콘크리트 구조물의 반복적 동결융해에 의한 확률론적 열화예측모델

Probabilistic Prediction Model for the Cyclic Freeze-Thaw Deteriorations in Concrete Structures

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ABSTRACT

In order to predict the accumulated damages by cyclic freeze-thaw, a regression analysis by the Response Surface Method (RSM) is used. RSM has merits when the other probabilistic simulation techniques can not guarantee the convergence of probability of occurrence or when the others can not differentiate the derivative terms of limit state functions, which are composed of random design variables in the model of complex system or the system having higher reliability. For composing limit state function, the important parameters for cyclic freeze-thaw-deterioration of concrete structures, such as water to cement ratio, entrained air pores, and the number of cycles of freezing and thawing, are used as input parameters of RSM. The predicted results of relative dynamic modulus and residual strains after 300 cycles of freeze-thaw for specimens show very good agreements with the experimental results. The RSM result can be used to predict the probability of occurrence for designer specified critical values. Therefore, it is possible to evaluate the life cycle management of concrete structures considering the accumulated damages by the cyclic freeze-thaw by the use of proposed prediction method.

1. Introduction

The important design parameters concerning the cyclic freeze-thaw damage in concrete are investigated and found by many researchers as: the distribution of micro-pores, the saturation of pores (Powers, 1949), freezing expansion pressure (Penttala, 1998), water to cement ratio (Ueda, 2004; Bishnoi, 2004), chloride ions (Cho, 2005), entrained air pores, and admixtures, among which are affecting each other with the accumulated number of cycles of freeze-thaw.

However, as all of the above parameters are important and correlated, there are few of prediction model for the damage. Furthermore, most of the previous research was focused on deterministic evaluation of the damages in concrete structures. Considering the distribution of

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random variables, which include material and environmental properties, the prediction of damage by cyclic freeze-thaw needs probabilistic approach. Therefore, the probabilistic prediction of damages induced by the cyclic freeze-thaw is required to identify the accumulated damage in concrete structures.

The overall objective of this study was to predict the damage of concrete structures, which are attacked by the cyclic freezing and thawing. More specific objectives of the study may be summarized as follows:

- Identify specific important parameters and/or behavioral characteristics that uniquely characterize the accumulated damage by the cyclic freeze-thaw. This is very important from the standpoint of quality control and field evaluation of deteriorated concrete structures.
- Predict and evaluate the accumulated damage as the probability of occurrence or reliability index using response surface method composed of input of the important design parameters for the cyclic freeze-thaw.

2. Prediction for the Damage by Cyclic Freeze-Thaw

Approximating the structural response by the input random variables, the response surface is used to evaluate the reliability and the probability of safety. The method has several merits like the following:

- The implicit limit state function, the system response is composed of user-specified selected input variables, which might be important or sensitive. The sensitivities can be easily checked by using the limit state function.
- After composed, the limit state function can be easily differentiated for obtaining the probability of occurrence for the performance. Therefore, different with Monte-Carlo simulation, it is possible for get extremely small probability of occurrence of even for the very complicated structures which have large degree of freedom.

2.1 Probabilistic prediction for accumulated residual strain

The performance function, also called as limit state function, is showing the current evaluation of the system, which can be used for the prediction of the performance in a probabilistic way. For determining the occurrence of the probability for the accumulated residual strain, the response surface coefficient is decided by the least square method. The probability of occurrence, the probability of event when accumulated residual strain is increased larger than 300 micro strains, is calculated by the AFOSM (Advanced First Order Second Moment) in iterated procedure. The limit state function for RSM is:

$$g()=300-\left(a_0+\sum_{i=1}^{n} a_i x_i+\sum_{i=1}^{n} a_i x_i^2\right) \qquad (1)$$

where is limit state function, RDM is relative dynamic modulus, ais are the coefficients of response function (regression equations of the response of random input variables as center and axis points).

The input data composing the response surface function was obtained from Figure 1 and Figure 2.

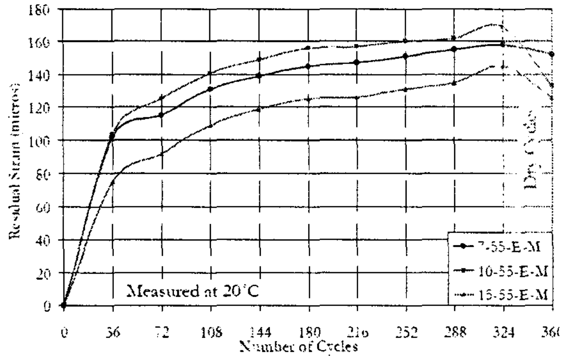


Fig. 1. Residual Strain of different size specimens (entrained cases) (Bishnoi, 2004)

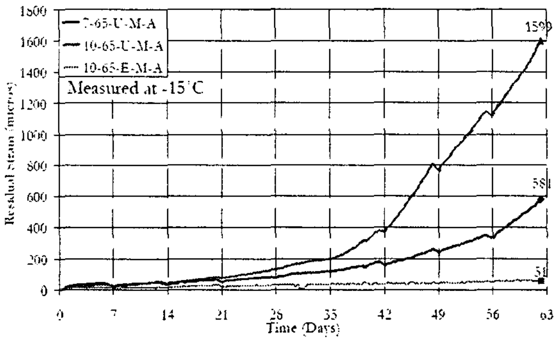


Fig. 2 Residual Strain of different size specimens (un-entrained cases) (Bishnoi, 2004)

The determined coefficients of response surface for tensile stress compose the limit state function as: $g() = 300 - (5632.71 + 4957.77x_1 - 2300x_2 + 6.64x_3 - 4411.99x_1^2 + 163.27x_2^2 - 8.88*10^{-3}x_3^2)$ (2)

The limit state function of Eq. 2 is used for the evaluation of the probability of occurrence, which will exceed the critical value (arbitrarily assumed as 300 in this case) of residual strain. The probability of occurrence is evaluated as 0.00802 by AFOSM.

2.2 Probabilistic prediction for degraded relative dynamic modulus

The limit state function for RSM is: $g()=300-\left(a_0+\sum_{i=1}^{n} a_i x_i+\sum_{i=1}^{n} a_i x_i^2\right)$ (3)

where is limit state function, RDM is relative dynamic modulus, a_is are the coefficients of response function (regression equations of the response of random input variables as center and axis points).

The determined coefficients of response surface for the ewlative dynamic modulus compose the limit state function as:

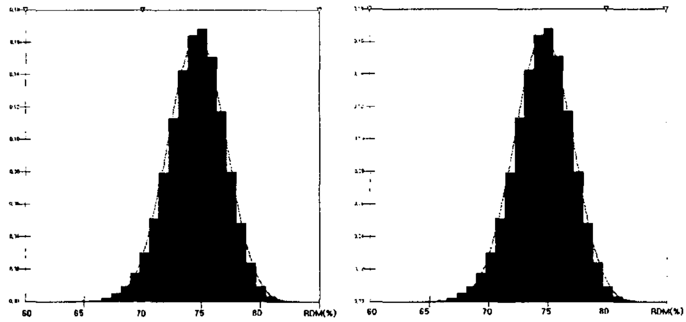
$$g() = 60 - (-265 \ -90.91\, x_1 + 700.0x_2 \text{-} 0.167x_3 + 1.81*10^{-5}x_1^2 - 277.78x_2^2 + 5.40*10^{-12}x_3^2) \quad (4)$$

The limit state function of Eq. 4 is used for the evaluation of the probability of occurrence, which will exceed the critical value (arbitrarily assumed as 60% of the initial value in this case) of RDM. The probability of occurrence of entrained air pore case, Pf, is calculated as 0.004295 by AFOSM.

The fitted results in Eq. 4 are simulated by Monte-Carlo Simulation as shown in Figure 3. The results are showing the sensitivity of input design parameters with the probabilistic prediction of the accumulated damage by the cyclic freezing and thawing.

3. CONCLUSIONS

Using the Response Surface Method of input design random variables, the accumulated damage by cyclic freeze-thaw in concrete specimen was predicted. The predicted results of relative dynamic modulus and residual strains after 300 cycles of freeze-thaw for specimens showed very good agreements with the experimental results. The result of RSM can be used for the prediction of the probability of failure as well.



(a) P_f = 3.1 % for lower than 70% of initial RDM

(b) P_f = 99.1 % for lower than 80% of initial RDM

Fig. 3. Probability Density Function of the Limit State Function for the reduced Relative Dynamic Modulus, Fitted to Beta General Distribution with mean value of 74.558 (RDM in %) by 200,000 cycles of Monte-Carlo Simulations

Determined response surface can be used for the evaluation of performance and the evaluation of sensitivity of input design values. The limit state functions (limit state function) were determined for the evaluation of the probabilities of failure. While varying the supplying terms in limit state functions, the probabilities of failure and the reliability indices are varying. The sensitivity of w/c and entrained air pores showed the decreased stiffness successfully, while increasing the numbers of cyclic-freeze-thaw.

Acknowledgement

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