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Performance Evaluation of Geotextile-Reinforced Flexible Pavements Using Experimental Investigation and Machine Learning Techniques

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Abstract: Flexible pavements constructed over weak, moisture-sensitive or variable subgrades are vulnerable to excessive deformation, rutting, loss of aggregate interlock and premature deterioration. Geotextiles and related geosynthetics are used in pavement systems to provide separation, filtration, drainage and, under suitable conditions, reinforcement. In parallel, machine learning (ML) methods have gained importance in pavement engineering because they can model nonlinear relationships among material properties, traffic loading, environmental conditions and observed performance. This paper reviews the state of knowledge on geotextile-reinforced flexible pavements, with emphasis on reinforcement mechanisms, material selection, placement, experimental evaluation and the potential integration of ML models. Published laboratory, cyclic plate-load, moving-wheel and full-scale field studies are synthesized. The review indicates that geosynthetic benefits depend strongly on subgrade strength, reinforcement stiffness and tensile response, interface interaction, aggregate characteristics, layer thickness, installation quality and loading conditions. Experimental studies commonly report reductions in permanent deformation or improved traffic-carrying capacity, but results cannot be transferred directly between products and sites without accounting for differences in test configuration and boundary conditions. ML literature demonstrates the potential of artificial neural networks, support vector regression, random forests and gradient-boosting methods for predicting pavement distress and material response. However, direct ML datasets for geotextile-reinforced pavement sections remain limited. A research framework is proposed in which controlled laboratory and field measurements are linked to interpretable, carefully validated ML models. Data standardization, external validation, uncertainty quantification, explainability and life-cycle cost assessment are identified as priority research needs.

Keywords: geotextile; geosynthetics; flexible pavement; subgrade reinforcement; rutting; cyclic plate-load test; California Bearing Ratio; machine learning; artificial neural network; pavement performance.

1. INTRODUCTION

Road pavements are layered systems that distribute repeated wheel loads to the underlying subgrade while providing a safe and durable riding surface. Flexible pavements rely on the combined response of asphalt surfacing, granular base and sub-base, and supporting subgrade. Their performance is affected by traffic magnitude and repetitions, axle configuration, material stiffness, drainage, temperature, moisture variation and construction quality. Where the subgrade is weak or saturated, high stresses and shear deformation can lead to rutting, aggregate intrusion, differential settlement and loss of pavement serviceability.

Geosynthetics are polymeric products used in contact with soil, aggregate or other geotechnical materials. Geotextiles are permeable textile materials that may be woven or nonwoven. In roadway applications, their functions include separation of fine subgrade soil from granular layers, filtration, drainage and reinforcement. Geogrids and geocells are also used in pavement reinforcement, but their geometry and load-transfer mechanisms differ from those of geotextiles. Findings from geogrid studies are relevant to the broader geosynthetic context, yet they should not be treated as direct evidence of identical geotextile performance.

The use of geosynthetics in roads has evolved from early unpaved-road applications to paved-road base reinforcement and asphalt interlayer systems. Foundational design concepts describe how tensile restraint, interfacial friction, aggregate confinement and improved separation can reduce deformation or preserve layer integrity [1,2,18]. Later laboratory and field studies have evaluated these effects using cyclic plate loading, full-scale trafficking and instrumented test sections [7–11,16,17]. At the same time, pavement performance modelling has moved beyond purely empirical relationships. ML

models can learn patterns from multivariable datasets and may assist in estimating rut depth, roughness, fatigue response and material properties [13–15,19–27].

2. SCOPE AND REVIEW APPROACH

This narrative review integrates peer-reviewed literature on (i) geotextile and geosynthetic functions in road systems, (ii) laboratory and field evaluation of reinforced pavement structures, (iii) asphalt interlayer applications, and (iv) ML methods used in pavement performance prediction. The synthesis emphasizes studies that report identifiable test configurations, performance measures or model-development procedures. Because the included studies use different products, pavement structures, soils, loading protocols and outcome definitions, a quantitative meta-analysis is not attempted.

Three evidence groups are distinguished: direct geotextile studies; broader geosynthetic pavement studies, including geogrids and geocells; and ML studies on pavement or asphalt performance that are methodologically relevant but do not necessarily include geotextile-reinforced sections. This distinction is important when transferring findings to a specific pavement design.

3. GEOTEXTILES AND THEIR FUNCTIONS IN FLEXIBLE PAVEMENTS

3.1 Separation

Separation is often the most dependable function of a geotextile placed at the subgrade–sub-base or subgrade–base interface. Under traffic-induced cyclic stresses, fine subgrade particles can migrate into the aggregate layer, while aggregate particles may penetrate into soft soil. This intermixing reduces the effective thickness and quality of the granular layer. A properly selected geotextile acts as a separator while allowing appropriate water flow. Its effectiveness depends on opening size, soil gradation, permeability, survivability and installation conditions.

3.2 Filtration and drainage

A geotextile filter must retain soil particles while permitting water to pass without excessive clogging. Selection therefore requires compatibility between soil particle-size distribution and geotextile opening characteristics, together with adequate permittivity and clogging resistance. Drainage performance is especially relevant in regions exposed to monsoon rainfall, seasonal groundwater changes or poor roadside drainage. A geotextile should not be assumed to solve a drainage problem where the pavement has no suitable outlet.

3.3 Reinforcement and confinement

Reinforcement may develop through tensile restraint, frictional interaction, interlocking with aggregate, membrane action and limitation of lateral spreading. The contribution of each mechanism depends on geosynthetic type, tensile stiffness at working strain, interface shear resistance, anchorage, depth and deformation level. Membrane action generally requires appreciable deformation to mobilize tensile forces; it should not be assumed to provide substantial benefit at very small strains. Geogrid aperture interlock and geotextile surface friction are also distinct mechanisms.

3.4 Asphalt interlayer applications

Geotextiles are also used between an existing pavement and an asphalt overlay. In this application, the fabric may act as a stress-relieving interlayer and moisture barrier when installed with a compatible tack coat and adequate bond. The purpose differs from subgrade separation: performance is governed by interlayer adhesion, asphalt retention, impregnation, shear resistance, temperature and water exposure. Poor bonding or wrinkles can cause slippage, debonding and premature distress [3–5,9,10,21].

4. REINFORCEMENT MECHANISMS AND FACTORS AFFECTING PERFORMANCE

The performance of a reinforced pavement is a system response rather than a property of the geotextile alone. The principal mechanisms and their practical implications are summarized below.

Mechanism	Expected contribution	Key controlling factors
Separation	Maintains integrity and thickness of granular layers	Soil gradation, opening size, puncture resistance, installation
Filtration/drainage	Limits particle migration while permitting water flow	Permittivity, apparent opening size, clogging, drainage outlet

Tensile restraint	Restricts lateral movement and helps distribute load	Tensile stiffness at working strain, anchorage, interface shear
Aggregate interaction	Improves confinement and resistance to shear deformation	Aggregate grading, angularity, geosynthetic surface/geometry
Membrane action	Provides tensile support after deformation develops	Strain level, tensile strength, embedment and boundary conditions
Interlayer stress relief	May delay reflection cracking in asphalt overlays	Tack coat, bond strength, fabric impregnation, temperature and moisture

Important design variables include subgrade CBR or resilient modulus, moisture condition, aggregate thickness and gradation, geotextile tensile properties, interface friction, reinforcement location, wheel load, tire pressure, load repetitions and construction quality. A geotextile selected primarily for separation may not have the tensile stiffness required for a reinforcement design. Product selection should therefore be application-specific and consistent with relevant standards and project specifications.

5. EXPERIMENTAL EVALUATION OF REINFORCED FLEXIBLE PAVEMENTS

5.1 Material characterization

A defensible experimental programme begins with characterization of the subgrade, granular materials, asphalt mixture and geotextile. Subgrade testing should include soil classification, particle-size distribution, Atterberg limits where applicable, compaction characteristics, moisture content and soaked/unsoaked CBR. Where facilities permit, resilient modulus and repeated-load triaxial testing provide more mechanistic measures of unbound-layer response. Granular materials should be assessed for gradation, aggregate strength, shape, abrasion resistance and compaction response.

Geotextile characterization should include mass per unit area, thickness, tensile strength and elongation, tensile stiffness, puncture resistance, tear resistance, apparent opening size and permittivity. Test methods should be reported with specimen conditioning, loading rate, number of specimens and variability. Nominal tensile strength alone is insufficient: tensile response at small working strains and interface interaction with the selected aggregate are often more relevant to pavement service behaviour.

5.2 California Bearing Ratio testing

CBR testing is widely used to characterize subgrade support and compare untreated and treated soil conditions. For a geotextile-reinforced system, the test arrangement must clearly state the location and orientation of the fabric, specimen dimensions, compaction level, surcharge, soaking condition and penetration procedure. A CBR increase observed in a small mould should not automatically be interpreted as a field-scale structural improvement. The fabric may alter confinement and boundary effects, and the result may be sensitive to placement relative to the penetration zone.

5.3 Plate-load and cyclic plate-load testing

Static plate-load tests provide load–settlement response and an indication of support stiffness. Cyclic plate-load tests are more representative of repeated wheel loading and can measure resilient and permanent deformation over successive load cycles. Large-scale studies have used instrumented test boxes and cyclic loading to compare control and reinforced sections [7,8,16]. Typical measurements include applied load, surface settlement, permanent deformation, resilient deflection, vertical stress at selected depths and strain in the reinforcement.

5.4 Moving-wheel and full-scale field testing

Moving-wheel tests reproduce a moving contact load and can capture rut accumulation under repeated passes. Field trials provide valuable evidence on construction practicality, drainage, spatial variability and realistic stress conditions. Research on geosynthetic-reinforced unpaved roads using moving-wheel loading has reported reduced surface deformation in reinforced sections [17]. Full-scale flexible pavement trials have also demonstrated that reinforcement depth and configuration influence measured pavement response [11].

5.5 Performance indicators

A consistent set of performance indicators is needed to compare studies. Common measures include rut depth, permanent deformation, resilient deflection, surface settlement, load–deformation stiffness, number of load repetitions to a defined rut threshold, traffic benefit ratio (TBR), traffic improvement ratio and reduction in base thickness. TBR is commonly defined as the number of load repetitions sustained by the reinforced section divided by the number sustained by the control section at the same specified rut depth. The threshold and loading protocol must always be stated.

Percentage reduction in rut depth can be calculated as: RDR (%) = [(rd_control − rd_reinforced) / rd_control] × 100, where rd is rut depth measured at the same number of load repetitions. A corresponding percentage reduction in permanent deformation can be calculated in the same way. Comparisons are meaningful only when control and reinforced sections have comparable geometry, compaction, moisture, loading and boundary conditions.

6. EVIDENCE FROM PUBLISHED EXPERIMENTAL AND FIELD STUDIES

Early work by Giroud and Noiray established a design approach for geotextile-reinforced unpaved roads and discussed reduction in aggregate thickness for specified traffic and subgrade conditions [1]. Giroud and Han subsequently presented a theoretical design method for geosynthetic-reinforced unpaved roads that incorporates traffic, wheel loading, subgrade strength, base strength, interfacial interaction and geosynthetic stiffness [2]. These methods are foundational but should not be applied outside their intended design domain without validation.

Studies of paved roads over soft subgrades have used cyclic plate loading to investigate the influence of geosynthetic type, reinforcement location and base thickness. Abu-Farsakh and co-workers reported improved pavement response and reduced permanent deformation in reinforced test sections [7,8]. Their later work addressed quantification of reinforcement benefits for flexible pavement design using cyclic plate-load testing [16]. These studies support the value of controlled comparisons, but their results are specific to the tested soils, materials and configurations.

Full-scale field trials by Imjai and colleagues examined geosynthetic reinforcement at different pavement depths and monitored structural response using instrumentation. The results showed that reinforcement configuration affects distribution of static and dynamic stresses and lateral strain response [11]. A review of large-scale laboratory studies concluded that reinforcement performance is influenced by geosynthetic stiffness and geometry, placement depth, pavement layer thickness and subgrade stiffness [12].

More recent research continues to investigate geosynthetic systems under repeated loading. Moving-wheel tests on unpaved road sections have quantified deformation and traffic benefit [17]. Repeated plate-load experiments on geosynthetic-reinforced road bases have evaluated permanent and resilient deformation [25]. A 2026 field study on geogrid-reinforced flexible pavements used several subgrade CBR levels and geogrid types, highlighting the need to link reinforcement benefit with subgrade strength [28]. Because that study concerns geogrids rather than geotextiles, it is supporting evidence for geosynthetic reinforcement generally, not direct validation of a geotextile design.

For asphalt overlays, research has examined geosynthetic interlayers to delay reflective cracking and improve fatigue response [4,5,9,10]. These studies show that interlayer performance is not determined by fabric tensile properties alone. Tack coat selection, application rate, bond strength, water exposure and construction temperature can be decisive. Recent reviews synthesize interlayer strategies for improving asphalt resistance to cracking [21].

Overall, the experimental literature supports the potential of geosynthetics to improve pavement performance in suitable conditions. However, differences in product type, test scale, loading protocol, soil condition and failure criteria limit direct comparison. A clear distinction must be maintained between geotextile, geogrid and geocell results.

7. MACHINE LEARNING IN PAVEMENT ENGINEERING

7.1 Overview of ML methods

ML methods identify relationships between input variables and response variables using data-driven algorithms. In pavement engineering, typical inputs include traffic volume, axle loading, climate, pavement age, layer thickness, material properties, drainage, maintenance history and measured condition. Outputs may include rut depth, fatigue cracking, IRI, resilient modulus or material properties.

- Artificial Neural Networks (ANN): model nonlinear relationships; performance depends on architecture, data quantity, scaling and regularization.

- Support Vector Regression (SVR): uses kernel functions for nonlinear regression; kernel and hyperparameter selection are important.
- Random Forest (RF): an ensemble of decision trees that models nonlinear interactions and can provide feature-importance measures.
- Gradient Boosting and XGBoost: sequential tree ensembles that often perform strongly on structured tabular data but require tuning and overfitting safeguards.
- Gaussian Process Regression: can provide predictive uncertainty for relatively small datasets, although computational cost increases with dataset size.
- Hybrid models: combine ML with feature selection, optimization or mechanistic relationships; added complexity should be justified by improved generalization.

7.2 ML applications reported in pavement literature

Reviews of ANN applications in pavement engineering describe uses across design, construction, inspection and maintenance [13]. Broader reviews of pavement performance prediction discuss supervised learning methods and challenges related to data quality, model selection and generalization [14,15,19]. ML has also been used to predict asphalt mixture properties and pavement rutting. Deng and Shi compare mechanical, empirical and ML approaches to rutting prediction and emphasize the importance of input variables and practical model use [19].

Recent systematic evidence on ML models for asphalt construction reports substantial use of ANN models but notes that evidence for their universal superiority is limited. The review also highlights inconsistent reporting of datasets and performance metrics, restricting comparison across studies [22]. Studies using field or network-level datasets have explored SVR, ANN, random forest and boosting methods for rutting prediction [23]. Tree-based algorithms have also been applied to IRI prediction using pavement and environmental variables [26]. These studies provide methodological guidance but do not necessarily represent geotextile-reinforced pavements.

7.3 Proposed ML framework for geotextile-reinforced pavements

A purpose-built ML dataset should combine material properties, construction details, loading history and measured pavement response. Suitable inputs include:

- Subgrade: soil classification, soaked CBR, moisture content, dry density, resilient modulus and plasticity index.
- Granular layers: base and sub-base thickness, gradation, aggregate type, compaction and resilient modulus.
- Geotextile: woven/nonwoven type, polymer, mass per unit area, tensile stiffness, tensile strength, elongation, puncture resistance, permittivity and opening size.
- Interface and placement: geotextile location, interface shear strength, anchorage, overlap, installation condition and tack coat parameters where relevant.
- Loading and environment: plate or wheel load, contact pressure, load repetitions, speed, temperature, rainfall or moisture condition and drainage.
- Response variables: rut depth, permanent deformation, resilient deflection, surface settlement, TBR, IRI and load repetitions to a defined distress threshold.

The initial modelling task should be selected according to data availability. Regression models can predict rut depth or resilient deflection; classification models can identify whether a section is likely to exceed a defined distress threshold; and time-to-event methods can estimate the number of load cycles to a specified rut depth. Separate models may be required for subgrade reinforcement and asphalt interlayer applications because their mechanisms and response variables differ.

7.4 Data preparation, validation and interpretability

Data preprocessing should include unit harmonization, outlier investigation, missing-data treatment, feature scaling where required and documentation of test protocols. Multiple measurements from the same test section must not be randomly divided across training and testing sets because this can cause data leakage. Grouped validation by test section, site, project or laboratory campaign is preferable. Where possible, a final external dataset from a different site or experimental programme should be reserved for independent validation.

Model performance should be reported using multiple metrics, such as coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE) and, where appropriate, mean absolute percentage error (MAPE). Residual plots, prediction intervals and error analysis across low- and high-CBR conditions should be provided. Feature

importance, permutation importance or SHAP analysis can help identify whether predictions are consistent with engineering understanding. Explainability does not establish causality; it helps diagnose model behaviour.

A transparent baseline model, such as multiple linear regression or a mechanistic/empirical relationship, should be compared with more complex ML algorithms. Hyperparameter tuning must be conducted within the training data using cross-validation. The test set should be used only for final evaluation. Small datasets should favour parsimonious models and uncertainty reporting rather than unnecessarily complex deep-learning architectures.

8. INTEGRATING EXPERIMENTAL INVESTIGATION WITH ML

The strongest research design is a closed-loop process in which experiments generate reliable observations, ML models identify influential variables and resulting predictions guide additional experiments. A proposed sequence is:

- Define control and reinforced pavement sections with identical layer thicknesses and compaction targets, changing only the reinforcement variable in each comparison.
- Select one or more geotextile products with documented index and performance properties; include a no-geotextile control.
- Prepare subgrade conditions spanning a realistic range of support levels and moisture states.
- Conduct material characterization, CBR tests and repeated plate-load or moving-wheel tests using a documented protocol.
- Record load, cycles, settlement, rut depth, moisture, density, temperature and reinforcement strain where instrumentation is available.
- Develop a structured database with a unique identifier for every specimen, test section, product and loading sequence.
- Train baseline and ML regression models, use grouped cross-validation and reserve independent test sections for final validation.
- Interpret feature effects, quantify uncertainty and compare model predictions with observed engineering trends.
- Assess practical implications through sensitivity analysis and life-cycle cost comparison, including installation and maintenance.

An illustrative conceptual model is: pavement response = f(subgrade properties, granular layer properties, geotextile properties, interface characteristics, geometry, traffic loading, environment and construction quality). The function f may be represented by a mechanistic model, an empirical model or an ML algorithm. A hybrid approach may use mechanistic features—such as layer stiffness ratios or normalized load—to improve transferability between test scales.

9. RESEARCH GAPS AND FUTURE DIRECTIONS

- Geotextile-specific datasets: many pavement reinforcement studies focus on geogrids or mixed geosynthetic systems. More controlled studies isolating geotextile effects are needed.
- Comparable experimental protocols: differences in specimen size, compaction, moisture, loading frequency and rut-depth criteria prevent direct pooling of results.
- Long-term durability: creep, installation damage, clogging, chemical exposure and cyclic degradation require further investigation.
- Interface characterization: direct shear, pullout and aggregate–geotextile interaction tests should be linked to full-scale pavement response.
- Field validation: laboratory improvements must be verified under real traffic, climate and drainage conditions.
- ML generalization: models trained on one laboratory or geographic region may not transfer to another. External validation and domain adaptation need attention.
- Explainability and uncertainty: model outputs should include confidence or prediction intervals and engineering interpretation.
- Cost and sustainability: reinforcement should be assessed against material costs, construction time, reduced aggregate demand, maintenance and service-life benefits.
- Integrated design guidance: application-specific selection criteria should connect product properties with subgrade conditions, pavement structure and performance targets.

10. PRACTICAL IMPLICATIONS FOR PAVEMENT DESIGN AND CONSTRUCTION

Geotextile selection should begin with a clearly defined function: separation, filtration, drainage, reinforcement or a combination. The designer should evaluate subgrade soil, aggregate gradation, groundwater and drainage conditions,

expected traffic, construction equipment and survivability requirements. The geotextile must be placed on a prepared surface without folds or damage, with overlaps or seams specified for the project. Aggregate should be placed and spread using methods that minimize displacement or puncture. Quality assurance should document product certificates, delivery condition, placement, overlaps, cover thickness and compaction.

For asphalt interlayers, surface preparation, crack treatment, tack coat type and application rate, fabric impregnation, paving temperature and bond quality require separate control. A product intended for subgrade separation should not automatically be specified as an asphalt interlayer. Similarly, a geogrid design chart should not be directly transferred to a geotextile product without validating relevant mechanical properties and interaction mechanisms.

For Indian road projects, applicable BIS standards, IRC guidance, project specifications and manufacturer data should be checked at the design stage. Standards should be cited by exact designation and edition in the final submitted manuscript. This review does not prescribe a universal geotextile type or placement depth because these depend on site-specific design inputs.

11. LIMITATIONS OF THE REVIEW

This paper is a narrative synthesis rather than a registered systematic review or meta-analysis. The studies considered differ in product type, scale, subgrade, pavement composition and loading protocol. Several ML studies address general asphalt or pavement performance rather than geotextile-reinforced sections; they are included to establish methodological opportunities, not as direct evidence of reinforcement effectiveness. The review does not claim that all geosynthetic products provide the same response. Product-specific design and independent field validation remain necessary.

12. CONCLUSIONS

Geotextiles can contribute to flexible pavement performance through separation, filtration, drainage and, where suitable tensile and interface conditions exist, reinforcement. The most consistent benefit in weak-subgrade applications is preservation of granular layer integrity and reduction of intermixing; reinforcement-related improvements depend on interaction among geotextile stiffness, aggregate, subgrade, placement and loading. Laboratory CBR tests, static and cyclic plate-load tests, moving-wheel tests and full-scale field trials provide complementary evidence, but results should be interpreted in the context of their test conditions.

Machine learning offers a promising means of predicting rutting, deformation and other pavement responses from multivariable data. ANN, SVR, random forest and gradient-boosting models are relevant candidates, but model complexity alone does not guarantee reliable prediction. High-quality geotextile-specific datasets, grouped and external validation, transparent reporting, uncertainty quantification and explainability are essential.

Future work should integrate carefully controlled experimental investigation with interpretable ML modelling and life-cycle evaluation. Such an approach can support evidence-based selection of geotextiles and more reliable performance prediction for flexible pavements, particularly on weak or moisture-sensitive subgrades.

REFERENCES

[1]. Giroud, J.P., & Noiray, L. (1981). Geotextile-reinforced unpaved road design. Journal of the Geotechnical Engineering Division, 107(9), 1233–1254. https://doi.org/10.1061/AJGEB6.0001187

[2]. Giroud, J.P., & Han, J. (2004). Design method for geogrid-reinforced unpaved roads. I. Development of design method. Journal of Geotechnical and Geoenvironmental Engineering, 130(8), 775–786. https://doi.org/10.1061/(ASCE)1090-0241(2004)130:8(775)

[3]. Button, J.W., & Lytton, R.L. (2007). Guidelines for using geosynthetics with hot-mix asphalt overlays to reduce reflective cracking. Transportation Research Record, 2004(1). https://doi.org/10.3141/2004-12

[4]. Influence of geosynthetic-interlayers on the performance of asphalt overlays on pre-cracked pavements. (2017). Geotextiles and Geomembranes, 45(3), 184–196. https://doi.org/10.1016/j.geotexmem.2017.01.010

[5]. Effects of geosynthetics on reduction of reflection cracking in asphalt overlays. (2009). Geotextiles and Geomembranes, 27(1), 1–8. https://doi.org/10.1016/j.geotexmem.2008.05.007

[6]. Al-Qadi, I.L., Dessouky, S.H., Kwon, J., & Tutumluer, E. (2008). Geogrid in flexible pavements: Validated mechanism. Transportation Research Record, 2045(1). https://doi.org/10.3141/2045-12

[7]. Abu-Farsakh, M.Y., Hanandeh, S., Mohammad, L., & Chen, Q. (2016). Performance of geosynthetic reinforced/stabilized paved roads built over soft soil under cyclic plate loads. Geotextiles and Geomembranes, 44(6), 845–853. https://doi.org/10.1016/j.geotexmem.2016.06.009

[8]. Abu-Farsakh, M.Y., Akond, I., & Chen, Q. (2016). Evaluating the performance of geosynthetic-reinforced unpaved roads using plate load tests. International Journal of Pavement Engineering, 17(10), 901–912.

https://doi.org/10.1080/10298436.2015.1031131

[9]. Sudarsanan, N., Mohapatra, S.R., Karpurapu, R., & Amirthalingam, V. (2018). Use of natural geotextiles to retard reflection cracking in highway pavements. Journal of Materials in Civil Engineering, 30(4). https://doi.org/10.1061/(ASCE)MT.1943-5533.0002195

[10]. Li, Y. (2022). Adhesive property and road performance evaluation of asphalt overlay pavement with geotextile interlayer. Advances in Materials Science and Engineering. https://doi.org/10.1155/2022/3084668

[11]. Imjai, T., Pilakoutas, K., & Guadagnini, M. (2019). Performance of geosynthetic-reinforced flexible pavements in full-scale field trials. Geotextiles and Geomembranes, 47(2), 217–229. https://doi.org/10.1016/j.geotexmem.2018.12.012

[12]. Evaluation of geogrid reinforcement of flexible pavement performance: A review of large-scale laboratory studies. (2021). Transportation Geotechnics, 27, 100471. https://doi.org/10.1016/j.trgeo.2020.100471

[13]. Yang, X., Guan, J., Ding, L., You, Z., Lee, V.C.S., Hasan, M.R.M., & Cheng, X. (2021). Research and applications of artificial neural network in pavement engineering: A state-of-the-art review. Journal of Traffic and Transportation Engineering (English Edition), 8(6), 1000–1021. https://doi.org/10.1016/j.jtte.2021.03.005

[14]. Justo-Silva, R., Ferreira, A., & Flintsch, G. (2021). Review on machine learning techniques for developing pavement performance prediction models. Sustainability, 13(9), 5248. https://doi.org/10.3390/su13095248

[15]. Cano-Ortiz, S., Pascual-Muñoz, P., & Castro-Fresno, D. (2022). Machine learning algorithms for monitoring pavement performance. Automation in Construction, 139, 104309. https://doi.org/10.1016/j.autcon.2022.104309

[16]. Abu-Farsakh, M.Y., Chen, Q., Hanandeh, S., & Saghebfar, M. (2022). Quantifying the benefits of geosynthetics reinforcement in flexible pavement design using cyclic plate load testing. Transportation Research Record, 2676(8). https://doi.org/10.1177/03611981221084691

[17]. Evaluation of geosynthetic reinforcement in unpaved road using moving wheel load test. (2022). Geotextiles and Geomembranes, 50(4), 581–589. https://doi.org/10.1016/j.geotexmem.2022.02.005

[18]. Giroud, J.P., Han, J., Tutumluer, E., & Dobie, M.J.D. (2023). The use of geosynthetics in roads. Geosynthetics International, 30(1), 47–80. https://doi.org/10.1680/jgein.21.00046

[19]. Deng, Y., & Shi, X. (2023). Modeling the rutting performance of asphalt pavements: A review. Journal of Infrastructure Preservation and Resilience, 4, 17. https://doi.org/10.1186/s43065-023-00082-9

[20]. Majidifard, H., Jahangiri, B., Rath, P., Urra Contreras, L., Buttlar, W.G., & Alavi, A.H. (2021). Developing a prediction model for rutting depth of asphalt mixtures using gene expression programming. Construction and Building Materials, 267, 120543. https://doi.org/10.1016/j.conbuildmat.2020.120543

[21]. Taghipoor, M., Balooch Sirgani, P., & Ahmadi Dehaghi, E. (2023). Improving the resistance of asphalt pavements against cracking with an interlayer: A comprehensive review. Construction and Building Materials, 409, 134086. https://doi.org/10.1016/j.conbuildmat.2023.134086

[22]. Machine learning models for predicting physical properties in asphalt road construction: A systematic review. (2024). Construction and Building Materials, 440, 137397. https://doi.org/10.1016/j.conbuildmat.2024.137397

[23]. Predicting rutting development using machine learning methods based on RIOHTrack data. (2024). Applied Sciences, 14(8), 3177. https://doi.org/10.3390/app14083177

[24]. Tamagusko, T., Correia, M.G., & Ferreira, A. (2024). Machine learning applications in road pavement management: A review, challenges and future directions. Infrastructures, 9(12), 213. https://doi.org/10.3390/infrastructures9120213

[25]. Demir, A., Ok, B., & Sarici, T. (2024). Evaluation of rockfill stabilized-geosynthetics reinforced road base with repeated plate loading tests. Applied Sciences, 14(7), 3042. https://doi.org/10.3390/app14073042

[26]. Pavement performance prediction using machine learning: Supervised learning with tree-based algorithms. (2025). Transportation Research Procedia, 82, 2521–2531. https://doi.org/10.1016/j.trpro.2024.12.202

[27]. Soft computing applications in asphalt pavement: A comprehensive review of data-driven techniques using response surface methodology and machine learning. (2025). Journal of Road Engineering, 5(2), 129–163. https://doi.org/10.1016/j.jreng.2024.12.003

[28]. Praveen, B.S., & Baadiga, R. (2026). Full-scale field studies on performance evaluation of geogrid reinforced flexible pavements through cyclic plate load tests. Geotextiles and Geomembranes, 54(4), 668–678. https://doi.org/10.1016/j.geotexmem.2026.03.004

[29]. Yeole, M., Jain, R.K., & Menon, R. (2023). Road traffic accident prediction for mixed traffic flow using artificial neural network. Materials Today: Proceedings, 77(3), 832–837. https://doi.org/10.1016/j.matpr.2022.11.490

[30]. Yeole, M.M., Kudoli, A., Patil, R., et al. (2026). A hybrid MCDM–GRU framework for Indian road accident risk prediction with real-time web deployment. Innovative Infrastructure Solutions, 11, 444. https://doi.org/10.1007/s41062-026-02811-x

[31]. Yeole, M.M., & Jagtap, V.A. (2014). Eco-friendly binder in flexible pavement. IMPACT: International Journal of Research in Engineering & Technology, 2(6), 45–50. DOI not identified in bibliographic information supplied.

[32]. Yeole, M.M., & Patil, J.R. (n.d.). Geotextile can be worth their cost in pavement. IOSR Journal of Engineering (IOSRJEN). Full year, volume, issue, pages and DOI require verification from the original publication.