

ENHANCING THE PROPERTIES OF SUBGRADE SOIL: INVESTIGATION FROM THE HIGHWAY PROJECT

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ABSTRACT: The present investigation focused on soil stabilization methodologies expected to improve the properties of subgrade soil while pavement building. The subgrade layer, located beneath the base or surface course of the pavement, often consists of weak soil that lacks the necessary strength to support pavement loading. Effective soil stabilization is essential to ensure long-term performance and reduce pavement distress such as cracking and rutting. Various soil stabilization methods have been explored, including mechanical, cement, lime, bitumen, electro-osmosis, thermal, and chemical stabilization. Researchers have investigated using different materials and techniques to enhance subgrade soil properties. The application of soil stabilization techniques in Pakistan remains limited, highlighting the need for further research and implementation in highway projects. This Study provides valuable insights into soil stabilization methods and their potential benefits for subgrade soil improvement in pavement construction.

Keywords: Subgrade, Soil, coarse-grain soil, highway project

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INTRODUCTION

The subgrade layer, crucial to pavement structure, can be strengthened through various methods. (Luo et al., 2017) emphasizes the importance of considering subgrade and unbound layers in pavement design, highlighting the need for models that account for factors like moisture and stress dependency. (Ardah et al., 2017) and (Zumrawi, 2015) both explore the use of cementitious materials, with Ardah focusing on the handling of extremely weak subgrade soils and (Zumrawi, 2015) on the stabilization of expansive subgrade soils. Both studies find that the addition of cementitious materials greatly enhances the intensity and strength of the subgrade. (Amhadi et al., 2021) proposes an innovative approach to improving the desert sand subgrade, using a mix of fly ash, ordinary Portland cement, and artificial sand. These studies collectively underscore the importance of understanding and enhancing the performance of subgrade materials in pavement construction. The design of pavement should prioritize efficient, cost-effective, and optimal utilization of subgrade materials (Alzaim et al., 2020). Weak subgrades may require treatment methods to improve workability and create a stable platform for pavement construction (Alzaim et al., 2020). Using high-modulus asphaltic materials at least three percent subgrade CBR is

one of these methods. (Rasul et al., 2018) emphasized the importance of considering soaking and dry up effects on the performing of become stable subgrade soils, and (Ardah et al., 2017) highlighted the correlation between water/additive ratio and performance-related properties in cementitious treated soils. (Nagrle & Patil, 2017) further demonstrated the significant stabilization has enhanced the subgrade soil's engineering properties., leading to enhanced pavement response. These studies collectively underscore the need for a comprehensive approach to evaluating and enhancing the strength and durability of subgrade soil in pavement construction.

Soil stabilization in road construction is a crucial process that seeks to improve soil's mechanical qualities, making it fitting for supporting infrastructure. This be able to be achieved through various methods, including mechanical and chemical stabilization (Amhadi et al., 2018) and (Afrin, 2017). The usage of natural ingredients, such as pozzolana activated with lime, has been identified as an effective approach to soil stabilization (Balan et al., 2021). Additionally, innovative techniques like the use of geosynthetics have been proposed to further improve soil stabilization methods (Danu, 2021). These approaches collectively contribute to the cost-effective and efficient construction of roadways.

The distress in pavement structures due to poor subgrade soil quality can be effectively addressed through cost-effective solutions. (Mishra et al., 2019) and

(Amhadi, & Assaf, 2018) both propose the use of stabilizers such as stone dust, coarse aggregate, cement, and fly ash to improve soil properties, resulting in increased strength and reduced pavement distress. (Bhat, 2018) further supports this by suggesting the use of construction and demolition waste as a soil stabilizer, which not only enhances subgrade properties but also reduces environmental hazards and construction costs. These studies collectively highlight the potential of cost-effective soil stabilization methods in addressing pavement distress in developing countries like Pakistan.

A range of studies have explored the use of various stabilizing materials to enhance the performance of subgrade soil in pavement construction. (Mishra et al., 2019) and (Bandara et al., 2015) both found that the addition of stabilizers such as stone dust, coarse aggregate, and recycled materials can significantly improve the engineering properties of subgrade soil, leading to cost savings and environmental benefits. (Adeyanju et al., 2020) further demonstrated the effectiveness of rice husk ash-based geopolimer and cement kiln dust in stabilizing subgrade soil, resulting in improved mechanical strength and cost reduction. (Nagrle et al., 2017) also highlighted the positive impact of stabilizers such as hydrated lime, class F fly ash, and polypropylene fibers on the properties of subgrade soil, leading to increased service life and reduced layer thickness in pavement construction. These findings collectively support the use of locally available coarse-grain soil as a sustainable and cost-effective alternative for subgrade enhancement in pavement projects.

While stabilized subgrade roads have been for years a topic of discussion on a global scale, relatively little work has been done in Pakistan to confirm their suitability in terms of performance and adaptation. In our

nation, subgrade soil stabilization is not done. A survey of the literature shows a lack of clarity on the use of stabilization methods in this nation. Thus, the following is the research's goal.

Highways play an essential character in the economic development of a country, and they are significant investments. However, subgrade soils in highways often deteriorate due to various factors, leading to excessive settlement of embankments and substantial maintenance costs. The weak subgrade is a prevalent issue in many highway projects. Researchers worldwide have extensively studied this topic. One prominent example is the N-55 Indus Highway, which serves as a vital transportation link connecting industrial, agricultural, tourism, airport, and Gwadar Seaport areas to China and central Asian countries. As this route is heavily traveled, it often requires the construction of roads in areas with unsuitable subgrade conditions. For instance, some regions have soft clay or swelling soils, such as the road section from Dera Ismail Khan to Karak. Consequently, pavement sections in these areas have exhibited defects, as observed recently in the Gaandi Chouk Lakki Marwat, Khyber Pakhtunkhwa Pakistan to Pezu Lakki Marwat, Khyber Pakhtunkhwa Pakistan.

A lot of research has been done to evaluate and improve the power of subgrade soil in order to address such problems. The goal of this study is to increase to the body of existing information by researching while improving the appearances of subgrade soil, particularly in the context of the identified problematic areas. By focusing on the subgrade soil along the N-55 Indus Highway and similar regions, this study marks to give valuable insights and recommendations for the effective management and enhancement of subgrade soil in highway construction projects.



Fig 1. N55 Road Segment near Pezo Bypass

LITERATURE REVIEW

A range of studies have explored the advantage of various stabilizers to enhance the properties of subgrade soil for pavement construction. (Nagrале et al., 2017) found that hydrated lime, class F fly ash, and polypropylene fibers significantly improved the soil's engineering properties, leading to a longer service life and reduced layer thickness. (Balan et al., 2021) emphasized the use of natural pozzolanic materials, such as lime-activated pozzolana, for effective soil stabilization. (Qubain et al., 2000) and (Zumrawi, 2015) both highlighted the benefits of lime and fly ash-cement stabilization, respectively, in reducing pavement thickness and enhancing the Strength and durability of subgrade soil. These studies collectively underscore the importance of soil stabilization in enhancing the performance and longevity of road pavements.

Significant laboratory experiments and organized research have focused on improving subgrade properties using different materials. For instance, the usage of weak subgrade ingredients with cement and hydraulic road binder (HRB) has shown promising results. Test results revealed that three types of subgrade soils, namely Dresden, Blenheim, and Niagara, exhibited fine-grained characteristics with significant silt, clayey particles, and organic matter. The application of cement and HRBs brought about important enhancements in the engineering properties of the soil. These improvements included shifting the soil's environment from acidic to alkaline, preventing the development of organic matter, and enhancing strength, durability, and resilient modulus. Moreover, subgrade soils treated with HRBs exhibited lower sulfate content compared to those treated with cement, reducing the risk of sulfate-induced issues (Wang & Baaj, 2021).

Through these research efforts, it is evident that various stabilization techniques, such as the use of cement and HRBs, have proven actual in improving the engineering properties of subgrade soils. These advancements contribute to the overall stability, durability, and load-bearing capacity of the subgrade, resulting in improved road performance and reduced risks associated with sulfate-induced problems.

In typical circumstances, clayey soil on construction sites might not have the required strength. It might result in obvious shrinkage and swell and cause significant harm to pavement infrastructure. The shifts in moisture content and the ensuing damage could be attributed to changes in the seasons. Volumetric changes lead to cracking, which erodes the subgrade and harms the buildings above. To give a high degree of durability and stability, the soil must be stabilized. (Agarwal et al., 2023).

A range of experiments have discovered the challenges of expansive soils in construction, particularly in Ethiopia. (Fentaw et al., 2021) and (Raut et al., 2014) both highlight the potential of industrial and agricultural waste materials, such as marble dust, rice husk ash, and fly ash, in stabilizing these soils. (Murali et al., 2018) further emphasizes the use of admixtures to improve soil properties. (Kabubo et al., 2017) presents an innovative approach, using heat to enhance the properties of expansive clay soil. These studies collectively underscore the importance of finding cost-effective and sustainable solutions to address the challenges posed by expansive soils in construction.

(Roy, 2013) found that the unconfined compressive strength (UCS) and California bearing ratio (CBR) of lime RHA and lime RRH stabilized soil increased with longer curing periods. Similarly, (Çanakçi et al., 2015) and (Roy, 2013) both reported that the addition of RHA to soil increased its strength, with (Çanakçi et al., 2015) identifying 15% RHA as the optimum content. (Gupta & Kumar, 2017) further supported these findings, showing that the addition of RHA and pond ash to clayey soil enhanced its strength, with the best results achieved with a combination of 40% pond ash, 10% RHA, and 4% cement. These studies collectively highlight the potential of RHA as a cost-effective and environmentally friendly soil stabilizer.

A range of studies have demonstrated the success of rice husk ash (RHA) in stabilizing soil. Biswas (2003) found that the unconfined compressive strength (UCS) and CBR of lime RHA and lime RRH stabilized soil increased with longer curing periods. Similarly, (Çanakçi et al., 2015) and (Roy, 2013) both reported that the addition of RHA to soil increased its strength, with (Çanakçi et al., 2015) identifying 15% RHA as the optimum content. (Gupta & Kumar, 2017) further supported these findings, showing that the addition of RHA and pond ash to clayey soil increased its strength, with the best results achieved with a combination of 40% pond ash, 10% RHA, and 4% cement. (Alhassan & Alhaji, 2017) and (Behak, 2017) both emphasized the potential of RHA as a cost-effective and environmentally friendly soil stabilizer, with (Alhassan & Alhaji, 2017) specifically highlighting its potential for improving deficient soils in Nigeria. (Behak, 2017) also noted the environmental, social, and financial benefits of using RHA as a soil stabilizer. Due to fly ash's wide accessibility, stabilizing the soil with fly ash and a lime or cement mixture has taken on more importance lately. When opposed to other stabilization methods, this one is cheaper and requires less time. In the field, fly ash can be mixed with soil while excavation is ongoing.

In the study on the strength enhancement of weak subgrade soil, a ground improvement technique was employed using truncated cone-shaped no-fenced

concrete nails. The effectiveness of this technique was validated through the California Bearing Ratio (CBR) test. No fine concrete nails of varying diameters and heights were inserted into the subgrade soil at different depths. The objective of this method was to provide an efficient solution for stabilizing weak subgrade soil on village roads with low traffic.

The researchers conducted CBR tests to evaluate the performance of the subgrade soil improved by the no fine concrete nails. They discovered that a practical mix with an aggregate with cement ratio of 6:1 or 7:1 yielded favorable results. They recommended the use of these mixtures for various applications such as casting in-situ walls in low-rise structures, low-cost housing (with external plastering to decrease air and water sponginess), drainage layers, and paving. However, further investigation is needed to explore the full potential and applications of these mixtures (Rai et al., 2021).

The use of proper compaction techniques and chemical stabilizers, such as Portland cement, lime, and fly ash, can significantly improve the strength and workability of weak subgrade soils, making them suitable for pavement construction. (Ardah et al., 2017) found that a low water/additive ratio is key to achieving better performance in cementitious treated/stabilized soils. (Eisa et al., 2022) further demonstrated that a mix of granular and chemical stabilization, particularly with 6% lime or cement kiln dust, can enhance the strength and reduce the plasticity of weak subgrade soils. (Nagrle & Patil, 2017) and (Rathod, 2017) both highlighted the significant improvements in engineering properties and pavement response due to stabilization, with Nagrle specifically noting the considerable reduction in layer thickness and construction cost.

The process of changing one or more soil qualities by chemical or mechanical stabilization in order to generate a developed soil material with the required engineering properties is known as soil stabilization. A desired gradation of the soil may be accomplished through blending it or by mixing it with easily obtainable additives that may alter its gradation, appearance, or plasticity or serve as a binder for the cementation of the soil. (Danu, 2021)

Soil modification/stabilization: The concept of "soil stabilization" or "modification" indicates a method for improving the physical or chemical properties of the soil using a range of methods, such as mechanical compaction and the application of compounds high in calcium. The kind and condition of the soil determine which stabilization measures are best. For coarse-grained soils at optimal or lower optimal moisture concentrations, mechanical stabilization works well. Clayey soils, however, respond well to chemical stabilization. According to Meshram et al. (2021), modification is the process of adding just enough stabilizer to a clayey soil to

make it feasible, better in texture, and compatible regardless of its strength and durability. However, modification is only allowed for soil with the AASTHO designations A-4, A-5, A-6, and A-7. However, in addition to change, stabilization also refers to the choice of stabilizer to get specific goal strength/stiffness values. In conclusion, part of modification/treatment is creating a working platform alone for construction, but stabilization is required if we're talking about building a subbase for pavements. Various nations developed their own standards for adjustment and stability. These suggestions are the same as those made by Indiana DOT when choosing stabilizers. The foundation of pavement structural design is a belief that every layer in the pavement system will meet the basic requirements for pavement structural quality. All layers of the pavement system should be capable of enduring shearing, prevent excessive deflection that could cause fatigue cracks, and then provide safeguards against extreme permanent deflections. The load distribution systems throughout each layer over a larger area grow as the quality of the pavement increases, resulting in a significant drop in the required thickness of the pavement system. Typically, soil stabilization results in better soil. Quality improvement: Decrease of the plasticity index or swelling potential and improving durability and strength with a better soil gradation are the most typical benefits achieved through soil stabilization. Improvement can also be used to provide a working surface for construction procedures when it's raining. Thickness reduction: By using additives to improve the layer's strength and stiffness, the enhanced material's design thickness can be lowered compared to an unbound or unsterilized version of the same material. If further inspection shows that the pavement's strength, regularity, and durability condition are sufficient, the layer thickness can be decreased. (Dhakal, 2012).

There are various methods employed for soil stabilization, and the degree of improvement achieved can vary within each method as well as between different methods. This variability is due to the wide range of soil types and their different responses to various stabilizers. The following methods are commonly used for soil stabilization:

Mechanical stabilization: A range of inquiries have explored the use of mechanical stabilization techniques to enhance soil stability and load-bearing capacity. (Amiralian et al., 2012) and (Hasan et al., 2019) both highlight the success of fly ash and lime as additives to enhance the qualities of soil such as strength, swelling, and plasticity index. (Ramaji et al., 2012) further emphasizes the cost-effectiveness of these additives, particularly Portland cement, lime, fly ash, and scrap tire. Finally, (Takhelmayum et al., 2013) underscore the role of using fine and coarse fly ash blends to stabilize black

cotton soil while preventing compaction and limiting compressive strength. These studies collectively underscore the potential of mechanical stabilization techniques in enhancing soil stability and load-bearing capacity.

Cement stabilization: Cement stabilization is a widely used method for improving soil strength and reducing its susceptibility to moisture-related changes, particularly in clayey soils. (Bowers et al., 2013) found that the accumulation of sodium chloride and calcium chloride can improve intensity gain in soil-cement stabilization, with varying results depending on the soil type. (Boobathiraja et al., 2014) testified that the addition of cement and other pozzolanic materials significantly improved the strength characteristics of peat soil. (Mudliar et al., 2019) emphasized the use of cement in soil stabilization to improve geotechnical features such as plasticity, compaction, and unconfined compressive strength. (Rivera et al., 2020) demonstrated the effectiveness of alkali-activated cementitious materials in stabilizing clayey soil, with comparable results to soil-cement mixtures.

Lime stabilization: An approach that is frequently employed to enhance cohesive soil qualities is lime stabilization, particularly those with high clay content. It enhances soil strength, reduces plasticity, and increases durability (Manzoor & Yousuf, 2020). This approach works successfully for stabilizing subgrade soils that are subjected to freeze-thaw cycles, with lime-treated soil showing higher unconfined compressive strength and lower plasticity (Ismeik & Ahmed, 2020). In clay-raised forest soil road subgrades, lime stabilization has been shown to decrease liquid limit and plasticity index, increase plastic limit, and improve compressive strength, with the most significant improvements observed at a 9% lime treatment (Keybondori & Abdi, 2021). The mechanism of alteration in soil properties through lime stabilization has been attributed to changes in ionic exchange, mineralogy, and microstructure (Jha & Sharma, 2021).

Bitumen stabilization: Bitumen stabilization of granular soil has been found to improve its strength and compaction characteristics, with 4% bitumen content being the optimal level (Ogundipe, 2014). This method has also been successfully applied to black soil, resulting in increased strength and improved CBR values (Verma, 2015). The combination of Portland cement and bitumen emulsion has been shown to enhance the stiffness and elasticity of soil, thereby increasing pavement-bearing capacity (Baghini et al., 2013). Furthermore, bitumen is effective in stabilizing lead-contaminated Iraqi soil, with 3% bitumen emulsion being the optimal level (Mutter, 2021).

Electro-osmosis: Electro-osmosis, a technique that applies an electric field to the soil to improve drainage and stability, has been extensively studied. (Sahib et al., 2020) and (Pandey, 2019) both highlight its potential for dewatering and stabilizing fine-grained soils, with (Pandey, 2019) emphasizing the need for suitable electrodes and treatment schemes. (Shin et al., 2017) further explores the technique's potential for remediation of arsenic-contaminated soil, finding that higher moisture content enhances its efficiency. (Estabragh et al., 2014) provides experimental evidence of the technique's ability to improve the settlement and strength of clay soil. These studies collectively underscore the potential of electro-osmosis for soil improvement, while also highlighting the need for further research to optimize its application.

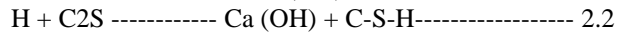
Thermal stabilization: Thermal stabilization, a key method in soil stabilization, has been the focus of several studies. (Sharma et al., 2022) provides a comprehensive review of various thermal stabilization techniques, highlighting their importance and comparing it with other methods. (Omer, 2017) explores the effects of soil thermal properties, including density, moisture, salt concentration, and organic matter, on the success of thermal stabilization. (Usman, 2018) emphasizes the role of thermal treatment in improving the availability of organic pollutants in contaminated soils, making them more amenable to subsequent remediation techniques. (Tiwari, S & Tiwari, N, 2016) investigate the use of waste fiber materials in soil stabilization, suggesting that these materials can enhance the shear strength of unsaturated soil.

Chemical stabilization: A range of soil stabilization methods have been explored in the literature. (Hasan et al., 2019) discusses the use of mechanical and chemical stabilization techniques, including the addition of certain proportions of additives such as lime, cement, gypsum, fly ash, and slag. (Leonard, & Latta, 2011) introduce the use of an epoxy resin ester of unsaturated fatty acids, with the option of adding small quantities of cement. (Lakhanpal & Chopra, 2018) emphasize the importance of proper testing and the use of alternative materials such as waste from various industries for soil stabilization. (Negi et al., 2013) provide a detailed analysis of soil stabilization using lime, highlighting its role in increasing soil-bearing capacity, resistance to weathering, and permeability. These studies collectively underscore the need for a comprehensive evaluation of soil composition, project requirements, and cost-effectiveness when selecting a suitable stabilization method.

Mechanism of stabilization: Knowing the performance and functions of the additive in connection beside the soil is vital before selecting a specific stabilizer. According to (Ardah et al., 2017), the soil maintenance process can be defined as the finishing and/or combining of soil particles

to create a production soil with enhanced quality. Despite a few distinct methods, the stabilization mechanism of these stabilizers is nearly identical. Four distinct steps can be used to sum up the whole stabilizing process (Dhakal, 2012). The basic techniques for mechanical stability consist of mechanical remediation, geo-reinforcement, and compaction, mixing, or blending of two or more levels. (Barasa, 2017). Cation exchange, Flocculation and agglomeration, Cementitious hydration, and Pozzolanic reaction.

The clay and stabilizer perform a quick reaction called as cation exchange a few minutes after mixing, which enhances the soil's texture. A charge shortage draws the cations or water molecules to the 2:1 (2T and 1O) or 1:1 (1T and 1O) tetrahedral (T) and octahedral (O) connectional of clay minerals. Clay minerals usually include sodium or potassium (Na⁺ or K⁺) in addition to water. However, higher valence cations like Al⁺³, Ca⁺², Mg⁺², etc. can replace them thanks to a process called "cation exchange". A calcium-rich chemical stabilizer supplies sufficient actions to replenish the monovalent cations during this stage, causing the diffused double layer to thicken. (Dhakal, 2012). The stabilizing agent, soil, and water mixture produces calcium, which then becomes available for soil stabilization. Equations represent the general cement-water reaction that creates calcium shown in equations 2.1 and 2.2.



where C2S = di-calcium silicate, C3S = tri-calcium silicate, H = H₂O, C = Ca, and S = SiO₂. The change in the arrangement of clay fragments from front arrangement to a smaller direction of the edge-face is known as flocculation and agglomeration. The coarser-grained soil, with significantly more strength/stiffness and workability, replaces the finer-grained soil (Barasa, 2017). Similar to cation exchange, flocculation and

agglomeration occur fast after mixing stabilizer and water with subgrade soil, typically within a few hours.

It has been found that incorporating carbonated cement paste in composite cement creates a dense microstructure with a rapid strength gain (Elarabi et al., 2016). This is further reinforced by the calcium hydrochloraluminum and calcium hydronitroaluminum stability conditions in the cement matrix, which improve the material's strength and stability (Elarabi et al., 2016). Collectively, these results highlight how various cement elements lead to the increased durability and resilience of soils treated with cement.

The Pozzolanic reaction is a long procedure, is crucial for the stability and strength of stabilized soils (Harty, 1970). The smallest possible pH of 12.4 is necessary to maintain this reaction (Grim, 1960). (Kadhim et al., 2020) and (Kang et al., 2019) both explore the use of alkali-activated materials, such as metakaolin/natural pozzolan and Class F fly ash, to enhance the pozzolanic reaction and improve material properties. (Turan et al., 2022) introduces a modification method for fly ash, which enhances its pozzolanic activity and material properties.

METHODOLOGY

The methodology for this research study involved a systematic approach to select a representative site and evaluate the subgrade performance. The specific road 52.8 km section between Gaandi Chouk Lakki Marwat, Khyber Pakhtunkhwa Pakistan, and Pezu Lakki Marwat, Khyber Pakhtunkhwa Pakistan on Indus Highway N-55 in the Lakki Marwat and DI Khan districts of KPK, Pakistan, was chosen as the site for the study.

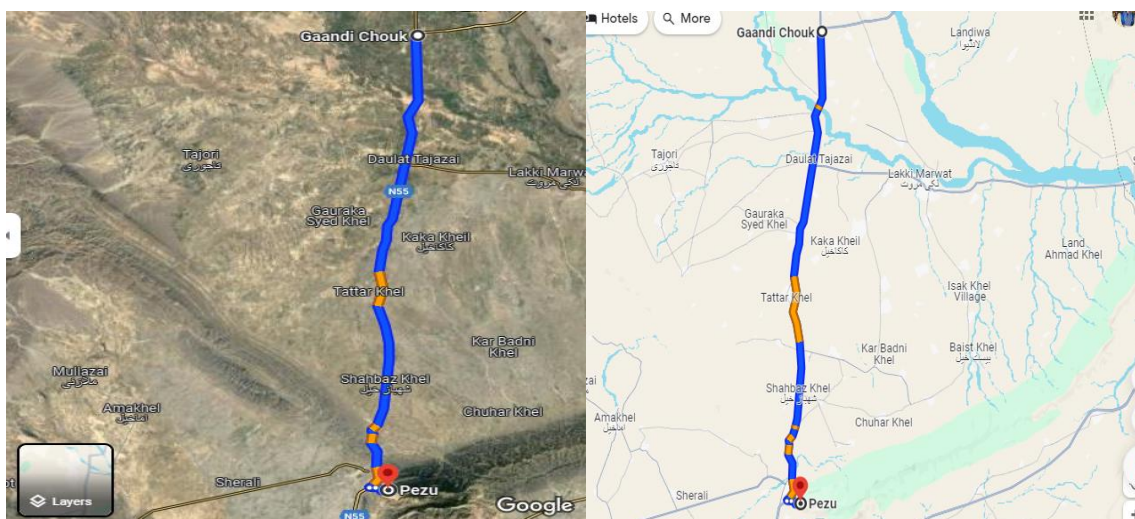


Fig 2. The road segment shown on each map from Pezu to Gaandi Chouk

The selection of this road section was based on several factors. Firstly, it exhibited a significant number of road defects, including rutting, cracking, potholes, and uneven pavement surfaces. These defects made it a suitable candidate for evaluating problematic subgrade performance. By studying this section, the research aimed to identify the underlying causes of these issues and propose potential solutions.

Furthermore, the chosen road section held great importance in terms of transportation and trade. Indus Highway N-55 played a vital role in facilitating trade

between District Lakki Marwat and District Bannu, as well as providing a crucial route to Peshawar. Therefore, improving the performance of the subgrade on this road had practical implications for enhancing transportation infrastructure, promoting trade, and ensuring efficient connectivity. By carefully selecting the site and focusing on this specific road section, the research aimed to gain a deeper understanding of subgrade performance, identify the factors contributing to road defects, and propose effective strategies for improving road durability and safety.

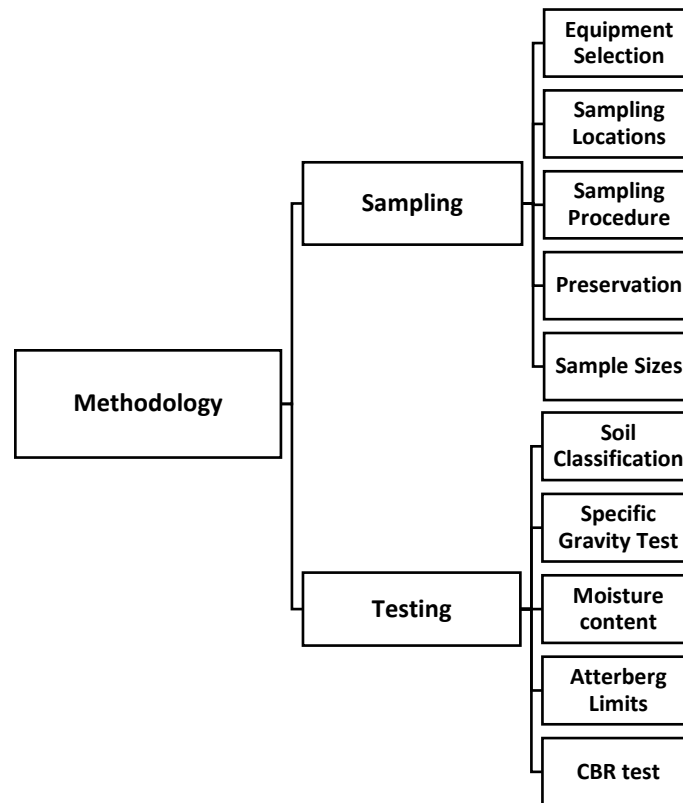


Fig 3. Flow chat

Sampling: The sampling process for this research study followed established standard practices and geotechnical standards to ensure accurate representation and preservation of soil samples. Appropriate equipment soil augers and core barrels, was chosen to extract soil samples from selected locations along the road section. The selection considered factors such as soil heterogeneity and identified road defects. Sampling locations were determined based on the need to capture representative subgrade conditions. Samples were collected at sufficient depths to encompass the entire subgrade profile and allow for a comprehensive analysis. Care was taken during the sampling process to ensure the integrity of the collected samples. Samples were properly

labeled, documented, and handled to maintain their original characteristics and prevent contamination.

Preservation: Soil sample preservation was crucial to prevent alteration or loss of properties. The collected samples were stored in a suitable environment, such as a temperature-controlled laboratory, to minimize moisture loss and preserve their original characteristics. Precautions were taken to avoid cross-contamination between samples during storage and transportation.

Sample Size: Geotechnical standards were considered when determining the sample size. Guidelines and requirements related to the expected variability of the subgrade soil and laboratory testing methods were considered.

Testing:

Soil Classification Test: ASTM Designation (ASTM D2487) - Standard Practice for Classification of Soils for Engineering Aims “Unified Soil Classification System” The objective of the soil classification test was to determine the group classification of the soil sample according to the AASHTO soil classification system. This categorization provided valuable info about the soil's engineering properties, such as grain size distribution, plasticity, and compaction characteristics.

The AASHTO soil classification system provided valuable information about soil behavior, engineering properties, and potential uses in construction projects. It categorized soils into various groups, such as gravel, sand, silt, clay, and their combinations, allowing engineers to make informed decisions regarding soil suitability, compaction requirements, and foundation design.

Moisture Content Test: One of the tests directed on the collected soil samples was the moisture content test. This test provided essential information about the water content present in the soil, which is crucial for understanding its behavior and properties. The standard procedure for conducting the moisture content test is outlined below, along with the ASTM designation and the objective of the test.

ASTM Designation: ASTM D2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. The objective of the moisture content test was to find the percentage of water content present in the soil sample. This information is important for various geotechnical analyses and engineering applications. Moisture Content

$$= \frac{W_3 - W_4}{W_4 - W_1} \times 100\%$$

The moisture content test, as per ASTM D2216, provided significant information about the water gratified in the soil sample. It helped in assessing the soil's

compaction characteristics, permeability, and potential for volume change. The test results sponsored in determining adopt soil management practices, foundation design considerations, and overall geotechnical engineering analyses.

Specific Gravity Test: ASTM Designation: ASTM D854 - The standard technique to evaluate soil solids' specific gravity using a water pyrometer. The objective of the specific gravity test was to determine the specific gravity of the soil solids. This information helped assess the soil's particle density and porosity.

Atterberg Limit Test: ASTM D4318 - Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. The objective of the Atterberg limit test was to determine the liquid limit, plastic limit, and plasticity index of the soil. These values aided in classifying the soil's plasticity and understanding its behavior during moisture changes.

CBR (California Bearing Ratio) Test: ASTM Designation: ASTM D1883 - Standard Test Method for CBR of Laboratory-Compacted Soils. The objective of the CBR test was to estimate the strength of subgrade soils and determine their bearing capacity relative to a standard material. This test helped in designing and evaluating pavement structures. Calculated the CBR value using the formula:

$$\text{CBR Value} = \frac{\text{Penetration of the soil}}{\text{Penetration}} \times 100$$

Relevant information concerning the strength and load-bearing capability of subgrade soils was made clear by the CBR test. It was frequently used to help engineers to figure out if soil is suitable for sustaining roads and highways throughout the construction and evaluation of pavement structures. The test allowed for sound choices to be made regarding the thickness of the pavement and design factors by contrasting the CBR value of the soil to a standard material.



Fig 4. Tests Sample

RESULTS AND DISCUSSION

Soil Classification Test: The soil classification test was conducted using the AASHTO classification system to find the form and properties of the clay soil at four different sites: Location A (Tajazai), Location B (Titter Khel), Location C (Pizzo), and Location D (Pizzo By-

pass). The results obtained from the classification indicate that all the sites have a subgrade rating that falls within the "Less favorable" category permitting to the AASHTO classification system. This suggests that the clay soil at these sites possesses Moderately favorable for subgrade construction purposes and need some enhancement to support road pavement.

**Table 1. Soil classification
4.2 Field Moisture Content.**

Soil classification			
Location	Soil type	Soil description	Subgrade Rating
Location A (Tajazai)	A-4	primarily composed of silts and clays with minimal to no sand content	Not favorable for subgrade construction
Location B (Titter Khel)	A-4	primarily composed of silts and clays with minimal to no sand content	Not favorable for subgrade construction
Location C (Pizzo)	A-6	primarily composed of fine-grained materials, often clayey soils with little or no sand.	bad for subgrade construction.
Location D (Pizzo By-pass)	A-5	primarily composed of clays with little or no sand or silt content	bad for subgrade construction.

The field moisture content was determined for the four Location A (Tajazai), Location B (Titter Khel), Location C (Pizzo), Location D (Pizzo Bypass) and expressed as a percentage. The results indicate that the moisture content varies across the sites, with Location B, **S1** (Titter Khel) showing the highest moisture content (1.87%) and Location A, **S1** (Tajazai) exhibiting the lowest moisture content (1.62%). The variations in moisture content can have suggestions for the engineering estates and behavior of the soil, such as its compaction characteristics and shear strength.

Specific Gravity: The specific gravity of the soil trials from the four sites (Location A (Tajazai), Location B (Titter Khel), Location C (Pizzo), Location D (Pizzo Bypass) was determined using the AASHTO T 84 and ASTM C128 test methods. The results show variations in specific gravity, with Location D, **S1** (Pizzo Bypass) having the highest value (1.74 g/cm³) and Location B, **S1** (Titter Khel) having the lowest value (1.52 g/cm³). Specific gravity is an important parameter as it provides an indication of the soil's density and porosity, which can influence its load-bearing capacity and permeability.

Atterberg Limits Test (Liquid Limit Test): The uniformity and plasticity of soil samples from four locations—Location A (Tajazai), Location B (Titter Khel), Location C (Pizzo), and Location D (Pizzo Bypass)—were assessed via the Atterberg Limits Test, in particular the Liquid Limit Test. The test was conducted out according to with ASTM D4318 and AASHTO T 89

standards. Study shows that the plasticity index and liquid limit differ based on the region. The moisture content at which soil transitions from a plastic to a liquid situation is known as the liquid limit. The shrink-swell potential and plasticity of the soil can be observed by the plasticity index.

For instance, Location D, **S3** (Pizzo Bypass) may have a higher liquid limit 59%, indicating greater plasticity compared to other locations. Conversely, (Location A, **S1** (Tajazai), and Location B (Titter Khel), **S4** may exhibit liquid limit 29% based on its liquid limit. Similarly, Location D, **S3** (Pizzo Bypass) may have a higher Plastic Index of 35%, indicating greater plasticity compared to other locations. Conversely, (Location A, **S1** (Tajazai), and Location B (Titter Khel), **S4** may exhibit the lowest Plastic Index of 14%.

California Bearing Ratio Test (CBR): The soil samples' potential to bear a load was evaluated using the California Bearing Ratio (CBR) test. The CBR value, which is a percentage, indicates the strength of the soil is in comparison to a standard crushed stone material. Location D, **S1** (Pizzo Bypass) exhibits lower CBR values of 1.9%, indicating the lowest strength characteristics. (Location A, **S1** (Tajazai), and Location B, **S2** (Titter Khel) have relatively higher CBR values 4.6% compared to other locations but it's still lower than standard values which is needed for subgrade according to Table 2 which needs to be an enhancement.

Table 2. Subgrade Rating

Standard Subgrade Rating	
Subgrade Rating	CBR Percentage (%)
Good Quality Subgrade	15% to 30%
Moderate Quality Subgrade	8% to 15%
Poor Quality Subgrade	Less than 8%

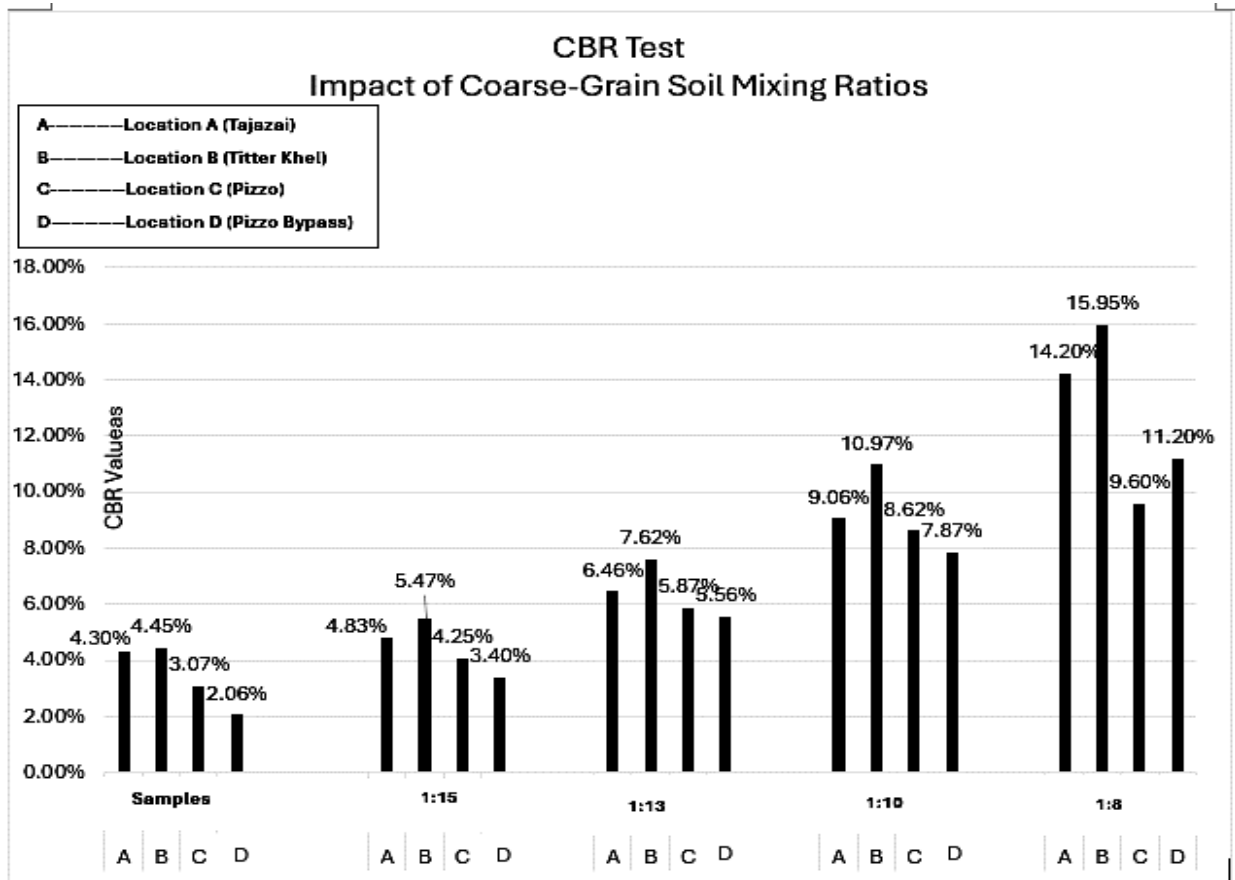


Fig 5. CBR Test

Table 3. Tests results after mixing course-grained soil

Location	Laboratory test results after mixing course-grained soil with different ratios.													
	Location A (Tajazai)			Location B (Titter Khel)				Location C (Pizzo)				Location D (Pizzo Bypass)		
Soil type (ASHTO)	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃
% Moisture content	1.62	1.67	1.63	1.87	1.80	1.79	1.63	1.76	1.77	1.77	1.82	1.69	1.68	1.83
Specific Gravity (g/cm ³)	1.60	1.57	1.59	1.52	1.55	1.56	1.57	1.71	1.69	1.69	1.65	1.74	1.73	1.70
Atterberg's limits LL, %	29	30	47	35	31	32	29	57	43	44	42	55	51	59
Atterberg's limits PI, %	14	15	23	17	16	15	14	31	26	28	26	29	27	35
CBR Value (%age)	4.6	4.5	3.8	4.4	4.4	4.5	4.6	2.1	3.5	3.4	3.3	1.9	2.1	2.2

Table 4. Test results of CBR after mixing coarse-grained soil

Location	Laboratory test results of CBR after mixing coarse-grained soil with different ratios.														
	Location A (Tajazai)			Location B (Titter Khel)				Location C (Pizzo)				Location D (Pizzo Bypass)			
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	
CBR Value (%age) 1:15	5.1	5.1	4.3	5.3	5.2	5.6	5.8	3.2	4.8	4.3	4.7	2.7	3.6	3.9	
CBR Value (%age) 1:12	6.7	6.8	5.9	7.3	7.2	7.9	8.1	4.8	6.2	5.7	6.8	4.2	4.5	5.0	
CBR Value (%age) 1:10	9.4	9.2	8.6	10.2	10.3	11.4	12.00	7.7	9.5	8.2	9.1	7.4	7.9	8.3	
CBR Value (%age) 1:8	14.5	14.2	13.9	15.4	15.7	16.2	16.5	12.5	15.2	13.7	14.2	10.1	10.8	12.7	

Conclusions: In conclusion, the subgrade strength, a critical parameter for highway construction, relies on the California Bearing Ratio (CBR) values. This research, conducted in N55 Indus Highway District Bannu, Pakistan, reveals variations in subgrade CBR values across different locations. Specifically, Location A (Tajazai), S1, and Location B, S2 (Titter Khel) exhibit the highest CBR values at 4.6%, while Location D, S1 (Pizzo Bypass) displays a lower CBR value of 1.9%, falling below the standard threshold. To address this, an investigation into improving CBR values was undertaken by incorporating coarse-grained soil at varying ratios. The results demonstrate a substantial enhancement in CBR values, notably from 1.9% to 10.1% for Location D (Pizzo Bypass), and substantial increases for Location A (Tajazai), S1, and Location B, S2 (Titter Khel) to 14.5% and 15.7%, respectively, with a 1:8 ratio of coarse-grained soil. It is noteworthy that further increases beyond a 1:8 ratios may lead to improved CBR values, but such ratios might prove uneconomical. Therefore, the optimal recommendation for maximizing CBR values while maintaining economic viability is to employ a mix with a 1:8 ratio of coarse-grained soil. This approach provides an effective balance between achieving desirable CBR values and cost-effectiveness in subgrade improvement for the N55 Indus Highway in District Bannu.

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