Study on time-varying reliability analysis method

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Abstract. This paper reviews the research on time-varying reliability of structures in recent years and sums up the problems existing in the system structure of the development of the time-varying reliability, according to the objectives and requirements of reliability theory, the paper introduces some of time-varying reliability calculation method and points out the shortages existing in the above calculation method. Moreover, it further discusses the future research direction of time-varying reliability. Finally, the paper puts forward several approaches for the time-varying reliability analysis of structure.

1. Introduction
In order to make the engineering structure meet the requirements of safety, applicability and durability under different design conditions and different limit states, it is necessary to ensure that the structure has certain reliability requirements. According to the definition of reliability in the existing research, reliability can be described as the ability to complete the predetermined function within the specified time and under the specified conditions. Once the engineering structure fails, it will cause huge economic and people's life and property loss, so the engineering reliability problem has always been a major problem in engineering design. Since the early 20th century, when the probability theory proposed to analyse and determine the structural safety degree, the reliability theory has developed rapidly, and many reliability calculation methods had emerged. For example, the first order second moment method (centre point method and the check point method) was proposed, and then the second order second moment method and Monte Carlo method with improved accuracy were developed. With the combination of fuzzy mathematics and probability theory, the theory system of fuzzy reliability appears. Response surface method (RSM) is a reliable method to solve the problem that the relationship between the input and output of random variables which is highly nonlinear and even under no explicit expression. In addition, the principles and methods of neural network science and genetics are also applied to structural reliability analysis, forming an effective algorithm [1]. Through long-term theoretical development and practical verification, the reliability theoretical analysis methods have been improved day by day. On the basis of reliability theory, a large number of design specifications and standards have been compiled internationally. China's code 《Unified standard for reliability design of engineering structure》 [2] stipulates that the reliability index can be directly used for structural design under certain specific conditions and the design method of reliability index is given.
Traditional reliability analysis methods assume that the force of the structure does not change with time. However, the structural resistance has randomness and changes with time in practical engineering, which means that the structure of the stress state has been changing all the time. So, the structural safety must meet the specified requirement of reliability at every moment. In recent years, with the increasing number of high-rise buildings, DAMS and other important structures, coupled with the deterioration of the use environment, the resistance of the structure will have a great decline even under normal use conditions. Therefore, the time-varying reliability analysis method considering the variation of resistance with time was proposed. Compared with the research method of reliability theory, the development of variable reliability is later because it was restricted by theoretical knowledge and economic conditions. Considering the attenuation of structural resistance with time, many scholars at domestic and overseas have studied the time-varying reliability after putting forward the time-varying reliability research method. Literature [3] studies the analysis method of structural reliability when structural resistance and load effect change with time. By using the important sampling method, the reliability of time-varying structures was studied in literature [4]. In reference [5], the reliability of degraded structures was studied by means of stochastic process theory. Literature [6] proposed a simple method to calculate time-varying reliability of structures. Li [7] proposed a time-varying reliability analysis method based on the grey system theory and adopted the GM model established by the grey system theory to analyse the resistance and load. After obtaining the mean value and standard deviation, the first-order second-moment method was used to analyse the reliability. In the analysis of actual engineering reliability, the form of limit state equation may be linear or nonlinear. Based on this, Jiang [8] used response surface method to study the time-varying reliability of nonlinear limit state equation. These valuable researches promote the development of time-varying reliability of structures.

2. The basic analysis method of time-varying reliability
By classifying their research contents, the current research methods on time-varying reliability methods can be divided into two categories [9].

2.1. The first methods: time-varying reliability problem
This kind of method is to deal with the resistance through the established resistance attenuation model function in the reliability analysis. At present, these methods can be divided into four kinds, such as time synthesis method, time discrete method, time discrete-synthesis method and Monte Carlo method.

Time synthesis method takes the whole service period or the whole evaluation base period of the structure as a reference period, and considers the change of structural resistance and load during the whole service period or evaluation base period. According to the principle of time synthesis, the failure probability of the structure is calculated as follows:

\[
P_{r}(T) = P[R_{\min} \leq S_{\min}]
\]

(1)

The time discrete method and the time discrete synthesis method are based on the time synthesis method. Based on the analysis of load and resistance in each time under period, the discrete load and resistance in the evaluation period can be obtained. The failure probability of the structure is calculated as follows:

\[
P_{r}(T) = P\left[\min_{0 \leq t_i \leq T} R_{\min} (t_i) \leq S_{\max} (t_i)\right]
\]

(2)

where, \(S_{\max}\) is the Maximum load effect over the duration of service \([0,T]\); \(R_{\min}\) is the Minimum resistance at different stages of service life; and \(\Delta t=T/N, t_i=i\Delta t, i=0,1,2,\ldots,N\). Through the analysis of load and resistance, the reliability of the structure can be calculated by the first-order second-moment method.
2.2. The second method: First transcendence probability method

The transcendence probability method analyses the time-varying reliability of the structure by considering the first overshoot failure criterion. In essence, this method assumes the failure of the structure is the time when the time-varying response value exceeds the critical value at the first time. The first transcendence probability is used to analyze and calculate time-varying reliability. However, this method will result in a lot of fuzzy solutions with complex degree for practical projects and cannot get their exact solutions due to the complexity of the calculation steps.

Using the first overshoot failure criterion, the cumulative failure probability of the structure is equivalent to the first overshoot critical value of the structure response:

\[ P_r(T) \leq \int_0^T \nu(t)dt \]  \hspace{1cm} (3)

If we assume that the external penetration rate follows the Poisson distribution, the calculation formula can be expressed as [11]:

\[ P_r(T) \approx 1 - \exp \left( -\int_0^T \nu(t)dt \right) \]  \hspace{1cm} (4)

Thus, outwear rate is the focus of the first transcendence method.

3. Some problems and main research directions in the current research

3.1. Collection and processing of information

The specific reliability information are verified by a large number of practices, but they still stay in an isolated and single level. In order to solve the problem of lack of information in existing structural reliability analysis, literature [12] puts forward the concept of consciousness information, proposes to describe consciousness information with trust function, establishes trust function with probability disk method and interval method, and takes Delphi method as the method of personnel investigation. In the mining and utilization of new information, Liu[13-14] believes that Bayes method can well integrate natural information and consciousness information, which will reduce subjective uncertainty and make the engineering decision-making and judgment more accurate. Therefore, Bayes method can provide an effective new way to solve the problem of time-varying reliability of structure.

3.2. The reliability model of time-varying resistance attenuation

In the study of time-varying reliability, we pay too much attention to the establishment of the accurate resistance attenuation model. As the engineering structure entity is constantly changing, it is not consistent with the reality that the safety verification of the model is simply considered. In addition, the attenuation model established at the present stage only considers the independent action of carbon erosion and chloride ion, etc. In fact, in actual working conditions, the work environment is extremely complex, it is rare for a single influencing factor to act.

3.3. Practical calculation and analysis method

In the time-varying reliability analysis, due to the complexity of its professional theoretical knowledge, it is difficult to apply the current research to practical engineers directly. So, it is very important to find a practical, simple and efficient analysis for the current reliability research. Thus the work requires the hard efforts of a large number of structural workers.

4. Conclusions

With the rapid development of construction technology, super-high-rise buildings are built frequently. The problem of time-varying reliability has become a difficult problem in structural analysis. The study of time-varying reliability is helpful to the design and maintenance of the structure. Though
there are still many difficulties at the present stage, the time-varying reliability problems are bound to be solved with the continuous development of science and technology.

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