LOUISIANA TRANSPORTATION RESEARCH CENTER

Technical Summary

LTRC Report 718

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Development of a Design Methodology for Geosynthetic Reinforced Pavement Using Finite Element Numerical Modeling

Introduction

According to the American Society of Civil Engineers (ASCE), more than 62% of funds invested in roadways are allocated to preservation due to the aging and deterioration of existing roadways. To address this issue, a significant increase is needed in the annual expenditure for repairing and building new pavements. The inadequacy of existing roads due to the rapid growth in traffic volume and the escalating costs of materials and energy provide motivation for exploring cost-effective alternatives to the existing methods of constructing and rehabilitating roads. Reinforcing and stabilizing paved and unpaved roads with geosynthetics is one such alternative. In recent years, many geosynthetics (e.g., geogrids and geotextiles) have been developed and used to improve the performance of pavements. The concept of using geosynthetics in roadway construction started in the 1970s. Since then, many experimental, analytical, and numerical studies have been conducted to evaluate the benefits of using geosynthetics in pavements. The geosynthetic type, geometry/interlocking of geogrids, location/layers of geosynthetics, base thickness, and subgrade strength have significant effect on the performance of geosynthetic reinforced pavements. The use of geosynthetics in pavements can extend the pavement's service life, reduce the thickness of the base layer for a given service life, and help construct pavements over weak subgrades. Although the benefits of including geosynthetics within pavement as a base reinforcement and/or subgrade stabilization have been widely recognized, the mechanism of reinforcement is still not fully understood. The literature reveals considerable studies aimed at developing design guidelines, empirical relationships, and design methods for certain reinforcement-pavement conditions. No available method for the design of flexible pavements with geosynthetic reinforcement is universally accepted due to the lack of proper understanding of the mechanisms and quantification of the benefits. Therefore, there is a need for continued research to better understand the geosynthetic mechanisms and benefits and incorporate their effects into mechanistic-empirical pavement design methods. This study focused on evaluating the benefits of using geosynthetic reinforcement in flexible pavements by conducting an extensive finite element (FE) parametric study of geosynthetic reinforced pavement systems.

Objective

- Develop and validate finite element (FE) models to simulate the performance of geosynthetic reinforced pavements built over subgrade soils of different strengths under various traffic conditions.
- Conduct an FE parametric study to evaluate the effect of different variables and parameters contributing to the benefits of geosynthetic reinforced pavements for different traffic loads and different subgrade soil strengths.
- Conduct a sensitivity analysis to examine the effect of reinforcement properties for a range of pavement cross sections on low, medium, and high volume roads in Louisiana.
- Develop a design procedure for geosynthetic reinforced pavements that adheres to the context of the Mechanistic-Empirical Pavement Design Guideline (MEPDG).

Scope

The project aimed to study the benefits and improved performance of flexible pavements reinforced with geosynthetics and develop a design methodology and guidelines for geosynthetic reinforced pavements aligned with the MEPDG. This included developing finite element (FE) models, validating and calibrating the models, conducting a comprehensive FE parametric study to evaluate the effects of different variables, conducting a sensitivity analysis, and developing a design methodology for geosynthetic reinforced flexible pavements. The developed FE models were first validated and calibrated using the results from cyclic plate load tests and full scale field accelerated load tests previously conducted at Louisiana Transportation Research Center (LTRC). The FE models were then utilized to conduct a comprehensive parametric study to determine the effect of different variables and parameters contributing to the effectiveness and performance of geosynthetic reinforced/stabilized pavements. This study explored the influence of factors such as the type and stiffness of geosynthetics, the number and placement of geosynthetic layers, thickness of the base course layer, strength and stiffness of subgrade soil, and traffic volume (low, medium, and heavy). Based on the results from the

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FE parametric study, several regression equations, ML models, and figures/charts were developed to help the Louisiana Department of Transportation and Development (DOTD) pavement and geotechnical engineers incorporate the geosynthetic benefits into a design methodology that lay within the framework of MEPDG.

Metholodology

A comprehensive finite element (FE) parametric study was conducted to evaluate the effect of different variables and parameters contributing to the benefits of using geosynthetic reinforcement, both geogrids and geotextiles, in flexible pavements for low, medium, and high volume traffic roads. These variables included the thickness of asphalt layer, thickness of base course layer, type and stiffness of geosynthetics, and subgrade stiffness. A total of 100 FE load cycles were first applied for each case. Proper constitutive models were used to simulate the behavior of different pavement materials. The developed FE model considers the confining effect on the base course aggregates caused by the geosynthetic reinforcement. A new modeling approach was proposed to simulate the interlocking mechanism between aggregates and geogrids, which differentiated the reinforcement effect in geogrids from that in geotextiles. The resilient vertical strain and rutting of each pavement sublayer obtained from the 100 loading cycles in FE models were incorporated into the mechanistic-empirical (ME) rut equations to establish the long-term rutting versus the number of load cycle curves for the various geosynthetic reinforced pavement sections. For each pavement layer, the corresponding calibration factor (β_{s1}) in the ME rutting equations was calibrated to fit the rutting curves obtained from the 100 load cycles of FE results using a regression analysis based on the least square of error criterion. The total load cycles to achieve 0.5 in., 0.75 in., and 1 in. total rutting targets were estimated for each geosynthetic reinforced and unreinforced case.

The benefits of geosynthetic reinforcement in flexible pavements were quantified in terms of Traffic Benefit Ratios (TBR) for different rutting targets, effective resilient modulus (MR_{eff}) of base course layer, equivalent base thickness (EBT), and permanent deformation reduction factors for base and subgrade (α_b and α_s) for use in rut models. The TBR values for each scenario were determined by dividing the number of load cycles required to achieve the specified rutting target for the reinforced section over the value for the unreinforced section. The calculated TBRs for the different sections were used as inputs in the AASHTOWare software to derive other benefit metrics (MR_{eff}, EBT) based on the calculated TBR benefits. The effective resilient modulus (MR_{eff}) of the base course layer, which represents the adjusted resilient modulus (MR) of the base aggregate layer to account for the increased stiffness caused by using geosynthetics, was calculated for each geosynthetic reinforced section. The values of EBT, which represents the additional thickness of base layer that would achieve the same performance as the geosynthetic reinforced pavement section, were also calculated for all geosynthetic reinforced sections. Several regression and machine learning (ML) models, figures, and tables were developed to evaluate the TBR, MR_{eff}, EBT, and α_b and α_s coefficients for use in the design of flexible pavements as a function of different variables and configurations within the context of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG).

Conclusions

- The inclusion of a single geosynthetic layer at the base-subgrade interface will significantly enhance the pavement's performance by providing lateral restrain and confinement effect, hence reducing the rutting of geosynthetic reinforced pavements.
- The benefits of geosynthetics, in terms of TBR, MR_{eff}, and EBT, increase when decreasing the base thickness, decreasing the subgrade strength, increasing geosynthetic tensile stiffness, and decreasing road traffic volume.
- Geogrid reinforced pavement sections performed better than geotextile reinforced pavement sections due to interlocking behavior with base aggregate.
- For low volume traffic roads (3.5 in. asphalt thickness), the optimal values of TBR, MR_{eff}, and EBT were obtained at 10 in. base thickness. However, in medium and high volume traffic roads, the benefits of geosynthetics decreases when increasing the thickness of the base layer.
- The selected rutting targets significantly influence the TBR, MR_{eff}, and EBT values, which tend to increase when increasing the rutting target for all geosynthetic reinforced pavements.
- The rutting reduction coefficient for the base layer (α_b) ranged from 0.84 to 0.98, while the rutting reduction coefficient for the subgrade layer (α_s) ranged from 0.72 to 0.95.
- Several regression and ML predictive models were developed to evaluate the geosynthetic benefits in terms of TBR, MR_{eff}, and EBT.

Recommendations

- It is recommended to consider reinforcing/stabilizing flexible pavements, especially in conditions in which it is difficult to stabilize weak subgrade soils with cement or lime; for widening highways; in construction of highway exits/entrances built over weak subgrades; and to create working platforms for constructing pavements and embankments over weak soils.
- It is recommended to consider using the values of TBR, MR_{eff}, EBT presented in Appendices A, B, and C of the accompanying Final Report, respectively, to evaluate the short- or long-term benefits in designing the geosynthetic reinforced/stabilized flexible pavements.
- It is recommended to consider using the rutting reduction coefficients for base and subgrade (α_b or α_s) presented in Appendix D of the accompanying Final Report to calculate the rutting performance of geosynthetic reinforced/stabilized pavements using the MEPDG permanent deformation (i.e., rutting) equations.
- It is recommended to consider constructing several geosynthetic reinforced field sections in parallel to sections treated/stabilized with cement or lime for long-term performance comparison, and to verify/validate the findings of this study.