Research Progress and Prospect of Structural Reliability of Asphalt Pavement

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Abstract: To clarify the status quo of structural reliability research in asphalt pavement field, the research advances on the following topics were reviewed, including probability analysis models for reliability of asphalt pavement structure, uncertainty factors, reliability calculation methods, as well as the research focuses for structural reliability. The existing probability analysis models of asphalt pavement structure were comparatively analyzed, the uncertainty factors in design and construction stage were discussed, and the reliability calculation methods were summarized. Finally, the development directions for structural reliability of asphalt pavement were discussed. The results show that the first order second moment method can reliability research for asphalt pavement structure, such as the reliability design indexes, limit states and the probability analysis models. Further research should be conducted from the following aspects, including time-dependent reliability, system reliability and random reliability. Furthermore, the robust and redundancy analysis should be developed based on the structure reliability.

Keywords: Road engineering; Asphalt road; Overview; Reliability; Probability model; Time-varying; System; Redundancy

1. Introduction

The study of structural reliability theory originates from the understanding of the uncertainty in the process of structural life, and the need for calculating the probability of structural failure in structural design risk decision theory [1]. Therefore, the theory of structural reliability has important application value in many fields. At present, the theory of structural reliability has been basically mature, and it is widely used in various fields, such as traffic construction, housing construction, energy supply and mechanical equipment. In accordance with the definition of unified standard for reliability design of engineering structures, structural reliability refers to the ability of a structure to complete a predetermined function under specified time and conditions, and the corresponding probability is the reliability of the structure [2]. In combination with the characteristics of pavement structure, the reliability is defined as the probability that the pavement performance meets the requirements of the predetermined level under the specified design period and traffic conditions [3].

In fact, the performance of asphalt pavement is affected by many objective factors, including: spatial variability. Variability caused by inaccuracy in quantizing parameters. Model errors due to assumptions and simplification of pavement analysis algorithms. Statistical errors due to a lack of regression equations. The first 2 factors are caused by the uncertainty of the design parameters, and the latter 2 can be attributed to systematic errors. Therefore, the solution of the uncertainty in asphalt pavement engineering will be the key to prolong the life of asphalt pavement and guarantee the quality of asphalt pavement.

The theory of structural reliability is a decision-making method used to solve the uncertainty in engineering design. However, the research on the theory of reliability is only a few decades [4]. The design of asphalt pavement should ensure its structure and performance with certain reliability. The reliability of asphalt pavement structure is a probabilistic measure of its reliability. Therefore, the reliability analysis of asphalt pavement structure is an important problem in its design and quality evaluation. The purpose of this paper is to put forward the problems existing in the theory of the reliability of asphalt pavement structure, to explain the hot spot of the application research of the reliability at present, and to put forward the development direction of the structural reliability of the asphalt pavement.

2. The Main Analysis Model of Asphalt Pavement Structure Reliability

In order to analyze the reliability of asphalt pavement structure, the mathematical analysis model of pavement structure reliability must be established firstly——probability model. Because the design methods, the design indexes, the definitions and the probability models are different, the analysis and research of the reliability of the pavement structure is very complex.

According to the design index and design method of different pavement structure analysis, foreign reliable probability model is mainly divided into: stress analysis and fatigue reliability probability model, probability model, probability model, service performance index of probability model and reliability analysis model of design coefficient [5], as shown in table 1.

Table 1. Analysis Models for Reliability of Pavement Structure Abroad

Category	Probability Model	Model Parameter
Stress Intensity	Pf=P(S>F)	Pf is the probability of failure, S stress, F is the strength of the structure, they are the normal distribution and independent, while P(▪)is the probability function
Fatigue Analysis	Pff=P(D>1.0)	Pff is the failure probability, D is the cumulative fatigue failure of pavement during the design period, and they all obey the lognormal distribution
Service Performance	Psf=P(w＞W)	Psf is the failure probability, W is the number of allowable fatigue action on standard axle load, and W is the cumulative number of standard axle load during the design period, and all of them obey lognormal distribution

In 1980s, Changsha Jiaotong University and Tongji University proposed 2 probability model according to the design method of Chinese pavement structure, namely the effect - resistance probability model [6] and traffic fatigue damage probability model, as shown in table 2.

Table 2. Analysis Models for Reliability of Pavement Structure in China

Category	Probability Model	Model Parameter
Effect - Resistance	R0 = P(ld －ls ≥0)	R0 is the reliability of road deflection, while Ld and Ls design deflection values and calculate deflection values respectively
	Ri= P（Ri－mi ≥0） i=1，2，…，n-1	Ri is the reliability of layer I tensile stress at the bottom of pavement structure. Ri and MI are the asphalt pavement and semi rigid base or allowable tensile stress and the maximum tensile stress at the bottom
Service Performance	R = P(Ne－N0 ≥0)	Ne and N0 are the standard axle load fatigue action calculated according to the limit state and the cumulative number of axle load action times in the design period

Since Ne and N0 need to be calculated according to deflection and tensile stresses, the 2 models are essentially identical. But due to the great changes in the actual role models and axle load on the road, but also need to calculate the fatigue life of pavement through the design of index value, so the application traffic fatigue failure probability model has certain difficulty and inconvenience. In view of this, the reliability of asphalt pavement structure is usually analyzed by using the effect resistance probability model.

In a word, in view of the problems existing in the current reliability model, the following aspects should be studied in depth: First of all, it is necessary to determine the indexes that can take place of the deflection of the road surface and the tensile stress at the bottom of the floor; Secondly, the ultimate limit state of asphalt pavement structure is determined according to the determined indexes; Finally, a new probabilistic model for reliability analysis of asphalt pavement structure is established, and the system reliability model of the whole structure of asphalt pavement is established.

3. Uncertainty Factors Affecting the Reliability of Asphalt Pavement Structure

3.1. The uncertainty factors in the design process

In the design process of asphalt pavement, the uncertainty of design parameters is mainly concerned, which mainly includes the following 3 aspects: The uncertainty of traffic parameters, the uncertainty of material performance of pavement structure and the uncertainty of geometric parameters of pavement structure. Among them, the uncertainty of traffic parameters is the variability of the cumulative number of axle loads in the reference period of pavement design. The performance of pavement material uncertainty refers to the variability of the physical and mechanical properties due to factors such as material, construction technology and management level and cause, including the splitting strength of rebound modulus of subgrade and pavement layer modulus and the integrity of the structure layer; At the same time, the material performance parameters which are often used in construction control include deflection and compressive strength of structural layer. The variability of geometric parameters of pavement structure mainly refers to the uncertainty of the thickness of pavement structure layer. The data of their coefficient of variation and the type of distribution function refer to document [7].

3.2. The uncertainty factors in the construction process

The researchers generally pay attention to the design of asphalt pavement structure and material composition, but less discuss the variability of construction technical parameters. The variation level of construction parameters is closely related to the quality of asphalt pavement construction, because it has great influence on the service performance and service life of asphalt pavement. For example, the long-term performance of

the pavement is greatly affected by the nature of the asphalt mixture.

Regardless of how well the mix design and structural design are prepared, the material properties delivered to the site will eventually control the pavement performance. In the construction of hot mix asphalt pavement, the on-site mixing formula allows a certain error. Bazi[8] studies the effects of construction variability on pavement performance when the product is delivered over allowable error, and draws the following conclusions: Regardless of the aggregate source and the type of binder, the variability of the construction will significantly affect the pavement performance. To sum up, the performance variation of the overall structure of the asphalt pavement is objective, and its variability depends on the variability of the design parameters and construction parameters of the structural layers of the asphalt pavement.

Therefore, improving the overall quality of asphalt pavement cannot be confined to the standard constraints, but should take into account the design methods, material characteristics, construction variation, maintenance technology and management tools.

4. Development Trend of Research on Structural Reliability of Asphalt Pavement

4.1. Time-dependent reliability

The relation between reliability and time can be understood from two aspects: Time domain reliability; Time dependent reliability. Time domain reliability refers to the ability of structure to meet time requirements under specified conditions and preconditions [9]. At present, there is little research on time domain reliability, and the main research work is carried out for time dependent reliability.

In the general theory of structural reliability of asphalt pavement, the problem that the performance of structure and material will be attenuated over time is not considered. However, under the influence of vehicle load and environmental factors, the deterioration of the performance of asphalt pavement structure will lead to the structural load capacity of the asphalt pavement to be reduced, thus the reliability of the asphalt pavement structure will decline.

An important engineering requirement for reliability is the ability to provide acceptable product performance over time. As time goes on, this may result in failure of the product. In some of its applications, time-dependent reliability concepts can be used to reduce life cycle costs or to develop preventive maintenance schemes. Therefore, it is of vital importance to perform time-dependent reliability analysis in practical engineering.

4.2. Stochastic reliability

The asphalt pavement structure is an uncertain structural system, and its reliability should be an uncertainty reliability. Uncertainty can be reduced to randomness and fuzziness. Therefore, the reliability of asphalt pavement structure is a fuzzy random reliability. Since 1986, researchers of structural fuzzy random reliability analysis carried out a series of research, and obtained some new results, which is a great contribution to the structural fuzzy random reliability analysis and research.

4.3. Maintenance and repair of Asphalt Pavement Based on Reliability

At present, some scholars have put forward the asphalt pavement maintenance strategy based on reliability. Ma Shih Bing [10] put RCM theory into the field of asphalt pavement, and he has carried on the thorough research to the asphalt pavement maintenance key technical question. Lapa et al. [11] proposed a new method for evaluating preventive maintenance schemes based on cost reliability model. This approach takes advantage of the flexible intervals between maintenance interventions and gives a continuous schedule to better handle the structural failure states. Chou et al proposed a new algorithm that uses MOPSO technology to evaluate the balance of cost and reliability in maintenance scheme. The simulation program for road reliability is shown in Figure 1.

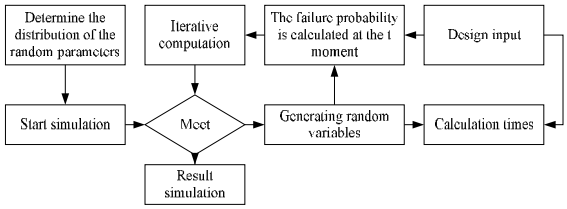

Figure 1. Simulation Procedure for Pavement Reliability

To sum up, the maintenance idea centered on reliability follows the law of occurrence and development of asphalt pavement diseases, which can make maintenance more flexible and targeted, and can also improve the efficiency and effectiveness of maintenance.

5 . Conclusions

In the asphalt pavement engineering, the application of structural reliability theory and the implementation of probabilistic limit state design is the inevitable trend of asphalt pavement development, and also is the necessary way to improve the whole life cycle of asphalt pavement. The reliability design and acceptance assessment of asphalt pavement can not only make the design of asphalt pavement more scientific and reasonable, but also help to improve the quality of the project and the management level of the construction.

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