Applying Method of Moments to Model Pavement Reliability Function

Abstract Submitted to the 1st Annual Inter-University Symposium on Infrastructure Management – August 6, 2005
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Abstract:
It has been recognized for a long time that the development of accurate deterioration models plays an important role in designing and managing pavements. Due to many different factors, such as simplified assumptions made for characterizing the behavior of pavement structures and the variability associated with material properties, the condition of a pavement can hardly be predicted with an absolute certainty; at best, what can be predicted is the probability that the pavement will be in a particular condition state. Failing to recognize such a fact can often lead to improper design and management decisions. Models that explicitly consider uncertainties in the prediction are often referred to as probabilistic models. Reliability models are probabilistic models that predict the probability that a system or a unit will perform its intended function under given environmental and operating conditions. If there is a clear definition of a failure event and the consequence of the failure, reliability models can be effectively used to predict the performance of pavements. Even though the concepts of pavement reliability and risk-based design have been recognized for a long time, their practical applications to probabilistic pavement design were limited to the utilization of Monte Carlo simulations and Taylor expansions.

The focus of this presentation is to discuss alternative methods for modeling pavement reliability. In this context, the applicability of the method of moments to modeling reliability function for pavements is introduced. The method of moments is based on two sequential steps. First, to allow for more estimating points, the moments of the limit state function are estimated using the point estimates obtained in the standard normal space; as a result, the accuracy of the calculated central moments is improved. Second, after the moments of the limit state function are obtained, the reliability index and the failure probability are estimated using the existing standardized functions. The advantages of the method of moments over Monte Carlo Simulation are its computational simplicity and analytical traceability, with the satisfactory level of accuracy even for highly nonlinear limit state functions.

To illustrate the applicability of the method of moments to modeling pavement reliability function, a case study was conducted, where three different estimates of failure probability were compared with the estimates from Monte Carlo Simulation. In the case study, the limit state function was defined as the difference between pavement strength and time-dependent stress. The AASHTO pavement design equations were used to specify the functional forms of the strength and the time-dependent stress. Without loss of generality, the basic random variables in the limit state function were assumed normal and statistically independent.
Based on the numerical study conducted for pavement structures using the AASHTO design procedure, it was concluded that the method of moments represents a viable approach to estimate the failure probability and reliability function. The result from the comparison of three different methods of moments with Monte Carlo simulations indicates that the method using all four moments of the limit state function (4M) yields the most accurate prediction of the failure probabilities.