic biology is a new field of study which has its roots in a wide range of disciplines, approaches and traditions, each using quite different Did the collaboration and integration of many different disciplines within synthetic biology, which is hailed by

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some as the next industrial revolution, contribute to a revolution in the use of metaphors or lead to the construction of new metaphors However, there are discontinuities too in the language and framing, between for example the Human Genome Project, billed as enabling us to read the book of life and synthetic biology which, at least according to Venter, should enable us to move "from reading the genetic code to writing it Apart from this reversal in metaphorical direction, there are other differences, relating, not entirely surprisingly, to the aims and the methods used in synthetic biology, of which many are rooted in mechanical and computer engineering. Another, more important, difference emerges in the promises that are made around this new field. Instead of promising to cure all human ills, as was implicit in promoting the Human Genome Project, the focus here is more on curing the ills of the planet

II. EXISTING SYSTEM

The existing system for pavement subgrade construction generally relies on the use of naturally available soil after basic preparation, compaction, and conventional soil improvement practices. Since the subgrade acts as the foundation of the pavement and receives stresses transferred from the upper pavement layers, its strength, stiffness, moisture condition, density, and bearing capacity have a direct influence on pavement performance. Weak, highly plastic, expansive, or moisture-sensitive soils may not provide sufficient support and can lead to rutting, cracking, settlement, deformation, and other pavement failures.

In conventional practice, weak soil can be improved through mechanical stabilization, which mainly involves compaction or blending the soil with other materials to obtain better density and engineering properties. Another traditional approach is to remove the unsuitable soil and replace it with better-quality material. However, removal and replacement can increase construction cost, transportation requirements, and construction time. Therefore, stabilization is considered a more economical alternative when suitable improvement can be achieved without completely replacing the existing subgrade.

Several conventional stabilizing materials are available, including lime, cement, fly ash, polymers, fibers, and other chemical or industrial by-products. Lime is commonly used for clayey and highly plastic soils, while cement improves soil strength and stiffness through the development of stronger particle bonds. Fly ash can be used independently or together with lime or cement to improve compaction and strength characteristics. Polymer and liquid chemical stabilizers can also improve particle bonding and reduce moisture sensitivity, although their effectiveness depends on soil type, dosage, chemical composition, and curing conditions.

The major limitation of the conventional system is that the performance of a stabilization method is highly dependent on the type of soil, stabilizer selected, additive dosage, moisture condition, mixing uniformity, curing period, environmental conditions, and cost. A stabilizing material that works effectively for one soil may not provide the same improvement for another soil. Inadequate selection or dosage may therefore result in insufficient improvement in strength and bearing capacity.

Another limitation is that untreated or inadequately stabilized weak subgrade soil remains vulnerable to moisture-related deterioration. Changes in water content can alter the strength, stiffness, volume, and deformation behavior of soil, while poor drainage can further reduce its supporting capacity. Low CBR and inadequate strength can cause permanent deformation under repeated traffic loading.

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Thus, the existing system provides several methods for improving pavement subgrade soil, but there is a need for a systematic evaluation of a suitable chemical additive at different dosages. The present study addresses this requirement by comparing untreated soil with chemically stabilized soil containing 0.1%, 0.2%, 0.3%, and 0.4% additive, and evaluating changes in MDD, OMC, UCS, and CBR to identify the optimum additive content.

III. PROPOSED SYSTEM

The proposed system focuses on improving the engineering performance of pavement subgrade soil through chemical stabilization. In this approach, the selected subgrade soil is first collected, air-dried, pulverized, sieved, and subjected to preliminary laboratory investigations to determine its basic physical and engineering properties. Tests such as sieve analysis, specific gravity, Atterberg limits, swell index, and compaction characteristics are carried out to establish the condition and suitability of the untreated soil as a pavement subgrade.

After characterization, a selected chemical additive is incorporated into the soil at different percentages of 0.1%, 0.2%, 0.3%, and 0.4% by dry weight of soil. The additive is thoroughly mixed with the soil, and water is gradually added according to the required moisture condition obtained from the Modified Proctor test. An untreated soil sample is maintained as the control mixture, allowing the performance of chemically stabilized samples to be compared directly with the natural soil.

The proposed system evaluates the influence of the chemical additive on important pavement subgrade properties. The Modified Proctor test is used to determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), while the Unconfined Compressive Strength (UCS) test evaluates the improvement in compressive strength. The California Bearing Ratio (CBR) test is conducted to assess the load-bearing capacity of the stabilized soil. These parameters provide a systematic basis for determining whether the chemical treatment improves the subgrade's strength and supporting capacity.

The performance of each stabilized mixture is compared with the untreated soil, and the percentage improvement in major parameters such as MDD, UCS, and CBR is calculated. Particular emphasis is given to UCS and CBR because they provide important indications of the strength and bearing capacity of the pavement subgrade. The additive percentage that provides the most desirable improvement while maintaining satisfactory compaction characteristics is selected as the optimum chemical additive content.

The proposed system therefore provides a structured laboratory-based approach for identifying an effective chemical additive dosage for weak pavement subgrade soil. By improving strength, stability, and bearing capacity without relying solely on removal and replacement of unsuitable soil, the proposed approach aims to provide a practical and economical method for improving flexible pavement subgrade performance and service life.

IV. SYSTEM ARCHITECTURE

The system architecture illustrates the complete workflow for stabilizing pavement subgrade soil using a chemical additive. The process begins with soil collection from the selected location, followed by soil preparation through air-drying, pulverizing, sieving, and homogeneous mixing. The prepared soil is then subjected to preliminary investigations, including sieve analysis, specific gravity, Atterberg limits, swell index, and classification. Next, the chemical additive is incorporated at

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different percentages of 0%, 0.1%, 0.2%, 0.3%, and 0.4% by dry weight of soil, and the mixtures are thoroughly prepared with the required moisture content. The stabilized specimens are then evaluated through Modified Proctor, UCS, and CBR tests to determine their compaction, compressive strength, and bearing capacity characteristics. The test results are recorded and compared with the untreated soil, followed by calculation of percentage improvement in MDD, OMC, UCS, and CBR. Based on this analysis, the optimum chemical additive percentage is identified, which provides the most desirable improvement in strength and bearing capacity. Finally, the system evaluates the overall performance of the stabilized subgrade in terms of improved strength, bearing capacity, reduced plasticity and moisture sensitivity, and economical stabilization.

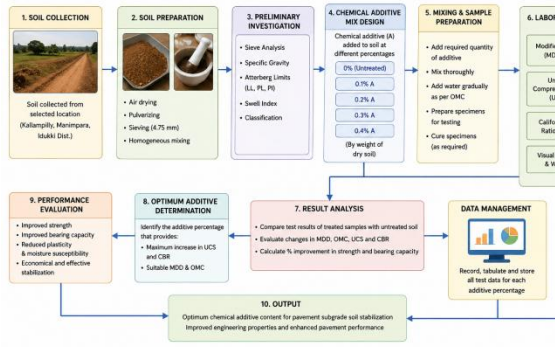


Fig 5.1: System Architecture

V. IMPLEMENTATION

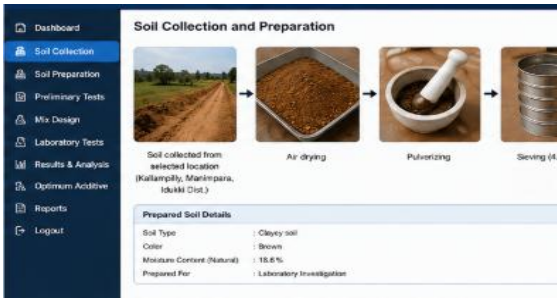


Fig 6.1: Soil Collection and Preparation

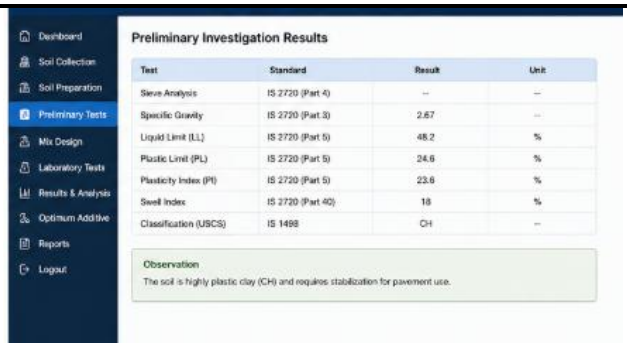


Fig6.2: Preliminary Investigation Results



Fig 6.3: Chemical Additive Mix Design and Sample Preparation

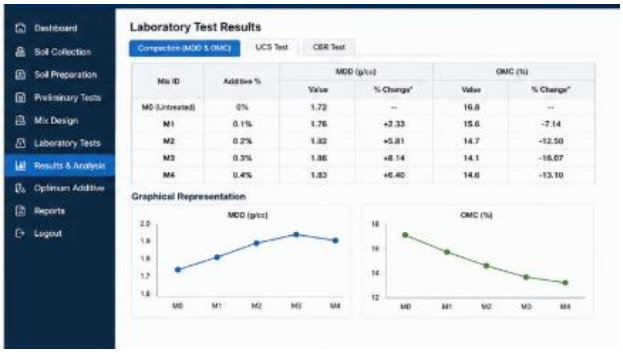


Fig 6.4: Test Results and Analysis

VI. CONCLUSION

The present study investigated the stabilization of pavement subgrade soil using a chemical additive at different percentages. The laboratory results showed that the addition of the chemical additive improved the engineering properties of the soil when compared with untreated soil. The Modified Proctor, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests were used to evaluate the effectiveness of stabilization.

The study demonstrated that chemical stabilization can improve the strength, compaction characteristics, and bearing

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capacity of pavement subgrade soil. The improvement in CBR and UCS indicates better resistance to traffic loading and deformation, thereby enhancing the expected performance of the pavement.

The results obtained for different additive percentages indicate that the effectiveness of stabilization depends on the quantity of chemical additive used. An optimum percentage can be identified based on the maximum improvement in the engineering properties of the treated soil.

The study also indicates that chemical stabilization can reduce the requirement for removal and replacement of weak subgrade soil. Therefore, it has the potential to provide a cost-effective and practical method for improving weak pavement subgrade soils and reducing pavement maintenance requirements.

Overall, the investigation confirms that the selected chemical additive can be effectively used for subgrade stabilization, subject to the soil type and optimum additive content determined through laboratory testing. The improved engineering properties can contribute to the construction of stronger, more stable, durable, and economical flexible pavement structures.

VII. FUTURE SCOPE

The future scope of this study can be extended by investigating a wider range of chemical additives and their combinations to identify more effective stabilizing agents for different types of pavement subgrade soils. Further studies can evaluate additive percentages beyond the 0.1%, 0.2%, 0.3%, and 0.4% levels considered in the present investigation and determine the optimum dosage for different soil conditions. Additional laboratory investigations can be carried out to study long-term durability, repeated traffic loading, moisture susceptibility, swelling and shrinkage behavior, and strength development with curing time. Field trials can also be conducted to validate the laboratory findings under actual pavement conditions. Future research may further examine the environmental and economic aspects of chemical stabilization, including the use of industrial by-products and sustainable additives. The influence of chemical stabilization on pavement thickness, maintenance requirements, and overall service life can also be evaluated to develop a more economical and durable pavement subgrade stabilization technique.

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