CS and RCPT Prediction of Concrete Samples Using Bayesian Inference and Performing Different Reliability Analyzes

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ABSTRACT

Compression strength (CS) and rapid chloride permeability test (RCPT) are very significant parameters in mechanical and durability properties in concrete respectively. Analytical methods such as formulas and graphs for prediction and reliability of CS and RCPT in concrete samples are gathered with many problems. Many soft computing methods are very accurate in the prediction of CS and RCPT but these methods are deterministic or have not reliability tools. For these reasons, Bayesian inference is used which is a probabilistic and linear method. For this purpose, according to some of the concrete samples, a probabilistic relation is proposed for each CS and RCPT. Accuracy of each proposed formula is tested, and after verification of them, reliability analysis is performed. In this study, first-order reliability method (FORM), Monte-Carlo sampling (MCS) and histogram sampling are used for reliability analysis. Each of these methods has unique properties that FORM is linear and has a very short time-consuming. MCS and histogram sampling are nonlinear and have high time-consuming but their accuracy are very high. Histogram sampling is similar to MCS but in this type of analysis, reliability results for any outcomes are given and time-consuming in this method is very high. Three-method analysis of CS and RCPT showed that the results are closed together. So, using of FORM because of use easily and save time-consuming can be a reasonable choice for reliability analysis of CS and RCPT in concrete samples.

KEYWORDS

Concrete samples, Bayesian inference, FORM, Monte-Carlo sampling, Histogram sampling.

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1. Introduction

CS and RCPT are very important parameters in quantity and quality of concrete and prediction of these parameters can help concrete design mixture [1]. In this study for prediction of CS and RCPT is used of Bayesian inference method. Bayesian inference is a probabilistic method but other methods are deterministic. Accuracy of Bayesian inference is reasonable and it can be said that this method can be used for future studies [2]. Next section of this study is about reliability analysis that contain FORM, MCS and histogram sampling. Results showed that all of different reliability methods have good accuracy and same solution. So, it can be used of linear reliability methods like FORM for this purpose.

2. Methodology

2.1. Bayesian inference method

For prediction of an event it can be used of Bayesian regression that is given in Eq. 1. In Eq. 1, θ_i and $h_i(x)$ are model parameters and functions respectively [3].

$$y = \theta_1 h_1(x) + \theta_2 h_2(x) + ... + \theta_k h_k(x) + \varepsilon \quad (1)$$

To find the factor of each model parameter the function like h(x) is considered that should be assigned a round number to the exponent of each explanatory variable. In Eq. (2), this relationship is given:

$$h(x) = x_1^{m_1} x_2^{m_2} ... x_k^{m_k} \quad (2)$$

In Eq. (2), different values of m_i are chosen from {-3, -2, -1, 0, 1, 2, 3} set. These values are selected for preventing complications of Bayesian inference model.

2.2. Different reliability methods

Each reliability problem is consists of two parts. The first part is a limit state function (LSF) and the second part is random variables (RVs). FORM, MCS and histogram sampling are the methods that have been used for reliability analysis.

2.2.1. FORM analysis

FORM is a linear method that by using linear Taylor series expansion about design point, separated LSF from overall space by a hyperplane [4]. Beta (β) is Equal to the distance from origin coordinate to the design point or the point that has a maximum probability density that is given in Eq. (3). Method of finding β is represented in Eq. (4) [5].

$$\beta = \| y^* \| \quad (3)$$

$$y = \arg\min\{\| y \|, G(y) = 0\} \quad (4)$$

2.2.2. Monte-Carlo sampling

In this method according to distribution function of RVs, stochastic samples are generated and after getting sufficient accuracy, analysis is finished. Failure probability is assessed by the samples that are in out the limit state surface (LSS) divided into the total number of samples [6]. Determination of P_f in MCS is given in Eq. (5). In Eq. (5), N is the total number of samples and I(x) is the indicator function.

$$P_f = \frac{1}{N} \sum_{i=1}^{N} I(x_i) \quad (5)$$

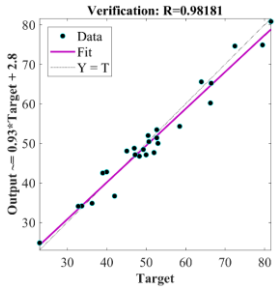
2.2.3 Histogram sampling

Histogram sampling is like MCS but in this method diverse RVs are entered as input and the solution is shown a function of input values.

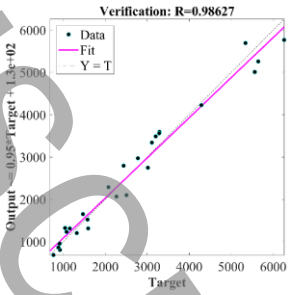
3. Discussion and Results

3.1. Bayesian inference

As can be seen in Figures (1-a) and (1-b), a high correlation exists between observations and predictions of concrete samples.



(a)



(b)

Figure 1. Correlation graph between observed and predicted values for RCPT by Bayesian inference (a) verification of RCPT (b) verification of CS

(10)

3.2. Results of FORM

FORM results for RCPT and CS are presented in Table 1. FORM is a linear method that has a low time-consuming. Reliability index or β can vary between 4 to -4 that if the β is positive P_f is less than 50% and if the β is negative, P_f is more than 50% [7].

Table 1. Reliability analysis of CS and RCPT for the mean values of HPC samples using FORM

Type of verification	Threshold values	Beta index	P_f (%)
CS (MPa)	35	2.7	0.34
	40	1.93	2.69
	45	1.13	12.80
	50	0.33	37.19
	55	-0.486	68.65
	60	-1.29	90.18
RCPT(Coulomb)	500	-0.97	83.46
	1000	-0.59	72.31
	2000	0.17	43.25
	3000	0.93	17.59
	4000	1.68	4.56
	5000	2.44	0.73

3.3. Results of MCS

Results of MCS are given in Table 2. As can be seen in Table 2, same threshold values are selected for MCS that is utilized for FORM analysis. Results of Table 2 are indicated that FORM and MCS are closed together. Therefore it can be concluded that FORM is a rigorous method although this is a linear method. As an example for RCPT threshold value is equal to 500 coulomb, β, and P_f in FORM are -0.97 and 83.46% respectively and these values for MCS are -0.99 and 83.92% respectively. Values of β and P_f of FORM for CS in 35 MPa as a threshold value are 2.7 and 0.34% respectively. These values for MCS are 2.72 and 0.32%. Results in other threshold values in CS and RCPT are the same for FORM and MCS.

Table 2. Reliability analysis by using MCS for CS and RCPT

Type of verification	Threshold values	Beta index	P_f (%)	Samples
CS (MPa)	35	2.72	0.32	774171
	40	1.93	2.68	90698
	45	1.15	12.58	17381
	50	0.32	37.28	4206
	55	-0.48	68.65	1142
	60	-1.34	91.06	246
RCPT(Coulomb)	500	-0.99	83.92	479
	1000	-0.58	72.15	966
	2000	0.15	43.98	3185
	3000	0.95	17.10	12123
	4000	1.70	4.41	54112
	5000	2.44	0.72	343722

4. Conclusion

- Bayesian inference unlike other meta-heuristic methods that are nonlinear and high time-consuming is linear and has a less time-consuming. The other advantage of this method is related to probabilistic modeling that other methods have not this capability and finally, Bayesian inference proposed an explicit formula for each prediction. For these reasons, it is used of Bayesian results as the tools for performing reliability analysis.
- Although Bayesian inference is a very useful method but this method proposed long equations for prediction of CS and RCPT. So it is recommended in the next researches is used for other functions like triangular, logarithmic, exponential, and user-defined functions for summarizing these relations.
- Results showed that FORM and MCS are closed together. Therefore, the accuracy of FORM that is a linear and low time-consuming analysis is very acceptable compared to MCS that is nonlinear and high time-consuming.

5. References

[1] Asghshahr, M.S., Rahai, A., Ashrafi, H., 2016. "Prediction of chloride content in concrete using ANN and CART". *Magazine of Concrete Research*, 68 (21), pp.1085-98.

[2] Shakouri, M., Trejo, D., 2019. "Estimating the critical chloride threshold of reinforcing steel in concrete using a hierarchical Bayesian model". *Sustainable and Resilient Infrastructure*, 4(4), pp. 152-72.

[3] Gardoni, P., Der Kiureghian, A., Mosalam, K.M., 2002. "Probabilistic capacity models and fragility estimates for RC columns based on experimental observations". *ASCE Journal of Engineering Mechanics*, 128 (10), pp.1024-38.

[4] Haukaas, T., Der Kiureghian, A., 2006. "Strategies for finding the design point in nonlinear finite element reliability analysis". *Probabilistic Engineering Mechanics*, 21(2), pp. 133-147.

[5] Bagheri, M., Chahkandi, A., Jahangir, H., 2019. "Seismic reliability analysis of rc frames rehabilitated by glass fiber-reinforced polymers". *International Journal of Civil Engineering*, 17(11), pp.1785-97.

[6] Rostami, P., Mahsuli, M., 2018. "Risk-Optimal arrangement of stiffeners in steel plate shear walls with door opening". *Frontiers in Built Environment*, 4, 59.

[7] Hussein, M., Sayed, T., Ismail, K., Van Espen, A., 2014. "Calibrating road design guides using risk-based reliability analysis". *Journal of Transportation Engineering*, 140(9), 04014041.