International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

Performance Evaluation of Reinforced Flexible Pavements Using Geotextiles and Geogrids Over Clay Subgrades

Ramanuj Singh[1], Hariram Sahu[2]
M.Tech scholar, Transportation and Highway Engineering, Department of Civil Engineering, School of Engineering, Eklavya University, Damoh (M.P.), India[1]
Assistant Professor, Department of Civil Engineering, School of Engineering, Eklavya University, Damoh (M.P.), India[2]

Abstract — Flexible pavements constructed over clay subgrades are highly susceptible to premature distress on account of the low bearing capacity and pronounced moisture sensitivity of clay soils. This paper presents an experimental investigation into the effectiveness of geosynthetic reinforcement in improving the California Bearing Ratio (CBR) of a high-plasticity clay (CH) subgrade collected from Damoh, Madhya Pradesh, India. Two commercially available geosynthetics, a Mirafi HP370 woven polyester geotextile and a Tensar BX1200 biaxial polypropylene geogrid, were evaluated at three reinforcement depths within the CBR mould, namely H/3, H/2, and 2H/3, under both soaked and unsoaked conditions. The soil was classified as CH under IS 1498, with a liquid limit of 55.36%, plasticity index of 30.03%, optimum moisture content of 19.5%, and maximum dry density of 1.69 g/cm³. The unreinforced clay exhibited unsoaked and soaked CBR values of 4.8% and 1.9%, respectively, both indicative of a very weak subgrade. Reinforcement with Tensar BX1200 at H/2 produced the greatest improvement, raising the CBR to 9.6% (unsoaked) and 4.9% (soaked), corresponding to gains of 100.0% and 157.9% over the unreinforced control. The Mirafi HP370 geotextile performed best at H/3, with improvements of 85.4% and 121.1%. The results confirm that both reinforcement type and placement depth significantly influence subgrade performance, and that biaxial geogrid reinforcement at mid-depth offers the greatest structural benefit for the clay investigated. The experimentally derived CBR values are discussed in relation to their implications for flexible pavement thickness design over weak clay subgrades.

Keywords— California Bearing Ratio, Clay subgrade, Woven geotextile, Biaxial geogrid, Flexible pavement, Subgrade reinforcement, Mirafi HP370, Tensar BX1200.

I. INTRODUCTION

A well-connected, durable road network underpins economic growth, agricultural marketing, industrial logistics, and social development, and in India this network is increasingly extended over regions where clay forms the natural subgrade. Clay subgrades, whether expansive or non-expansive, combine low bearing capacity with pronounced moisture sensitivity, and the resulting rutting, heave, and cracking are a major cause of premature flexible pavement distress, particularly on rural and low-volume roads built with limited engineering supervision and modest budgets.

Conventional ground-improvement measures, such as soil replacement, chemical stabilization, and cohesive non-swelling cushioning, can mitigate these problems but are frequently uneconomical or only partially effective over the long service life expected of a modern pavement. Geosynthetic reinforcement, in the form of geotextiles and geogrids placed within or beneath the granular pavement layers, has emerged as a complementary and increasingly preferred approach: woven geotextiles improve subgrade performance chiefly through tensioned-membrane action, while geogrids act principally through aggregate interlock and a reinforced-mattress mechanism. The California Bearing Ratio (CBR) test remains the most widely used laboratory method for evaluating the resulting improvement in subgrade bearing capacity and for translating it into flexible pavement thickness design under Indian practice (IRC:37).

While the beneficial effect of geosynthetic reinforcement is well established in the literature, the relative performance of different reinforcement types and, in particular, the optimum placement depth within the subgrade remain sensitive to soil plasticity, moisture condition, and product characteristics, and are best resolved through direct experimental comparison. This paper presents an experimental study evaluating the CBR performance of a high-plasticity clay subgrade reinforced separately with a Mirafi HP370 woven geotextile and a Tensar BX1200 biaxial geogrid, each placed at three depths (H/3, H/2, and 2H/3) and tested under both soaked and unsoaked conditions, with the objective of identifying the more effective reinforcement type and its optimum placement depth for this soil.

International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

The remainder of the paper is organized as follows. Section II reviews the literature relevant to clay subgrades, the mechanisms of geosynthetic reinforcement, and previous experimental studies. Section III describes the materials, specimen preparation, and testing procedure adopted in the present investigation. Section IV presents and discusses the results of the soil characterization and CBR testing programme, including the comparative evaluation of the two reinforcement types. Section V draws conclusions from the study, and Section VI outlines directions for future research.

II. LITERATURE REVIEW

A substantial body of laboratory, test-track, and limited field research has quantified the performance benefits of geosynthetic reinforcement over weak or problematic clay subgrades, with the CBR test the most consistently adopted evaluation framework in Indian and comparable international practice.

1. Clay Subgrades and Conventional Design Limitations

Clay and clayey soils underlie a very large part of the Indian landmass, with expansive black-cotton soils concentrated in the Deccan trap region and non-expansive clays and silts dominating the Indo-Gangetic plain and coastal alluvial tracts. Expansive clays undergo cyclic swelling and shrinkage that produces heave and cracking, whereas non-expansive clays exhibit low undrained shear strength and high compressibility that manifest as rutting and shear failure under repeated traffic loading. The CBR-based empirical design method used across India, principally under IRC:37, correlates pavement thickness with the soaked CBR of the subgrade but was not developed with the volumetric and shear-strength complexities of expansive clays in mind, and it offers no explicit provision for the beneficial contribution of geosynthetic reinforcement.

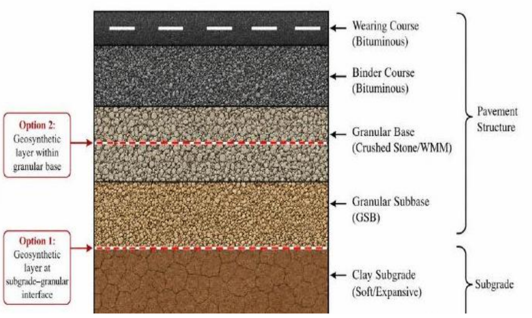

Fig. 1. Typical flexible pavement cross-section showing the position of a geosynthetic reinforcement layer relative to the clay subgrade

2. Mechanisms of Geosynthetic Reinforcement

Woven geotextiles, placed at the interface between a soft clay subgrade and the overlying granular layer, perform separation, filtration, and reinforcement functions. As the subgrade beneath a wheel load deforms, the geotextile stretches and develops tensile stress in its plane; the vertical component of this stress acts upward against the applied load, reducing the net stress transmitted to the subgrade, a mechanism termed tensioned membrane action. Geogrids, by contrast, are not primarily filtration elements; their reinforcing action depends on mechanical interlock with surrounding aggregate. When placed within or beneath a granular layer, aggregate particles interlock within the geogrid apertures, restraining lateral movement and increasing the effective shear strength and stiffness of the reinforced layer, a behaviour commonly termed the reinforced-mattress effect.

3. Previous Experimental Studies

Several Indian and international investigations have examined the improvement in CBR achieved through geotextile or geogrid inclusion in clay or otherwise weak subgrades. Pupalwad et al. [17] found that placing a geotextile closer to the top of the CBR mould produced a greater CBR gain than deeper placement, and that woven geotextiles outperformed nonwoven products on expansive clay. Ramjiram Thakur et al. [18] reported that nonwoven geotextile inclusion consistently raised the CBR of a high-plasticity clay, with the degree of improvement dependent on geotextile thickness and number of layers. Aga [19] found that both polypropylene and HDPE geogrids raised the soaked CBR of an expansive black soil, with the polypropylene geogrid outperforming HDPE. Rajesh et al. [20] observed that soils with the poorest unreinforced CBR benefited most from geogrid inclusion, while Balamaheswari et al. [21] showed that an anchored geogrid produced a greater CBR improvement than a conventional geogrid at its own optimum depth. These studies collectively indicate that both the type of geosynthetic and its placement depth strongly influence the resulting CBR improvement, a finding directly relevant to the comparative, depth-sensitive investigation undertaken in the present study.

4. Research Gap

Notwithstanding this convergence of evidence, comparative data establishing the optimum placement depth for a woven geotextile versus a biaxial geogrid within the same high-plasticity clay, under both soaked and unsoaked conditions, remain limited, and existing Indian design guidance stops short of a fully quantitative procedure that incorporates such reinforcement effects. This gap motivates the direct experimental comparison presented in this paper.

International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

III. MATERIALS AND METHODOLOGY

1. Materials

Clay Soil

The clay soil used as the subgrade material was collected from a road construction site near Damoh, Madhya Pradesh, from a depth below the zone of seasonal moisture variation. The soil was air-dried, pulverized, and passed through a 4.75 mm IS sieve prior to testing. Index and engineering properties were determined in accordance with the relevant parts of IS 2720, comprising specific gravity, particle-size distribution, Atterberg limits, Standard Proctor compaction, and CBR.

Woven Geotextile (Mirafi HP370)

Mirafi HP370 is a high-strength woven polyester (PET) geotextile widely used for pavement reinforcement, separation, and stabilization. Its principal manufacturer-reported properties are summarized in Table I.

Property	Typical Value
Polymer	Polyester (PET)
Type	High-strength woven geotextile
Tensile strength (MD)	≈ 370 kN/m
Elongation at break	≈ 10–12 %
Mass per unit area	≈ 450–550 g/m²

Biaxial Geogrid (Tensar BX1200)

Tensar BX1200 is an integrally formed biaxial geogrid manufactured from polypropylene (PP) by a punching and drawing process, deriving its reinforcing action principally from mechanical interlock with surrounding aggregate rather than separation or membrane action. Its principal properties are summarized in Table II.

Property	Typical Value
Polymer	Polypropylene (PP)
Type	Integrally formed biaxial geogrid
Tensile strength	≈ 20–30 kN/m
Junction efficiency	> 90 %
Aperture size	≈ 39 × 39 mm

2. Experimental Program and Specimen Preparation

Standard CBR moulds, 150 mm internal diameter and 175 mm height, were used throughout. Soil was prepared at the Optimum Moisture Content corresponding to the Maximum Dry Density obtained from the Standard Proctor Compaction Test, cured for approximately 24 hours in sealed bags, and compacted in accordance with IS 2720 (Part 16). For reinforced specimens, circular pieces of geotextile or geogrid, cut to match the internal diameter of the mould, were placed horizontally at one of three depths, H/3, H/2, or 2H/3, measured from the top of the compacted specimen (H denotes the total specimen height), by interrupting compaction at the appropriate stage, placing the reinforcement flat and free of wrinkles, and completing compaction of the remaining layers. Unreinforced control specimens were prepared identically but without a reinforcement layer. Each configuration was tested under both unsoaked conditions (tested immediately after compaction) and soaked conditions (submerged for four days in accordance with IS 2720, Part 16, with a surcharge load applied), giving a full matrix of unreinforced, geotextile-reinforced, and geogrid-reinforced specimens at three depths and two moisture conditions.

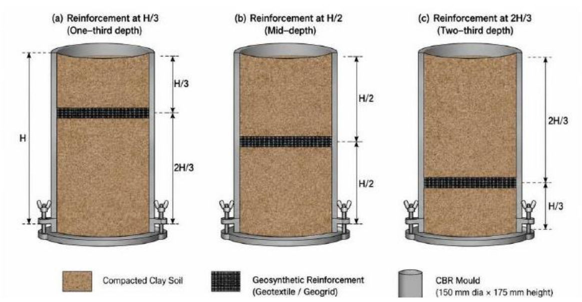

Fig. 2. Schematic illustration of geosynthetic reinforcement positions (H/3, H/2, and 2H/3) within the CBR mould

3. Testing Procedure

The California Bearing Ratio was calculated as the ratio of the test load sustained by the specimen to the load sustained by a standard, well-graded crushed-stone material at the corresponding penetration, expressed as a percentage, in accordance with IS 2720 (Part 16). For soaked specimens, the compacted mould, fitted with a perforated base plate and a surcharge weight equivalent to the overlying pavement load, was immersed in a water tank for four days, with periodic measurement of swell through a dial gauge mounted on a tripod resting on the mould, before being removed, allowed to drain for fifteen minutes, and tested. Unsoaked specimens were tested immediately after compaction and surcharge placement, without immersion. In both cases, the penetration plunger was advanced into the specimen at a uniform rate of 1.25 mm/min,

International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

and the corresponding load was recorded at penetrations of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0, and 12.5 mm. Load–penetration data were recorded up to 12.5 mm penetration, and the CBR value was taken as the greater of the values calculated at 2.5 mm and 5.0 mm penetration, in accordance with standard practice.

IV. RESULTS AND DISCUSSION

1. Index Properties and Soil Classification

The average specific gravity of the soil solids, determined from three pycnometer trials, was 2.68, typical of inorganic clay minerals. Combined wet sieve and hydrometer analysis showed the soil to comprise 58% clay, 34% silt, and 8% sand, with no gravel-sized particles (Fig. 3), confirming a predominantly fine-grained, cohesive soil of low permeability and high compressibility.

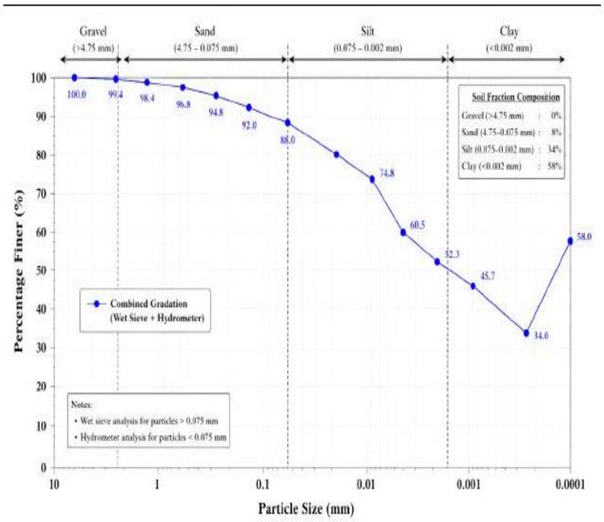

Fig. 3. Combined grain-size distribution curve of the clay soil

The average liquid limit, from four trials, was 55.36%, and the average plastic limit was 25.33%, giving a plasticity index of 30.03%. Since the plasticity index (30.03%) exceeds the A-line value of 25.81% and the liquid limit exceeds 50%, the soil plots above the A-line on the Casagrande plasticity chart (Fig. 4) and is classified as CH (clay of high plasticity) under IS 1498. This classification confirms high plasticity, low permeability, and significant volume-change potential, consistent with the problematic clay subgrades that motivate the use of geosynthetic reinforcement.

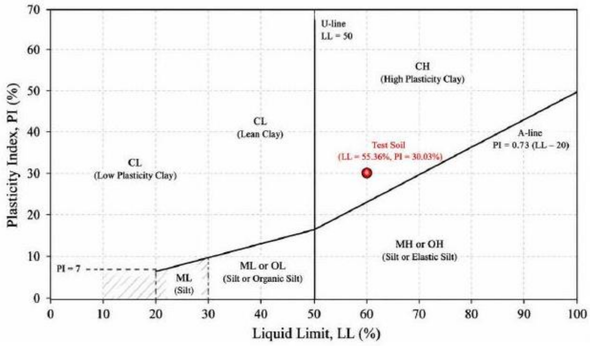

Fig. 4. Casagrande plasticity chart showing the position of the test soil

2. Compaction Characteristics

The Standard Proctor Compaction Test gave a Maximum Dry Density of 1.69 g/cm³ at an Optimum Moisture Content of 19.5% (Fig. 5), a relatively high OMC characteristic of highly plastic clay soils. These values were adopted as the target compaction condition for every unreinforced and reinforced specimen, so that observed differences in CBR could be attributed solely to the presence, type, and position of reinforcement rather than to variation in specimen density or moisture.

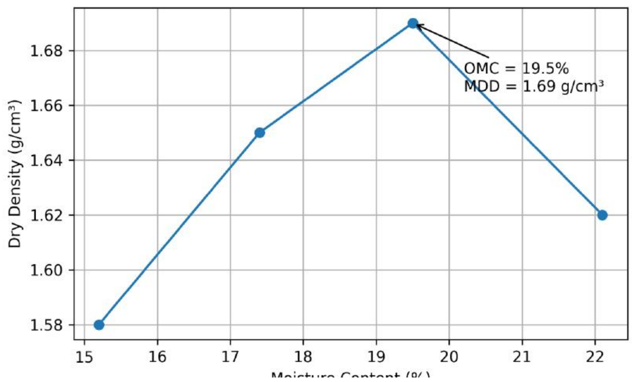

Fig. 5. Moisture content–dry density relationship (Standard Proctor compaction curve)

3. CBR of Unreinforced Clay Subgrade

The unreinforced clay exhibited a CBR of 4.8% under unsoaked conditions and 1.9% under soaked conditions (Fig. 6), a reduction of approximately 60% on saturation, attributed to the decrease in matric suction and weakening of interparticle bonding within the clay matrix upon wetting. The soaked CBR value of 1.9% classifies the soil as a very weak subgrade under IRC:37, which would require stabilization or reinforcement before use in flexible pavement construction.

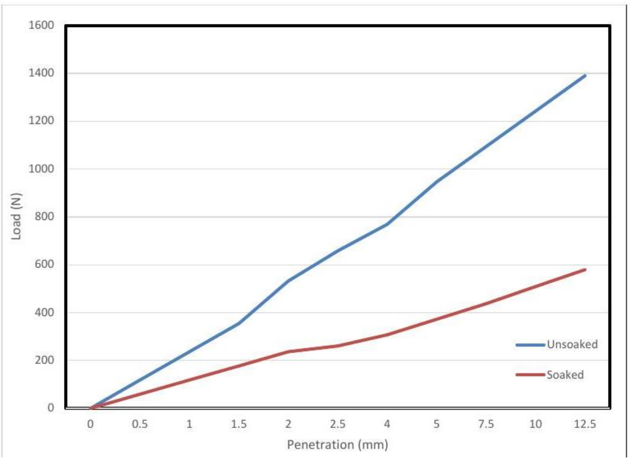

Fig. 6. Load–penetration curves for unreinforced clay under unsoaked and soaked conditions

4. CBR of Geotextile- and Geogrid-Reinforced Clay Subgrade

For the Mirafi HP370 woven geotextile, the highest CBR values were obtained at H/3 (8.9% unsoaked, 4.2% soaked), corresponding to improvements of 85.4% and 121.1% over the unreinforced control; the CBR declined progressively as the geotextile was placed deeper, reaching 6.1% and 2.7% at 2H/3 (Fig. 7). This pattern indicates that reinforcement located nearer the loaded surface intercepts the stress bulb generated beneath the CBR plunger more effectively, mobilizing the tensioned-membrane mechanism to a greater degree.

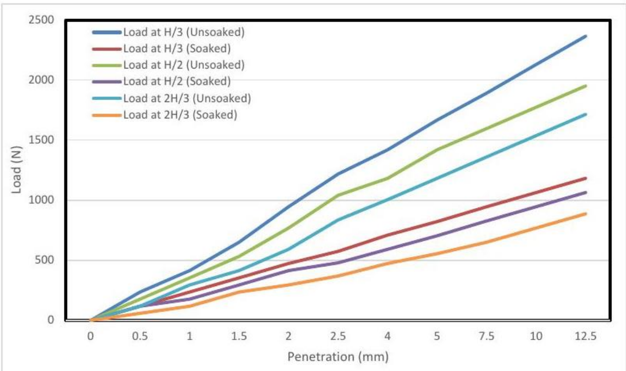

Fig. 7. Load–penetration curves for clay reinforced with Mirafi HP370 geotextile at three depths

For the Tensar BX1200 biaxial geogrid, the optimum position was different: the highest CBR values were obtained at H/2 (9.6% unsoaked, 4.9% soaked), corresponding to improvements of 100.0% and 157.9%, while H/3 gave the lowest geogrid improvement (41.7% and 57.9%) (Fig. 8). This behaviour is consistent with the geogrid's aggregate-interlock mechanism, which requires adequate confinement of the surrounding soil on both sides of the reinforcement layer to mobilize its full lateral-restraint and reinforced-mattress action; placement too close to the loaded surface (H/3) apparently provided insufficient confinement, while mid-depth placement (H/2) balanced proximity to the stress bulb with adequate confinement.

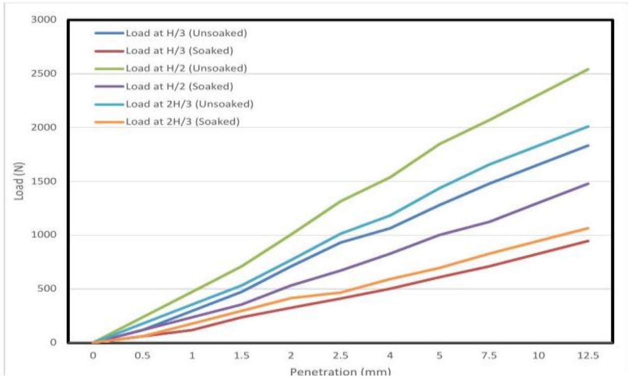

Fig. 8. Load–penetration curves for clay reinforced with Tensar BX1200 geogrid at three depths

5. Comparative Evaluation and Improvement Factor

Table III summarizes the CBR values and percentage improvement for every configuration tested. All reinforced specimens exhibited higher CBR values than the unreinforced control, confirming the effectiveness of both geosynthetics in enhancing subgrade strength.

Table 3. Comparative CBR Values of Reinforced and Unreinforced Clay Subgrade

Specimen	Pos.	Unsoaked CBR (%)	Soaked CBR (%)	Improv. Unsoak. (%)	Improv. Soaked (%)
Unreinforced (Control)	—	4.8	1.9	—	—
Mirafi HP370	H/3	8.9	4.2	85.4	121.1
Mirafi HP370	H/2	7.6	3.5	58.3	84.2
Mirafi HP370	2H/3	6.1	2.7	27.1	42.1
Tensar BX1200	H/3	6.8	3.0	41.7	57.9
Tensar BX1200	H/2	9.6	4.9	100.0	157.9
Tensar BX1200	2H/3	7.4	3.4	54.2	78.9

The improvement factor, defined as the ratio of reinforced to unreinforced CBR, is compared for all six configurations under both moisture conditions in Fig. 9. The highest improvement factor (2.58, soaked) was obtained for Tensar BX1200 at H/2, and the lowest (1.27, unsoaked) for Mirafi HP370 at 2H/3, confirming that both the type of geosynthetic and its placement depth significantly influence the effectiveness of subgrade reinforcement. Overall, the Tensar BX1200 biaxial geogrid at its optimum depth (H/2) outperformed the Mirafi HP370 woven geotextile at its own optimum depth (H/3), indicating that, for this high-plasticity clay, the aggregate-interlock and reinforced-mattress mechanism of the geogrid mobilized a greater structural benefit than the tensioned-membrane action of the geotextile. The improvement factor was consistently higher under soaked conditions than unsoaked conditions for every configuration, indicating that geosynthetic reinforcement is of proportionately greater benefit precisely when the subgrade is weakest, that is, in the saturated, monsoon-affected condition most critical for Indian pavement design.

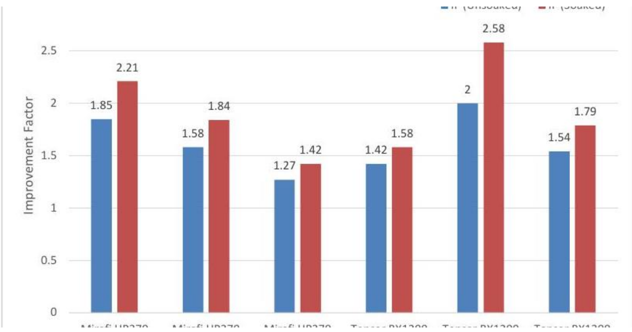

Fig. 9. Comparison of improvement factor (IF) for reinforced clay subgrade under soaked and unsoaked conditions

6. Effect of Reinforcement Position and Design Implications

The position of the reinforcement layer relative to the stress bulb generated beneath the CBR plunger is the principal factor governing the effectiveness of each geosynthetic. For the woven geotextile, reinforcement located near the top of the specimen intercepted the applied stress more directly, reducing vertical deformation and improving load distribution; as the geotextile was placed deeper, its contribution to resisting penetration decreased because it lay increasingly outside the zone of maximum stress concentration. The biaxial geogrid behaved differently: at H/2 it effectively mobilized aggregate interlocking and lateral confinement on both sides of the reinforcement plane, allowing better distribution of the applied load within the soil mass, whereas at H/3 the comparatively lower performance is attributed to insufficient confinement of the surrounding soil, which limited full mobilization of the interlock mechanism. This contrast demonstrates that the optimum reinforcement depth is not a universal constant but depends on the underlying reinforcement mechanism, tensioned-membrane action favouring shallow placement and aggregate interlock favouring mid-depth placement, and should therefore be selected according to the specific geosynthetic product adopted in design.

Since the CBR value is a direct input to the IRC:37 empirical design procedure, the higher CBR obtained with reinforcement, particularly under soaked conditions, translates directly into a reduction in the total flexible pavement thickness required to carry a given design traffic, or, equivalently, into a higher permissible traffic loading for a given pavement thickness. The proportionately larger soaked-condition improvement is of particular practical significance for Indian rural and low-volume roads, where the design subgrade strength is governed by the worst-case, monsoon-saturated condition. On this basis, Tensar BX1200 placed at H/2 would be expected to permit the greatest reduction in design pavement thickness among the configurations tested, while even the least effective configuration, Mirafi HP370 at 2H/3, still provides a meaningful improvement over the unreinforced subgrade.

7. Comparison with Previous Studies

The trends observed in the present investigation are broadly consistent with previous experimental studies reviewed in Section II. As with the geotextile-reinforced expansive clay tested by Pupalwad et al. [17], the woven geotextile in the present study produced its greatest CBR improvement when placed nearer the top of the mould, supporting the general finding that tensioned-membrane reinforcement is mobilized most effectively close to the applied load. The magnitude of improvement obtained for Mirafi HP370 at H/3 (85.4% unsoaked, 121.1% soaked) is comparable in order of magnitude to the improvements reported by Ramjiram Thakur et al. [18] for nonwoven geotextile reinforcement of a similarly high-plasticity clay, although the woven product used here achieved a somewhat greater gain, consistent with the literature finding that woven geotextiles generally outperform nonwoven products on plastic clay subgrades.

For the geogrid, the mid-depth optimum observed for Tensar BX1200 parallels the depth-sensitivity reported by Aga [19] and Balamaheswari et al. [21] for geogrid reinforcement of weak and expansive subgrades, both of which found that adequate confinement of the reinforcement layer, rather than proximity to the loaded surface alone, governed the degree of CBR improvement. The larger improvement obtained for the geogrid relative to the geotextile at their respective optimum depths is also consistent with Rajesh et al. [20], who observed that subgrades with the poorest unreinforced CBR, such as the very weak clay tested here (soaked CBR of 1.9%), tend to benefit most from geogrid inclusion. Taken together, these comparisons indicate that the present results are representative of the wider body of experimental evidence on geosynthetic-reinforced clay subgrades, while providing soil- and product-specific optimum depths directly applicable to the Damoh clay investigated.

V. CONCLUSION

The clay soil investigated was classified as CH (high-plasticity clay) with a liquid limit of 55.36%, plasticity index of 30.03%, optimum moisture content of 19.5%, and maximum dry density of 1.69 g/cm³, and exhibited a soaked CBR of only 1.9% in its unreinforced state, confirming its classification as a very weak pavement subgrade. Reinforcement with either the Mirafi HP370 woven geotextile or the Tensar BX1200 biaxial geogrid substantially improved the CBR under both soaked and unsoaked conditions, with the degree of improvement strongly dependent on placement depth and reinforcement type.

The Mirafi HP370 geotextile performed best when placed at H/3 (one-third depth from the top), consistent with its tensioned-membrane mechanism, which is mobilized most effectively close to the applied load. The Tensar BX1200 geogrid performed best at H/2 (mid-depth), consistent with its aggregate-interlock mechanism, which requires adequate confinement on both sides of the reinforcement layer. At their respective optimum depths, the geogrid (100.0% unsoaked, 157.9% soaked improvement) outperformed the geotextile (85.4% unsoaked, 121.1% soaked improvement), indicating that, for the high-plasticity clay tested, biaxial geogrid reinforcement offers the greater structural benefit. The consistently larger improvement under soaked conditions confirms that geosynthetic reinforcement is of particular value under the saturated, monsoon-affected conditions that govern subgrade design for Indian roads, and supports the incorporation of reinforcement effects into routine flexible pavement thickness design over weak clay subgrades.

Future Scope

The present investigation was limited to a single clay soil, two commercially available geosynthetics, and three placement depths, evaluated through laboratory CBR testing alone. Full-scale or accelerated pavement testing is needed to validate these laboratory findings under actual traffic loading conditions, and the behaviour of the reinforced subgrade under repeated cyclic loading warrants further investigation to better simulate long-term traffic effects. The influence of multiple reinforcement layers and intermediate placement depths remains to be examined, and further evaluation of other geosynthetic products, including nonwoven geotextiles, triaxial geogrids, geocells, and geocomposites, would broaden the evidence base available to designers.

Numerical modelling using finite element software such as Abaqus or PLAXIS could usefully simulate the stress distribution and reinforcement mechanisms observed experimentally, while the long-term durability of the reinforcement under repeated monsoon wetting and drying requires further field-oriented study. The experimentally derived CBR values could also be used to develop a quantitative flexible pavement thickness design incorporating reinforcement effects under IRC:37 for both expansive and non-expansive clay subgrades, together with a cost-benefit analysis to establish the economic feasibility of geosynthetic reinforcement relative to conventional subgrade treatment.

REFERENCES

1. Holtz, W. G., & Gibbs, H. J. (1956). Engineering properties of expansive clays. Transactions of the American Society of Civil Engineers, 121, 641–663.
2. Chen, F. H. (1975). Foundations on expansive soils. Elsevier.
3. Bureau of Indian Standards. (1970). IS 1498: Classification and identification of soils for general engineering purposes. BIS.
4. Bureau of Indian Standards. (1987). IS 2720 (Part 16): Methods of test for soils — Laboratory determination of California Bearing Ratio (CBR). BIS.
5. Bureau of Indian Standards. IS 2720 (Parts 3, 4, 5, 7): Methods of test for soils — Specific gravity, grain-size analysis, Atterberg limits, and compaction. BIS.
6. Barenberg, E. J., Anderson, K. A., & Lamb, D. (1975). Evaluation of fabrics in asphalt pavements. University of Illinois.
7. Giroud, J. P., & Noiray, L. (1981). Geotextile-reinforced unpaved roads. Journal of the Geotechnical Engineering Division, ASCE, 107(9), 1233–1254.
8. Al-Qadi, I. L., & Brandon, T. L. (1988). Laboratory evaluation of geogrid-reinforced pavement sections. Transportation Research Record.
9. Zornberg, J. G., Christopher, B. R., & Canéla, A. (2003). Geosynthetics in pavements: North American contributions. Geosynthetics International, 10(4), 97–122.
10. Giroud, J. P., & Han, J. (2004). Design method for geogrid-reinforced unpaved roads. Parts I & II. Journal of Geotechnical and Geoenvironmental Engineering, 130(8), 775–797.
11. Pokharel, S. K., Han, J., Leshchinsky, D., & Parsons, R. L. (2011). Performance of geocell-reinforced bases under

dynamic loading. Geotextiles and Geomembranes, 29(5), 377–388.

12. Indraratna, B., Ngo, T., Rujikiatkamjorn, C., & Vinod, J. S. (2018). Behaviour of geosynthetic-reinforced granular layers under cyclic loading. Engineering Geology, 235, 34–48.
13. Katti, R. K. (1978). Search for solutions to problems in black cotton soils. Indian Geotechnical Society.
14. Indian Roads Congress. (2018). IRC:37-2018: Guidelines for the design of flexible pavements. IRC.
15. Indian Roads Congress. (2002). IRC:SP:59-2002: Guidelines for the use of geotextiles in road pavements and associated works. IRC.
16. Zornberg, J. G. (2017). Functions and applications of geosynthetics in roadways. Procedia Engineering, 189, 298–306.
17. Pupalwad, A. S., Padmavathi, M., Ravikumar, K., & Nagaraju, M. (2019). An experimental study on CBR of expansive soil subgrades using geotextiles. International Journal of Civil and Structural Engineering Research, 7(1).
18. Ramjiram Thakur, S., Naveen, B. P., & Tegar, J. P. (2021). Improvement in CBR value of soil reinforced with nonwoven geotextile sheets. International Journal of GeoEngineering, 12, 8.
19. Aga, S. Y. (2021). Physical stabilization of expansive subgrade soil using locally produced geogrid material. SN Applied Sciences, 3(5), 568.
20. Rajesh, U., Sajja, S., & Chakravarthi, V. K. (2016). Studies on engineering performance of geogrid reinforced soft subgrade. Transportation Research Procedia, 17, 164–173.
21. Balamaheswari, M., Anitha, B., Kanimozhi, B., & Prabhu, N. (2022). Improvement of California bearing ratio value in weak subgrade soil with the developed anchored geogrid. Materials Today: Proceedings, 49, 1537–1542.
22. Banyhussan, Q. S., Abdulrazzaq, J., Hussein, A. A., Dulaimi, A., Andrade, J. M. A., & Bernardo, L. F. A. (2025). Stabilization of clay subgrade soil by using waste foundry sand with a geogrid. CivilEng, 6(2), 26.
23. Harshitha, M., Kumar, R., Vidyashree, J. C., Agrawal, U., & Sathvik, S. (2025). Investigating the impact of biaxial geogrid reinforcement on subgrade soil strength enhancement: A machine learning analysis using the MARS model. Indian Geotechnical Journal.
24. Tiwari, N., & Satyam, N. (2022). An experimental study on strength improvement of expansive subgrades by polypropylene fibers and geogrid reinforcement. Scientific Reports, 12(1), 6685.