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Prediction Method for the Remaining Life of Transmission Tower Foundation Based on Reliability Theory

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Abstract. According to the idea of fuzzy reliability evaluation of foundation engineering, the attenuation model of foundation resistance with time is established by introducing the evolution model of important parameters with time in the limit state of foundation engineering. On this basis, the attenuation law of reliability with time is found and the remaining service life is determined according to the specified threshold of reliability decline. Based on a specific engineering case, the remaining service life is calculated to verify the rationality of the proposed method.

Keywords. Fuzzy reliability evaluation, foundation engineering, reliability decline

1. Introduction

With the rapid development of China's electric power industry, transmission towers as an important component of transmission lines [1, 2], the reliability and safety of transmission towers have put forward higher requirements, especially in recent years, due to the power grid structure, operation mode and load characteristics have changed greatly, resulting in more and more cases of damage to the foundation of transmission towers, the safe operation ability of transmission lines has always been highly concerned by all sectors of society [3, 4], therefore, it is very important to study and analyze the causes of foundation failure of transmission towers, find out the appropriate detection variables, develop corresponding measures and standards, and improve their safety performance.Currently, the research on the remaining service life of concrete structures is limited, with most studies primarily focusing on concrete structures exposed to general atmospheric conditions or chloride-induced corrosion [5]. There is a lack of research specifically addressing the remaining service life of buried foundation structures.In view of the above situation, it is proposed to start the establishment and research of the remaining life prediction model of the foundation based on the reliability theory. Reference [6] proposed the idea of fuzzy reliability evaluation of foundation engineering. Building upon this concept, the development and evolution model of important parameters of foundation engineering with time under limit state was introduced, and the degradation model of foundation resistance with time was

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established. Thus, the decay law of reliability with time was obtained, and the remaining service life was determined according to the reliability degradation threshold.

2. Research Ideas

Around the idea of fuzzy reliability evaluation of foundation engineering [6], by bringing in the evolution model of the development of important parameters in foundation engineering under the relevant limit state with time, so as to establish the decay model of the relevant foundation resistance with time, on the basis of which the decay law of reliability with time is found and its remaining service life is determined according to the specified threshold of reliability decline. The specific ideas are as follows:

(1) Decay model of relevant parameters with time: The existing literature was synthesized to collect and organize the representative parameters affecting the durability of foundation projects under different environmental conditions, such as the decay model of concrete strength and steel corrosion rate with time.

(2) Decay model of structural reliability index with time: By substituting the above decay model of representative parameters with time into the fuzzy reliability calculation model of foundation engineering given in Reference [6], the specific idea is: in the limit state expression, the average value of random parameters of relevant variables is modified according to the above decay model with time and substituted into the reliability calculation model to carry out reliability calculation and obtain the time-varying reliability decay curve of foundation engineering.

(3) Structural remaining service life prediction model: It is noted that the determination of the state variable V in Reference [6] is comparable to the decay of the reliability (reflecting the ratio of the decayed reliability to the initial reliability). Based on this, select the limit state condition with the fastest decay of bearing capacity over time. Combine the actual test results and the corresponding state variable V value calculated in Reference [6], input the base form and V value into the corresponding bearing capacity reliability decay model program. Determine the remaining service life threshold based on design requirements or the Party A’ s claims on remaining service life. It is suggested that the annual quantile value corresponding to the base existing variable V when it is further reduced to near low to C and D levels can be taken as the basis for its future service life.

3. Decay of Concrete Strength with Time and the Resulting Time Varying Decay Model of Load Bearing Capacity Reliability

3.1. Concrete Strength Degradation Model

Combining the expressions of concrete strength mean value variation with age derived from existing studies, the concrete strength mean value decay model is brought into the fuzzy reliability calculation model for foundation projects given in Reference [6]. The deterministic time function of the mean concrete relative strength is shown in equation (1), and it can be inferred from equation (1) that the concrete strength tends to increase until the age reaches 22 years. After 22 years, the deterioration effect of the erosion factor in the environment exceeds the growth effect of the concrete strength itself, and the concrete strength starts to show a decreasing trend.

$$\mu_f(t) = -1.315*10^{-4}t^2+5.837*10^{-3}t+0.8618 \tag{1}$$

Similarly fitting the deterministic time function of standard deviation, the expression fitted by using the quadratic function can better fit the variation law of concrete relative strength standard deviation with age.

$$\sigma_f(t) = -2.655*10^{-5}t^2+2.674*10^{-3}t+0.06787 \tag{2}$$

The relative strength of the concrete decay model is the ratio of the concrete converted strength obtained by the rebound method divided by the standard value of the concrete cubic compressive strength $f_{cu}/f_{cu,k}$ at moment t. Formula for concrete conversion strength obtained by rebound method at time t:

$$f_{cu}=(-1.315*10^{-4}t^2+5.837*10^{-3}t+0.8618)f_{cu,k} \tag{3}$$

The Design Code for Concrete Structures gives the design strength as $f_c=0.76\,f_{cu}$, and for the consideration of structural safety, the lower value is generally taken in the design code. A large number of tests on the tensile properties of concrete have been conducted in China, and the empirical formula is obtained after regression analysis:

$$f_t=0.26\,f_{cu}^{2/3} \tag{4}$$

The above concrete strength decay model is brought into the fuzzy reliability calculation model for foundation engineering in Reference [6], and the specific calculation process is shown as Figure 1.

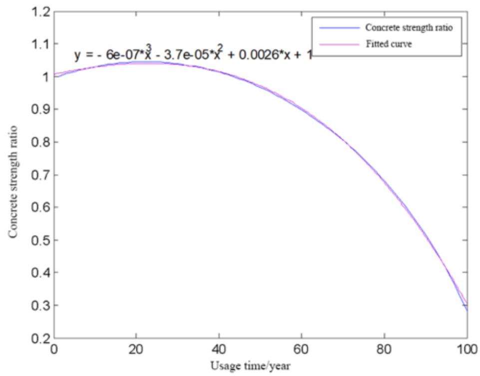


Figure 1. Concrete strength ratio time-varying decay curve.

To address the issue of the conditions of applicability of the above-mentioned concrete strength decay law with time, the analysis of the above-mentioned References [7-9] shows that the raw data of the existing time-varying models are mainly derived from rebound data and drilled core data of office buildings and residences. The service life of the buildings at the time of testing ranged from 1 to 60 years. In order to achieve a unified comparison, the available information does not explicitly mention the specific concrete strength values, but the strength decay ratio of concrete in the same measurement area in different years as the object of statistical analysis, according to the analysis of the subject group that: around the above time-varying decay model of concrete strength, should be commonly used in general civil buildings as a benchmark to obtain the range of concrete strength, its main applicable strength should be in C20-C40 [10]. In the absence of accurate time-varying statistics corresponding to different strength classes of concrete, the above data curve data is used as a reference for the time-varying decay curve of concrete strength in general foundations.

3.2. Calculation of Sloping Section Bearing Capacity of Large Slab Foundation and Excavated Foundation

The calculation of the bearing capacity of the oblique section of a large slab foundation and the hollow foundation is divided into two categories of eccentric tension and eccentric pressure [11].

Eccentric tension:

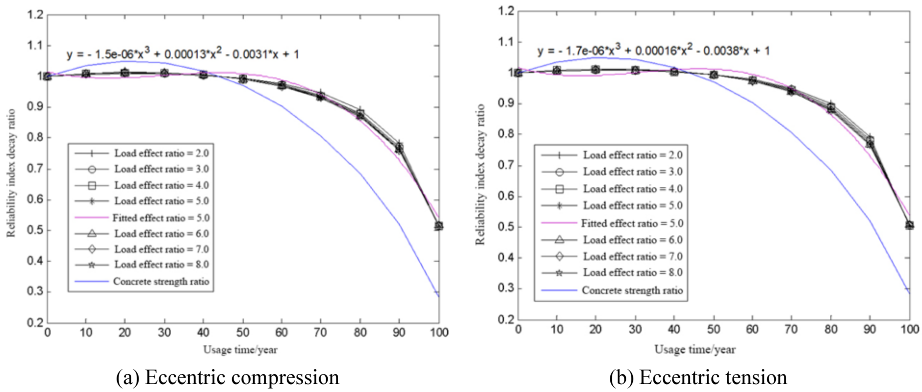
$$V_{cs} = \frac{1.75}{\lambda + 1} f_t b h_0 + f_y \frac{nA_{sv1}}{s} h_0 - 0.2N_m \tag{5}$$

Eccentric compression:

$$V_{cs} = \frac{1.75}{\lambda + 1} f_t b h_0 + f_y \frac{nA_{sv1}}{s} h_0 + 0.07N_m \tag{6}$$

In the formula: V_{cs} is the design value of shear bearing capacity of concrete and hoop reinforcement on the oblique section of the member; s is the spacing of hoop reinforcement along the length of the member; h_0 is the effective height of the section; n is the number of limbs of hoop reinforcement in the same section; A_{sV1} is the cross-sectional area of single limb hoop reinforcement; N_m is the design value of axial tension or axial pressure corresponding to the design value of shear force V when N_m as the design value of axial pressure is greater than 0.3 $f_c A$, take 0.3 $f_c A$, when A is the cross-sectional area of the member; λ is the shear-to-span ratio of the calculated cross-section of the eccentric force member.

Therefore, the relationship curve between the reliability index degradation ratio for bearing capacity of oblique section and the service life has been established for the large plate foundation and the hollow foundation, as shown in Figure 2.



(a) Eccentric compression (b) Eccentric tension

Figure 2. Reliability ratio curve of the eccentric oblique section of large slab foundation with concrete strength decay.

4. Conclusion

Based on the idea of fuzzy reliability evaluation of foundation engineering, by bringing in the model of development evolution of concrete, steel and other important parameters in foundation engineering under the limit state with time, the model of decay of the relevant foundation resistance with time is established and the decay law of reliability with time is found. Based on the grading of the degradation degree of the reliability index ratio, the prediction model and method of the remaining life of the foundation under different quantitative reliability rating levels are formed. It should be noted that this method is based on the case when the corrosion of reinforcement starts to appear, as mentioned before, when the depth of concrete carbonation has not yet reached the thickness of the protective layer and no significant cracking has occurred, usually the reinforcement in the member has not yet entered the corrosion state. Thus, this method is applicable to the case where the results of the relevant test parameters have shown significant attenuation (the depth of carbonation reaches the thickness of the protective layer, or the longitudinal cracking is severe) at the time of testing.

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