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Reliability Analysis of Water Leakage in Tunnels with Cracked and Uncracked Concrete Using Monte Carlo Simulation

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ABSTRACT: Water leakage from concrete tunnel structures is one of the phenomena which can affect their serviceability with certain problems. In this paper, the limit states of water leakage from cracked and uncracked concrete elements have been introduced whilst uncertainty of governing parameters is modelled as random variables. Using Monte Carlo simulation, failure probability and corresponding reliability index of tunnel sections with cracked concrete have been calculated in three modes, namely constant crack width, self-healing and expanding. The results of this analysis showed that concrete self-healing does not have significant role in reduction of leakage probability. On the other hand, since crack width spreads during the service life of structure, an appropriate crack width increase model with time is necessary in order to determine the remaining life of tunnels. Moreover, for uncracked sections and sections that must be necessarily sealed, probability of leakage initiation has been computed during the service life of tunnel. For such structures, this reliability analysis can be utilized to determine the remaining life corresponding to the acceptable failure risk or in designing the minimum required thickness of element and determining the properties of mix design and permeability of concrete.

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1- Introduction

In recent decades, considering the growth in population and industrial advancements, the optimized use of urban spaces have gained a considerable importance. Underground spaces are among those as the most important foundation for railway transportation [1]. Whereas most of these tunnels are constructed in a depth which is usually beneath underground water reservoir, water leakage control is one of the most significant items. Basically water leakage is the main reason for most destructions in tunnel structures and its elements and also it causes the bereaved of comfort and peace of users. Different countries endure great expenses pertaining to repair and maintenance of tunnels, destructed by water leakage [2]. Most studies related to water leakage in tunnels is based on laboratory results in which reliability analysis is not studied [3-7].

2- Methodology

Time dependent water leakage limit state function inside tunnel structures can be described based on two parameters, i.e., acceptable amount of water leakage $SP_{lim}(t)$ and the amount of water leakage discharge Q as follows [8]:

$$G(SP_{\lim}, Q, t) = SP_{\lim}(t) - Q(t) \quad (1)$$

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The aforementioned function is affected by several random variables along with different probability distribution functions, which are dependent to the type of materials and exposed load on intended piece. Failed condition and the corresponding probability by occurrence of these condition $(G \le 0)$ is described as [9]:

$$p_f(t) = p_r(G \le 0) = \iint_{G \le 0} f_{sp_{\lim}, Q}(s, q)\, ds\, dq \quad (2)$$

$f_{sp_{\lim}, Q}$ is the joint probability distribution function of two random variables of $SP_{lim}(t)$ and Q .Solving the integral of the Equation 2, the probability of failure $p_f(t)$ is calculated. Analytic solution of the Equation 2 is not readily available however using approximate methods of reliability or numerical methods such as Monte Carlo Stimulation can calculate the probability of failure. In this paper, Monte Carlo Stimulation method is used. Also as per definition the reliability index can be calculated as follows [10]:

$$\beta = -\Phi^{-1}(p_f(t)) \quad (3)$$

where β represents the reliability index, Φ^{-1} represents the inverse function of standard normal probability of failure .

In this paper, the mechanism of tunnel serviceability failure is described under the effect of cracking in 3 conditions namely self-healing conditions, constant and expanding [3, 4]. And the uncertainty of parameters of water leakage model in cracked concrete [5] is considered as random. Furthermore the equations of water stream governing the uncracked concrete [7] is used and the probability of the initiation of leakage in sections with uncracked concrete during the life time of tunnel is calculated.

3- Results and Discussion

Results of the water leakage reliability analysis of concrete structure of discussed tunnel based on Monte Carlo simulation method with 100,000 repetitions is represented in Figure 1. In self-healing condition, the probability of failure decreases from 40% in first year to 30% in fifth year. In constant crack width condition the probability of failure during 50 years is stable and equals to 50%.

In expanding crack width with time condition, the probability of failure in first five years of the life of tunnel equals to zero and then with increasing tilt sharp increase in 45 years to come, it reaches higher points up to 80 %.

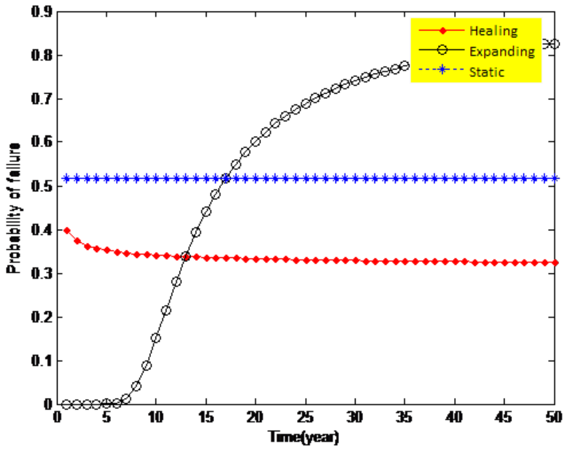

Figure 1. Probability of failure in cracked concrete with three conditions of self-healing crack, expanding and constant

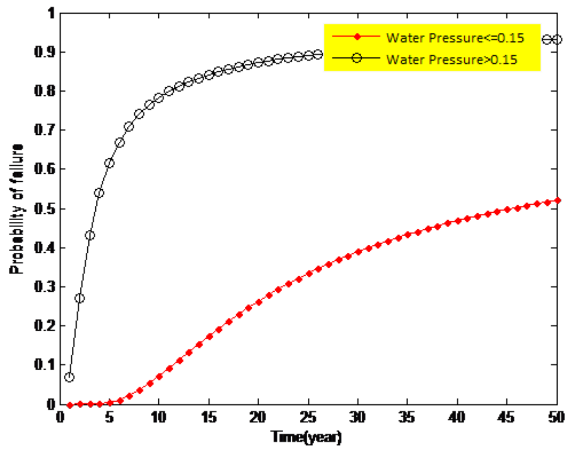

Figure 2. Probability of failure in uncracked concrete

Supposing that there is no crack as per Figure 2, it is recognized that if water pressure around tunnel is less than 0.15 Mpa, the probability of a leakage up to the 3rd year of service can be ignored and then this probability reaches around 10 % on 11th year and continuously on the 50th year it will reach up to more than 50 %. In the case that water pressure around tunnel is more than 0.15 Mpa, by probability of 7%, the water leakage will start from the first year and at the end of 50th year it will reach about 93 %.

This case will occur for tunnels buried in high depth with saturated soil.

4- Conclusion

Water leakage from concrete structure specially tunnels is a matter of great importance from the serviceability point of view. In this paper, after a review of relevant theories pertaining to water leakage in cracked and uncracked concrete, due to inherent uncertainty in most governing parameters appropriate random variables are used for estimating probability of water leakage in tunnels. For existing cracks three conditions are assumed as: self-healing, constant and expanding crack width and the probabilities of failure during 50 years of service are calculated, assuming a predetermined threshold for leakage using Monte Carlo Stimulation. Results represent that concrete self-healing has not an important role in decreasing the probability of leakage. On the other hand sensitivity analysis of the model used for crack width increase revealed that more experiments shall be done for making the model more accurate. Finally a reliability analysis of buried uncracked tunnel structures in saturated soils is conducted to determine the probability of leakage initiation during the service life. It is found that this analysis has the merit in risk based design of concrete elements and their mix design.

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