EXECUTIVE SUMMARY

Base reinforcement in pavement systems using geosynthetics has been found under certain conditions to provide improved performance. Current design methods for flexible pavements reinforced with a geosynthetic in the unbound aggregate base layer are largely empirical methods based on a limited set of design conditions over which test sections have been constructed. These design methods have been limited in use due to the fact that the methods are not part of a nationally recognized pavement design procedure, the methods are limited to the design conditions in the test sections from which the method was calibrated, and the design methods are often times proprietary and pertain to a single geosynthetic product.

The first U.S. nationally recognized mechanistic-empirical design guide for flexible pavements is currently under development and review (NCHRP Project 1-37A, NCHRP 2003). The purpose of this project was to develop design methods for geosynthetic reinforced flexible pavements that are compatible with the methods being developed in NCHRP Project 1-37A. The methods developed in this project, while compatible with the NCHRP 1-37A Design Guide, are sufficiently general so as to allow the incorporation of these methods into other mechanistic-empirical design methods.

The design components addressed in this project include material and damage models for the different layers of the pavement cross section, incorporation of reinforcement into a finite element response model, and the development of response model modules that account for fundamental mechanisms of reinforcement. Mechanistic material models are required for all components of the pavement cross section included in the finite element response model. Material models from the NCHRP 1-37A Design Guide for the asphalt concrete, and the unbound aggregate and subgrade layers are used in this study. Additional material models for the unbound aggregate layer are also examined. Material models for components associated with the reinforcement are developed in this project. These include a material model for the reinforcement itself, and an interface shear interaction model for the reinforcement-aggregate and reinforcement-subgrade interaction surfaces. Along with these material models, testing methods providing parameters for use in the material models have been examined and preliminarily evaluated. These testing methods include tension tests for evaluating non linear direction dependent elastic constants for the reinforcement and cyclic pullout tests for evaluating a stress dependent interface shear resilient modulus. These tests have been devised to provide parameters pertinent to small strain and displacement conditions present in pavement applications.

Empirical damage models from the NCHRP 1-37A Design Guide for asphalt concrete fatigue and permanent deformation of asphalt concrete, and unbound aggregate and subgrade layers have been used in this project. A damage model for permanent deformation of unbound aggregate within a zone influenced by the reinforcement was developed and is based on the NCHRP 1-37A Design Guide model for unbound aggregate but with parameters adjusted by reinforcement ratios. Large-scale reinforced repeated load triaxial tests have been performed on aggregate materials to provide methods for assessing reinforcement ratios and the zone of reinforcement over which these ratios apply.

An additional empirical model was developed to describe growth of permanent interface shear stress with traffic passes on a reinforced pavement. Theoretical considerations are made to relate the permanent shear stress to permanent and resilient strains seen in the reinforcement. Normalized relationships between the permanent to resilient reinforcement strain ratio and traffic passes are developed for three reinforcement materials from reinforcement strain data from

previously constructed test sections. The permanent interface shear stress is used in response model modules to account for confinement effects of the reinforcement on base aggregate materials during vehicular loading of the pavement.

Finite element response models for unreinforced pavement cross sections were developed following guidelines in the NCHRP 1-37A Design Guide. Reinforcement was added to the response model by including a layer of membrane elements for the reinforcement and contact interface surfaces for both sides of the reinforcement. Evaluation of reinforced response models by simply including a reinforcement sheet with interface surfaces clearly showed the inability of such a simple static single load cycle analysis for predicting performance of reinforced pavements. This exercise indicated that fundamental mechanisms and processes involved in reinforced pavements are missing from such an approach and that auxiliary response model modules were needed to account for these mechanisms.

Additional models include a response model module created to account for effects of the reinforcement on the aggregate layer during construction. This compaction model describes the increase in confinement of the aggregate layer as lateral movement of the aggregate is restrained during compaction through shear interaction with the reinforcement. Modeling of this process within the context of a finite element response model consisted of the application of a shrinkage strain to the reinforcement and the monitoring of increased lateral stress in the aggregate. Pavement load is not applied in this model. The lateral stresses in the aggregate arising from this analysis are used as initial stresses in subsequent response model modules.

A second response model module (traffic I model) of the reinforcement pavement is then created by using the initial stresses from the compaction model. Pavement load is applied to this model with the distribution of interface shear stress between the reinforcement and the surrounding materials being extracted from the model. The interface shear stresses are taken as resilient values and used in the interface shear stress growth model to determine a permanent interface shear stress distribution for different periods in the life of the pavement. A finite number (typically 6) of distributions are created for different periods and used to compute equivalent lateral force distributions acting horizontally on the aggregate layer.

A third response model module (traffic II model) is created by applying the force distribution arising from the traffic I model to nodes at the level of the reinforcement in an otherwise unreinforced pavement cross section. This analysis is repeated for the number of force distributions created from the traffic I model. For each analysis, the lateral stresses in the base aggregate layer are extracted and used as initial stresses in subsequent response models. This step describes the influence of traffic loading on the increase in confinement of the aggregate layer as shear interaction occurs between the aggregate and the reinforcement.

A fourth response model module (traffic III model) of the reinforced pavement is created by using the initial stresses from the traffic II model. Pavement load is applied to this model and is repeated for each of the initial stress conditions corresponding to different periods in the life of the pavement. From these analyses, vertical strain in the pavement layers and tensile strain in the asphalt concrete layer are extracted as response measures and used in damage models to compute permanent surface deformation of the pavement as a function of traffic passes and fatigue life of the asphalt concrete. The damage model for permanent deformation of aggregate within a zone of reinforcement is used to compute permanent surface deformation.

The unreinforced models were field calibrated from test sections constructed in two pavement test facilities. One facility involved the use of full scale tests loaded by a heavy vehicle simulator. The second facility involved the use of large-scale laboratory model tests. Reinforced models were then compared to test sections from these same two facilities. In general, favorable agreement was seen between predictions from the models and results from pavement test sections.

A sensitivity study was performed to examine the effect of reinforcement for a range of pavement cross sections. In general, the effects of reinforcement on permanent surface deformation are consistent with observed results from pavement test sections. Modest benefits were observed for thick pavement cross sections and pavement sections on a firm subgrade while test sections are not available to confirm these results. In terms of fatigue life, significant effects from the reinforcement were observed. Since the distress feature of rutting has been readily observed in reinforced pavement test sections while asphalt concrete fatigue life has been more difficult to observe and quantify, experimental support for these predictions is lacking.

In general, the methods developed in this project appear to describe reinforced pavement performance generally observed in test sections constructed to date. Significant improvement in terms of the number of traffic passes needed to reach a specified pavement surface deformation was observed for pavements constructed over relatively weak subgrades. The method has been formulated to be generic such that properties of the reinforcement established from different test methods are used as input. Steps needed for implementation of these procedures in the NCHRP 1-37A Design Guide software are provided in this report.