A Review About Pavements: Soil Type, Challenges and Solution

Amol Eknath Thoke[1], Dr. Premanand L. Naktode[2]

[1,2]*Sandip University, Nashik, Maharashtra, India*

Abstract-*The soil problems in the pavement or bed layers might severely impact pavement performance if not addressed during the design stage. They obstruct the movement of accessible vehicles. As a result of structural deformation caused by climate changes, pavement distress occurs. The fluctuations in the load-bearing capability of these soils, which cause pavement discomfort, are primarily connected to seasonal moisture changes. The structure and behavior of problematic soils vary with soil mineralogy, location, stress history, and climate. These elements significantly impact the design, construction, and maintenance of sealed and unsealed road pavements. Black Cotton (BC) soils are a significant soil category in India. They have significant shrinkage and edema. BC soils are found primarily in India's central and western portions, covering around 20%. The BC soils' significant swelling and shrinkage properties have been a problem for roadway engineers. The BC soil is substantial while dry but ultimately weakens when wet. The paper theoretically discusses the challenges and solutions of pavement on BC soil.*

Keywords: *Pavement; Soil; Challenges; Solutions; Soil Interactions*

1. INTRODUCTION

Pavements are made up of many materials [1]. The characteristics of the resulting pavement are determined by these materials, their properties, and their interactions [2]. The knowledge is essential to comprehend pavement. The highway engineer is particularly interested in the materials used in highway building [2]. The soil and aggregate characteristics must be understood and the binding materials that may be used to increase pavement stability, durability, and performance [4]. The BC soil produces various depth fractures upon dried BC Soil fractures. The wetting and drying of the soil mass cause vertical movement in it [5]. Pavement settling, severe depression, cracking, and unevenness are the result of these motions. There are several case studies on highway construction in BC soils. The paper discusses the challenges faced during the construction of pavements on BC soil. The structure of the paper further discusses the theoretical background, challenges and solutions.

2. BACKGROUND

BC soil is clay in nature [6]. It's so hard that the clods can't be crushed for road construction treatment. Problematic for the road's later performance [6]. For sub-bases made of stone soling with plenty of cavities, this softening can cause upheaving into the top layers of the pavement. Water penetration causes road breakdown [8]. Roads built on BC soil acquire undulations at the road surface as the subgrade softens during the monsoon [9]. The dark hue of BC soil is due to traces of titanium oxide. The BC soil contains a significant proportion of montmorillonite clay, black or blackish-grey in appearance. The physical characteristics of BC soil differ geographically [10]. 40-60% of BC soil has a size smaller than 0.001 mm. The volume change is 200-300 percent at the liquid limit, resulting in swelling pressures of 8-10 kg/cm2/ [11]. As a result, BC soil has a low bearing capacity and excessive swelling and shrinking. Due to its unique properties, it is a poor road foundation material [12]. The CBR values of wet BC soils range from 2 to 4%. Due to the low CBR of BC soil [13], extra pavement thickness is necessary to construct flexible pavement. New technologies have been used in R&D to increase the strength of BC soil [14].

3. TYPES OF PAVEMENTS

In India, rigid and flexible pavements are installed [15]. Flexible pavement is a layer of heated aggregates and bitumen placed and compacted on a granular layer base [16]. Dry lean concrete (DLC) or a highly compacted layer of aggregates are used to construct rigid pavements.

3.1. Flexible Pavement

A bituminous surface course covers a base and sub-base course in flexible pavement. In some instances, the surface course is made up of many layers of hot mix asphalt (HMA) [17]. Low flexural strength means these pavements deform when loaded. The joint action of the flexible pavement layers achieves structural capability. In the base, subbase, and subgrade courses, the truckload is spread as a truncated cone with depth. The surface layer experiences the most incredible traffic-induced stress and has the highest resilient modulus [18]. They are less rigid yet equally significant in the pavement composition. Layers above the subgrade layer transfer load to the earth. Flexible pavements do not exceed soil carrying capacity. Soil strength affects the thickness of the layers above the subgrade, impacting the cost of pavement [19].

Figure 1: Flexible Pavement

3.2. Rigid Pavement

The solid flexural rigidity of the concrete slab and the high modulus of elasticity of the surface course make rigid pavements highly stable under load [20]. The concrete slab may distribute the traffic load across a broad area with minimal depth, reducing the requirement for many layers to alleviate stress [21]. Dowels and tie bars are the most typical stiff pavement. Dowel bars are short steel bars that mechanically link slabs without impeding horizontal joint mobility. On the other hand, Tie bars are bent steel bars or connectors used to join abutting slabs. Although they may offer some load transmission, they are not meant to do so and are merely utilized to 'tie' the two concrete slabs together [22].

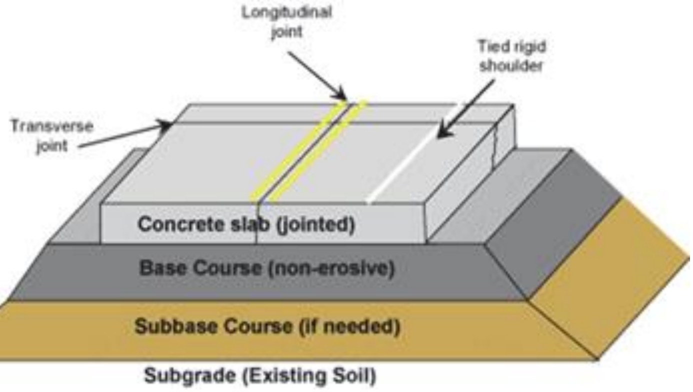

Figure 2: Rigid Pavement Layers

3.3. Design Strategy

It is because pavement design is dependent on soil conditions and traffic loads. They are built using CBR of subgrade soil and MSA (million standard axles) of cumulated axles [23]. It is meant to last 15 years. Using conventional or stabilized materials in any pavement layer is allowed using the IRC design code's templates. Transport, subgrade soil, moisture, and temperature differentials all affect the thickness of rigid pavements [24]. First, rigid pavements are thick enough to fail due to wear. The pavement thicknesses are next tested for the critical load-temperature combination [25].

3.4. Pavement Comparison

Different characteristics differentiate flexible and stiff pavements [26]. Construction costs and carbon footprints are the only criteria evaluated. A typical two-lane road with a 7.0 m roadway and 1.5 m broad shoulders is studied. One kilometer is used to compute the cost [27] . Two types of pavements were developed for various soil subgrade CBR ranging from 2 to 10% and design traffic 1 to 150 MSA, and the cost of each layer was estimated using the Dehradun PWD schedule of rates. So, 90 pavements were developed, and their construction and maintenance costs were estimated [28]. The given ranges of soil and traffic values are believed to cover almost all conceivable soil CBR and traffic loading combinations [29]. A comparison of carbon footprints between flexible and rigid pavements may also be made. Road construction uses energy in five stages.

- Energy used to manufacture building materials Embodied Energy Preparation Energy Pre-Building
- Energy used in road construction and material transport Impact of construction equipment, materials, and site
- Energy used in road maintenance

- Energy used in deconstruction and recycling

4. TYPES OF SOILS

There are many soil types accessible for highway buildings, the highway engineer must identify and classify them [30]. In India, a review of locally accessible materials and soil types found a wide range of soil types, gravel, moorum, and naturally existing soft aggregates suitable for road building. Soils include Laterite, Moorum/red, Desert Sands, Alluvial, Clay, and BC Soil [31].

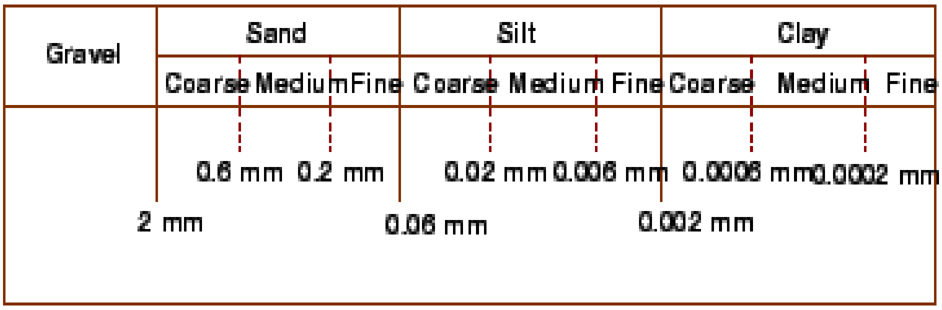

Figure 3: Type of Soil

Soil classification is used to predict subgrade performance. Strength and drainage are required in soils beneath pavements. Understanding moisture-related strength or volume fluctuations, frost resistance, and compaction characteristics are critical for excellent construction and future pavement lifespan [32]. For optimal pavement design, soil characteristics must be evaluated in greater detail than the broad soil categorization allows. The strength of soil depends on its density, void ratio, and moisture content [33]. The fine-grained soils are more susceptible to changes in characteristics like moisture, they are less stable. The pavement and base course thickness design are dependent on finished subgrade strength, soil testing is required. Soil testing can estimate bearing capacity based on moisture and density [34]. A soil's bearing capacity determines its strength to sustain the pavement construction. Therefore, a larger pavement cross-section is required [35].

5. CHALLENGES

The base layer is crucial in constructing any item, be it a road or a building foundation. Nothing on top of a weak basis will survive the shifting and settling [36]. One further factor to consider is the soil type. Soil is classified as sand, silt, or clay. Understanding how the three soil types differ is critical.

- Sand is granular substance made up of rock and mineral fragments.
- Silt is fine soil carried by the wind or water. Silt is made up of microscopic rock and mineral particles and is exceedingly fine.
- Clay is the most mineralized organic soil. Growing in clay is excellent. Clays are challenging to build on because they are plastic.

Sand is the best soil for building since it is versatile and easy to work with. Sand is made up of tiny rocks, so it may be compacted firmly and not change shape when water or other substances are added to the soil [37]. Clay soils are the worst to build on, with sandy soils being the finest. Clay soils are unstable because they are plastic [38]. When clay soil gets wet, the clay particles frequently change form. BC soil are the most difficult soils to build on. Drying these clays can cause them to expand or shrink. In building, this makes it challenging to compact evenly and shape the earth after it dries [39]. As a result of the foundation shifting so much, the topcoat (asphalt, concrete, etc.) typically fails due to catastrophic failures caused by water or other liquids seeping into the soil.

6. SOLUTION

Expansive clays like BC Soil are challenging to work with, whether for unpaved or paved roadways. While possibilities for rehabilitating BC soils for an unpaved road are limited, the following alternatives are possible [40].

6.2. Treatment with Gravel

Adding gravel to BC soil reduces the quantity of water entering the soil, reducing its potential expansion [41]. It will help prevent muddy or rutty roads, but the treatment will not stay forever. The treatment might last from a few weeks to 6 months, depending on the environment and soil growth. While most individuals can afford to treat the soil with gravel, the cost of road upkeep may quickly mount up [42].

6.3. Polymer Treatment

Polymer-based soil stabilization is widely used globally. The polymer soil stabilizer functions as a glue, gluing the soil particles together [43]. Polymers are simple to utilize but need additional procedures, such as compacting the soil. Polymer soil stabilization works on most soils but has a limited lifetime. The project's lifespan varies depending on the polymer and soil. However, difficult for polymers to link them together [44].

6.4. Excavation Treatment

Over excavation is a simple technique where the construction crew removes more, ideally all, of the expanding clay soils from the site [45]. The void would then be filled with a stable foundation course range from imported sand to Type II aggregate. This method is quite frequent since the dirt that might create future issues is eliminated. Over excavating is typically highly costly and time-consuming due to carrying out old material and bringing in fresh material. The expenditures are not only increased by the transportation of the different base coarse material [46].

6.5. Cement Treatment

Cement or lime-treated base (CTB) is widely used globally. The technique involves mixing a tiny amount of cement or lime into the native soil, compacting it, and curing it with the cement [47]. This procedure strengthens soil and provides a chemical connection to soil particles, reducing soil expansion and contraction. The cement-treated foundation technique has been developed over time, making it quick and straightforward to apply. The only disadvantage of Cement Treated Base is the high cost of cement [48]. However, the cost varies by area and cement supply; however, utilizing a Cement Treated Base can add 40% to the cost of standard road construction methods.

6.6. Prema-Zyme Treatment

Perma-Zyme is also a choice for unpaved and paved roads. Perma-Zyme is a patented enzyme-based soil stabilizer [49]. A persistent electrochemical reaction occurs when Perma-Zyme interacts with clay particles, causing permanent bonding. Like other alternatives for treating BC soils, Perma-Zyme has a ten-year unpaved lifespan and a 30-year paved lifespan. Perma-Zyme accelerates the chemical interaction with clay particles, which usually takes decades [50]. Constructing with very BC soil requires careful planning and preparation. It is now possible to create more durable roads with numerous pieces of equipment available on the market. Choosing the proper instrument for the job is critical when working with BC soil.

7. CONCLUSION

The world's significant roadways are bituminous. For example, in the US, 86% of rural highways and 78% of urban roadways are flexible. Most runways worldwide feature flexible pavements, as does the German Autobahn. The type of pavement used depends on the traffic and soil conditions. In places with poor soil subgrades, such as clay, and problematic drainage conditions, such as urban areas or areas where roads run through dwellings, rigid pavements can be a viable option. Flexible pavements can be more cost-effective when the soil subgrade is good, and traffic is less. Another benefit of flexible pavement is that it may be constructed in phases. An expert committee's economic research for the planned Nagpur-Mumbai Access controlled expressway found that flexible pavement is considerably cheaper than rigid pavement when built in stages. The future scope of the paper is to discuss precisely the challenges of BC soil for flexible pavements.

REFERENCES

[1] K. P. Verian, N. M. Whiting, J. Olek and J. Jain, "Using recycled concrete as aggregate in concrete pavements to reduce materials cost," Joint Transportation Research Program, Purdue University, 2013.

[2] N. P. Sharifi and et. al., "A review on the best practices in concrete pavement design and materials in wet-freeze climates similar to Michigan," Journal of Traffic and Transportation Engineering, vol. 6, no. 3, pp. 245-255, 2019.

[3] F. G. Praticò, M. Giunta, M. Mistretta and Gulot, "Energy and environmental life cycle assessment of sustainable pavement materials and technologies for urban roads," Sustainability, vol. 12, no. 2, p. 704, 2020.

[4] J. Zhang, H. Lin and J. Doolittle, "Soil layering and preferential flow impacts on seasonal changes of GPR signals in two contrasting soils," Geoderma, vol. 213, pp. 560-569.

[5] K. F. DeCarlo and K. K. Caylor, "Biophysical effects on soil crack morphology in a faunally active dryland vertisol," Geoderma, vol. 334, pp. 134-145, 2019.

[6] M. H. Rayhani, E. K. Yanful and A. Fakher, "Desiccation-induced cracking and its effect on the hydraulic conductivity of clayey soils from Iran.," Canadian geotechnical journal, vol. 44, no. 3, pp. 276-283, 2007.

[7] J. R. Nimmo, "Preferential flow occurs in unsaturated conditions," Hydrological Processes, vol. 26, no. 5, pp. 786-789, 2012.

[8] K. Beven and P. Germann, "Macropores and water flow in soils," Water resources research, vol. 18, no. 5, pp. 1311-1325, 1982.

[9] K. S. Mehta and et. al., "Analysis of engineering properties of black cotton soil & stabilization using by lime," Journal of Engineering Research and Application, vol. 4, no. 5, pp. 25-32, 2014.

[10] M. Vastrad and et. al. , "Stabilization of black cotton soil by using GGBS, lime and nano-silica," International Journal of Research in Engineering, Science and Management, vol. 3, no. 9, pp. 1-7, 2020.

[11] B. G. Sreedevi and A. Benny Mathews, "A study on the performance of flexible Pavements on mature soil subgrades," Doctoral dissertation, Cochin University of Science and Technology, 2014.

[12] S. Kandpal, A. Pandey and H. Ingawale, "Study of Stabilization of Black Cotton Soil using Lime".

[13] K. S. Mehta and et. al. , "Analysis of engineering properties of black cotton soil & stabilization using by lime," Journal of Engineering Research and Application, vol. 4, no. 5, pp. 25-32, 2014.

[14] K. Meshram, S. K. Mittal, P. K. Jain and Agarwal, "Application of Coir Geotextile in Rural Roads Construction on BC Soil Subgrade," International journal of engineering and innovative technology, vol. 3, no. 4, pp. 264-268, 2013.

[15] O. Kief , Y. Schary and S. K. Pokharel, "High-modulus geocells for sustainable highway infrastructure," Indian Geotechnical Journal, vol. 45, no. 4, pp. 389-400, 2015.

[16] B. Kermani, M. Xiao, S. Stoffels and T. Qiu, "Measuring the migration of subgrade fine particles into subbase using scaled accelerated flexible pavement testing–a laboratory study," Road Materials and Pavement Design, vol. 20, no. 1, pp. 36-57, 2019.

[17] W. R. Barker, A. Bianchini, E. Brown and Gonzale, "Minimum thickness requirements for asphalt surface course and base layer in airfield pavements," 2011.

[18] Y. Huang, R. N. Bird and O. Heidrich, "A review of the use of recycled solid waste materials in asphalt pavements," Resources, conservation and recycling, vol. 52, no. 1, pp. 58-73, 2007.

[19] N. C. Madu, C. C. Joshua and U. J. Nwachukwu, "Influence of spatial variation in subgrade properties on the design of highway flexible pavements," American Journal of Applied Scientific Research, vol. 2, no. 6, pp. 65-74, 2016.

[20] R. B. Mallick and T. El-Korchi, "Pavement engineering," CRC Press, NY, 2008.

[21] M. V. Mohod and K. N. Kadam, "A comparative study on rigid and flexible pavement: a review," IOSR Journal of Mechanical and Civil Engineering, vol. 13, no. 3, pp. 84-88, 2016.

[22] S. S. Adlinge and A. K. Gupta, "Pavement deterioration and its causes," International Journal of Innovative Research and Development, vol. 2, no. 4, pp. 437-450, 2013.

[23] I. R. Congress, "Guidelines for the design of flexible pavements," Indian code of practice, IRC,, p. 37, 2001.

[24] A. G. Bezabih and S. Chandra, "Comparative study of flexible and rigid pavements for different soil and traffic conditions," Journal of the Indian Roads Congress, pp. 153-162, 2009.

[25] F. Canestrari and L. p. Ingrassia, "A review of top-down cracking in asphalt pavements: Causes, models, experimental tools and future challenges," Journal of Traffic and Transportation Engineering, 2020.

[26] A. Loulizi, I. L. Al-Qadi and M. Elseifi, "Difference between in situ flexible pavement measured and calculated stresses and strains.," Journal of transportation engineering, vol. 132, no. 7, pp. 574-579, 2006.

[27] S. Jain, Y. P. Joshi and S. S. Goliya, "Design of rigid and flexible pavements by various methods & their cost analysis of each method," International Journal of Engineering Research and Applications, vol. 3, no. 5, pp. 119-123, 2013.

[28] A. M. ALKASAH, "HYBRID PAVEMENT: ASSESSMENT OF RIGID AND FLEXIBLE PAVEMENTS TOGETHER," Doctoral dissertation, 2020.

[29] A. Alsaif and et. al., "Mechanical performance of steel fibre reinforced rubberised concrete for flexible concrete pavements," Construction and Building Materials, vol. 172, pp. 533-543, 2018.

[30] S. SINGH, "A STUDY OF SAND USED FOR ROAD CONSTRUCTION IN HARYANA," Doctoral dissertation, NATIONAL

INSTITUTE OF TECHNOLOGY KURUKSHETRA, 2010.

[31] P. C. Varghese, "Building materials," PHI Learning Pvt. Ltd., 2015.

[32] B. R. Christopher, C. W. Schwartz and R. Boudreaux, "Geotechnical aspects of pavements (No. FHWA-NHI-05-037)," United States. Federal Highway Administration, 2006.

[33] S. Gupta and et. al., "Pavement design using unsaturated soil technology," 2007.

[34] M. M. Zumrawi and H. Elnour, "Predicting bearing strength characteristics from soil index properties," International Journal of Civil Engineering and Technology, vol. 7, no. 2, pp. 266-277, 2016.

[35] N. Jafarifar, K. Pilakoutas and T. Bennett, "The effect of shrinkage cracks on the load bearing capacity of steel-fibre-reinforced roller-compacted-concrete pavements," Materials and structures, vol. 49, no. 6, pp. 2329-2347, 2016.

[36] P. Singh and K. S. Gill, "CBR improvement of clayey soil with geo-grid reinforcement," International Journal of Emerging Technology and Advanced Engineering, vol. 2, no. 6, pp. 456-462, 2012.

[37] E. A. Adam and A. R. Agib, "Compressed stabilised earth block manufacture in Sudan," France, Paris: Printed by Graphoprint for UNESCO, 2001.

[38] M. S. Shetty and A. K. Jain, "Concrete Technology (Theory and Practice)," S. Chand Publishing, 2019.

[39] E. Sebastián, G. Cultrone and D. Benavente, "Swelling damage in clay-rich sandstones used in the church of San Mateo in Tarifa (Spain).," Journal of cultural heritage, vol. 9, no. 1, pp. 66-76, 2008.

[40] V. M. Ramdas and et. al. , "Review of current and future bio-based stabilisation products (enzymatic and polymeric) for road construction materials," 2021.

[41] K. N. Mahdi and et. al., "Tracking the transport of silver nanoparticles in soil: a saturated column experiment.," Water, Air, & Soil Pollution, vol. 229, no. 10, pp. 1-13, 2018.

[42] R. D. Ludwig and et. al., "A permeable reactive barrier for treatment of heavy metals," Groundwater, vol. 40, no. 1, pp. 59-66, 2002.

[43] J. Zhang. , A. Deng and M. Jaksa, "Optimizing micaceous soil stabilization using response surface method," Journal of Rock Mechanics and Geotechnical Engineering, vol. 13, no. 1, pp. 212-220, 2021.

[44] M. Kah and P. Machinski, "Analysing the fate of nanopesticides in soil and the applicability of regulatory protocols using a polymer-based nanoformulation of atrazine," Environmental Science and Pollution Research, vol. 21, no. 20, pp. 11699-11707, 2014.

[45] W. Critchley and et. al., "Water harvesting: A manual for the design and construction of water harvesting schemes for plant production," Scientific Publishers, 2013.

[46] J. Dunnicliff, "Geotechnical instrumentation for monitoring field performance," John Wiley & Sons, 1993.

[47] T. E. Kowalski and et. al., "Modern soil stabilization techniques," Annual Conference of the Transportation Association of Canada, Saskatoon, Saskatchewan, pp. 14-17, 2007.

[48] R. R. Kraeling and S. K. Webel, "Current strategies for reproductive management of gilts and sows in North America," Journal of Animal Science and Biotechnology, vol. 6, no. 1, pp. 1-14, 2015.

[49] M. Van Veelen and A. T. Visser, "The performance of unpaved road material using soil stabilisers. Journal of the South African Institution of Civil Engineering," Joernaal van die Suid-Afrikaanse Instituut van Siviele Ingenieurswese, vol. 49, no. 4, pp. 2-9, 2007.

[50] P. Agarwal and S. Kaur, "Effect of bio-enzyme stabilization on unconfined compressive strength of expansive soil," International Journal of Research in Engineering and Technology, vol. 3, no. 5, pp. 30-33, 2014.