ABSTRACT

Stochastic analysis provides a rationale for the treatment of uncertainties, founded on the principles of probability theory and statistics, and is concerned with a quantifiable measure of the confidence or the reliability associated with any design process. In this thesis, a stochastic approach is employed in the design of flexible pavement structures, to facilitate the development of safe and reliable pavement structures. The important aspects that have been explored in sufficient detail include the system reliability and global sensitivity analysis, and the spatial and temporal uncertainties that pervade the life of pavements.

Chapter 1 of the thesis provides an introduction to the stochastic modelling of flexible pavements and its significance in the present day. Highlighting the need for this study, this chapter also enumerates its objectives and presents an overview of the organization of the thesis.

Chapter 2 provides a review of the existing literature of the design of flexible pavements and the approaches adopted to deal with the various sources of uncertainties in a probabilistic setting. The estimation of the uncertainties in fundamental pavement design inputs and their integration into the general performance prediction procedures has become a required component of the modern Mechanistic-Empirical pavement design methodology, which has been described in detail. This chapter also provides the scope of the thesis by identifying the areas of stochastic analysis that have received little attention

in the flexible pavement design, which include the effect of spatial variability on the pavement structural responses and the techniques of global sensitivity analysis.

Chapter 3 provides a detailed overview of the various methodologies adopted in this thesis to carry out the stochastic modelling of flexible pavements. The fundamental technique adopted for the analysis of reliability is the Monte Carlo Simulation (MCS), which relies upon a numerical/analytical model of the physical system, i.e. the pavement model and a probabilistic description of the design parameters represented by random variables or random fields. The high computational expense associated with the MCS, particularly in the case of random fields, is tackled by the use of meta-models based on the stochastic response surface methodology. The chapter outlines the steps followed to develop the meta-models in the form of Polynomial Chaos Equations (PCEs) and its extension to the Sparse PCE that can conveniently represent the spatial variability of the pavement fields.

Chapter 4 deals with the probabilistic modelling of flexible pavements, where the design parameter and model uncertainties are quantified based on the available literature studies. The global sensitivity analysis, which aims to study the impact of the input uncertainty on the variation of a model output (critical pavement responses) through uncertainty propagation, is achieved by the construction of the Polynomial Chaos Equations (PCEs). To implement the global sensitivity analysis in a system reliability framework, a generalized approach based on Bayes' theorem and the concept of entropy as a sensitivity measure, has been proposed in this chapter.

Chapter 5 deals with the characterization of the spatial variability inherent in the pavement layer by employing random fields and analyzing the effect on the pavement responses. The discretization of the random field into a vector of random variables is achieved through the simple Midpoint Discretization and the efficient Expansion Optimal

Linear Estimation method. Since the computational effort in stochastic problems is proportional to the number of random variables involved, it is desirable to use a small number of random variables to represent the random field. To achieve this, the principle of transformation of the original random variables into a set of uncorrelated random variables through an eigenvalue orthogonalization procedure is adopted. To further increase the computational efficiency of generating random fields for Monte Carlo Simulation, the variance reduction technique of Latin Hypercube Sampling and the meta-modelling technique using Sparse Polynomial Chaos Equations (SPCEs) are implemented. The primary focus of this chapter is to analyze the influence of the spatial variability of the pavement layer moduli, including its anisotropic characteristics on the pavement structural responses.

Chapter 6 focuses on the time-dependent reliability of the pavement structures as they age in service, with due consideration given to degradation of strength with traffic loading. The study is concerned with the fatigue reliability and thereby only the decrease in the asphalt modulus with time is considered as a function of the accumulated damage due to repeated loading, whose uncertainty is determined by the uncertainties of material parameters and the traffic loading. The time-dependent model adopted in this chapter can be quite effortlessly embedded in the Mechanistic-Empirical design framework, and provides a tool to effectively schedule the maintenance of the pavement structure and ensure that the reliability level remains at the desired level for the entire design life of the structure.

Chapter 7 summarizes the various studies reported in this thesis and highlights the important conclusions.