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Finding RCC Dams Risky Zones Due to NASR

Zaniar Tokmechi

Islamic Azad University, Sanandaj Branch, Sanandaj, Iran

Abstract: In this article, the cracked zones percentage due to Normal Alkali Silica Reaction (NASR) in a sample Roller Compacted Concrete dam body is investigated. Finally, using results risky zones contours were presented. The Alkali Silica Reaction is a stochastic reaction causing the inflammation of aggregates. Increasing in volume results in an expansive pressure inside the material. As a result, concrete strength losses and concrete spalls. The exact place of the reaction is not definite. Thus, it is perplexing to anticipate. Thus, dealing with this type of problem is really challengeable. Monte Carlo Method as a random method is useful to solve complex systems and is useful for studying systems that are too complicated to be solved analytically. The results show that when the expansions are%0.05 and%0.10 (NASR expansion limit), about%0.117 and%0.179 of dam body is cracked, respectively. The results illustrate that percentage of cracked zones varies from%0.01 to%0.40 for NASR.

Key words: Risky zones · Cracked zones · Normal Alkali Silica · Dam · Monte Carlo

INTRODUCTION

Studies on the safety of dams were done in different parts of the world [1, 2]. The unpleasant expansion of concrete due to reaction between cement alkalis and reactive siliceous aggregates continues to be a cause for major concern [3, 4]. Cement and aggregates vary infinitely in various regions. In areas with reactive siliceous rocks, the probability of Alkali Silica Reaction (ASR) would be high [5, 6]. ASR occurs in different parts of Europe, the United States, Canada and Middle East [7]. It results in an expansive pressure inside the material. This expansion creates cracks in concrete which ease absorption of water [8].

According to preceding findings, ASR has harmful effects on the bond between steel reinforcement and concrete. Also, it is pernicious for flexural members [9-11]. In these studies cantilever beams, simply supported large scale beams and ASTM C231 standard are used [12-14]. The cracks have effects on the durability of structures. In addition, researches concern with the effect of cracks on temperature variation and fire in structures involved in ASR [15-20]. The findings indicate that ASR affects the serviceability, strength and stability of structures. For example, the reduction in flexural capacity is as high as 25% [21-22].

Considerable safety of hydro structures such as dams [23,24] adds the study of risky. However, unfortunately there is not enough study on the effects of ASR on the crack distribution in dams. Thus, in this paper, using Monte Carlo Method and Finite Element method, the cracked zones percentage in Roller Compacted Concrete dams due to Normal Alkali Silica Reaction (NASR) is analyzed and the contours of risky zones are presented.

Alkali Silica Reaction: In general, expansion studies are performed according to a method mentioned in ASTM C1260 [25, 11]. Referring to this standard, expansion in concrete is divided in three groups including normal expansion (NASR, expansion between 0 percent and 0.1 percent), harmful expansion (HASR, expansion between 0.1 percent and 0.2 percent) and dangerous expansion (DASR, expansion more than 0.2 percent) [25].

As it can be seen from Figure 1, tests performed by researchers have shown that expansion varies from 0 percent to 0.6 percent [26]. In this paper, the study of the crack distribution under normal expansion conditions (NASR) including 0.05 and 0.1 percent are investigated.

Corresponding Author: Zaniar Tokmechi, Islamic Azad University, Sanandaj Branch, Sanandaj, Iran
Tel: +98-918-873-1933, Fax: +98-871-3229437, E-mail: z.tokmechi@gmail.com.

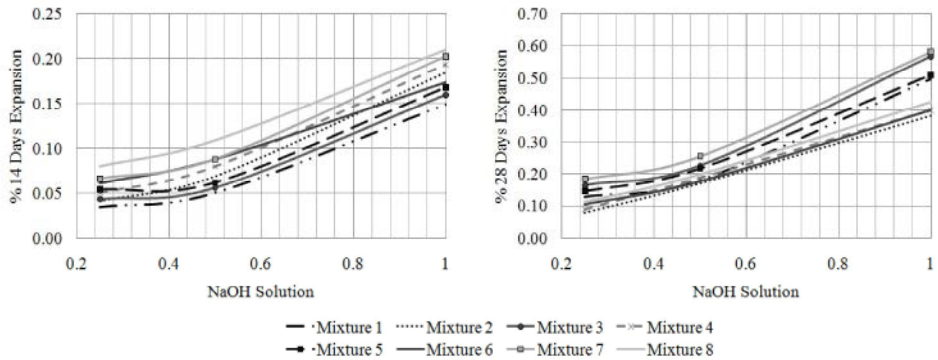


Fig. 1: Expansion due to Alkali Silica Reaction

Table 1- Properties of the dam body material

Dam body material properties		
Elasticity Modulus (GPa)	*Poison's ratio*	*Density (kg/m^3)*
20	*0.25*	*2400*

Table 2- Properties of the foundation material

Foundation material properties		
Elasticity Modulus (GPa)	*Poison's ratio*	*Density (kg/m^3)*
0.75	*0.3*	*2200*

Table 3- Dam body strengths

Dam body strengths			
Compressive strength (MPa)	*Tensile strength (MPa)*	*Safety factor in compression*	*Safety factor in tension*
25	*0.65*	*2*	*1.7*

Roller Compacted Concrete Dams: Roller Compacted Concrete (RCC) is a special blend of concrete that is much drier than conventional concrete and essentially has no slump. RCC has been increasingly used to build concrete dams. In this study, a typical cross section of a sample RCC dam is used. The characteristics of the dam body material are mentioned in Table 1. Table 2 shows the properties of the foundation material. Also, Table 3 shows the strength properties of the dam body material.

Finite Element Method: Since strains are approximately constant in Alkali Silica zones, Constant Strain Triangle element is used [27]. Equation 1 is used to calculate the element stresses. The calculated stress is used as the value at the center of each element.

$$\sigma = DBq \tag{1}$$

Where D is material property matrix, B is element strain displacement matrix and q is element nodal displacement from the global displacements vector Q.

For plane strain conditions, the material property matrix is given by Equation 2.

$$D = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & {1-2\nu}/{2} \end{bmatrix} \tag{2}$$

Element strain-displacement matrix is given by Equation 3.

$$B = \frac{1}{\det J}\begin{bmatrix} y_{23} & 0 & y_{31} & 0 & y_{12} & 0 \\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21} \\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12} \end{bmatrix} \tag{3}$$

In which, J is jacobian matrix and the points 1, 2 and 3 are ordered in a counterclockwise manner. Jacobian matrix is given by Equation 4.

$$J = \begin{bmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{bmatrix} \tag{4}$$

Global displacements vector Q is given by Equation 5.

$$KQ = F \tag{5}$$

In which, K and F are modified stiffness matrix and force vector, respectively. The global stiffness matrix K is formed using element stiffness matrix k^e which is given by Equation 6.

$$k^e = t_e A_e B^T DB \tag{6}$$

In which, t_e and A_e are element thickness and element area, respectively.

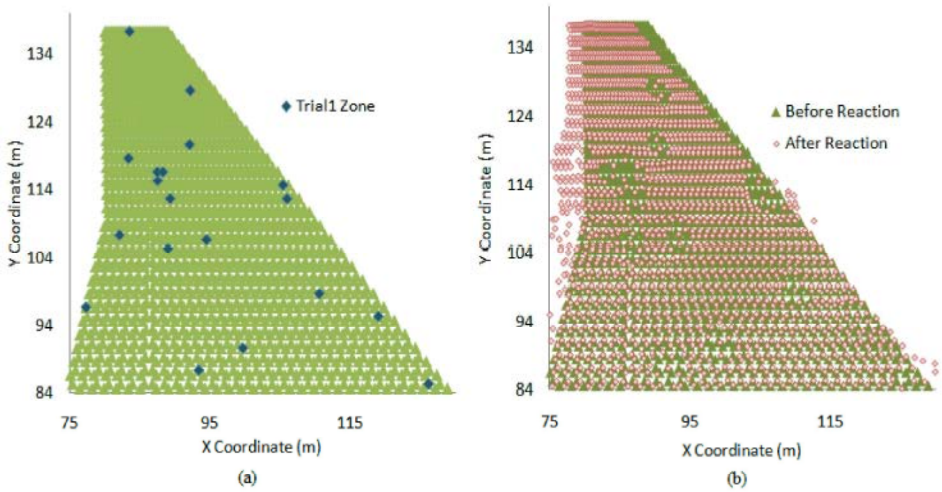


Fig. 2a,b: (a) Alkali Silica zone in the first trial, (b). Displacement in the first trial

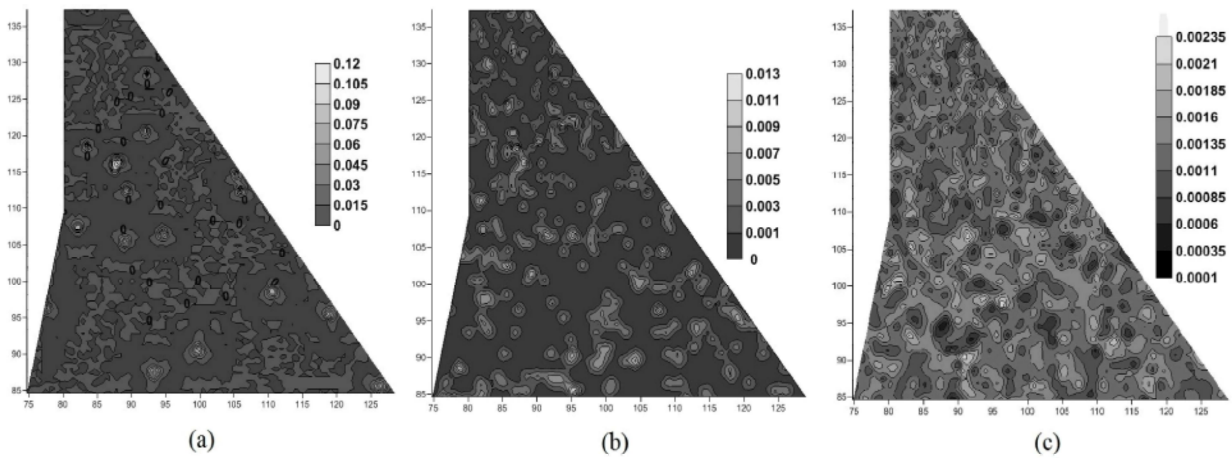


Fig. 3a,c: Zones risk (Expansion=%0.05)
(a). after one trial, (b). after 20 trials, (c). after 1000 trials

Monte Carlo Method: The Monte Carlo Method uses random numbers to determine the answer to problems. The Monte Carlo method usually gives an approximate answer and we should use numerous trials to find the exact answer. This method is used to solve complicated problems in many areas of engineering by generating suitable random numbers and observing that fraction of the numbers that obeys some properties [28-30]. Analysis using this method has six steps [31]. Generating a parametric model, generating a set of random inputs, evaluating the model and finding inputs that obey model properties (live points), repeating steps 1 to 3 (trials) and finding the probability which is given by equation 7.

$$RESULT = \frac{NUMBER \quad OF \quad LIVE \quad POINTS}{TOTAL \quad NUMBER \quad OF \quad POINTS} \qquad (7)$$

Crack Distribution: Supposing that Alkali Silica Reaction expansion happens in 1 percent of the dam body, the study of the crack distribution is evaluated. For the mentioned condition, different Normal Alkali Silica conditions (0.05 and 0.1 percent expansion) are considered.

1000 trials are used for the Monte Carlo Method solution process. In each trial, a number of stochastic elements are selected (Figure 2a). Then, referring to the supposed reactivity of Normal Alkali Silica zone, displacements in each node of the elements are calculated and applied to the model (Figure 2b). After that, the model is analyzed and principle stresses are calculated. Using the calculated stresses and comparing with the compressive and tensile strength of the dam body material, presenting in Table 3, cracked elements (live points) are recognized. Subsequently, using Equation 7, the study of the crack distribution is done.

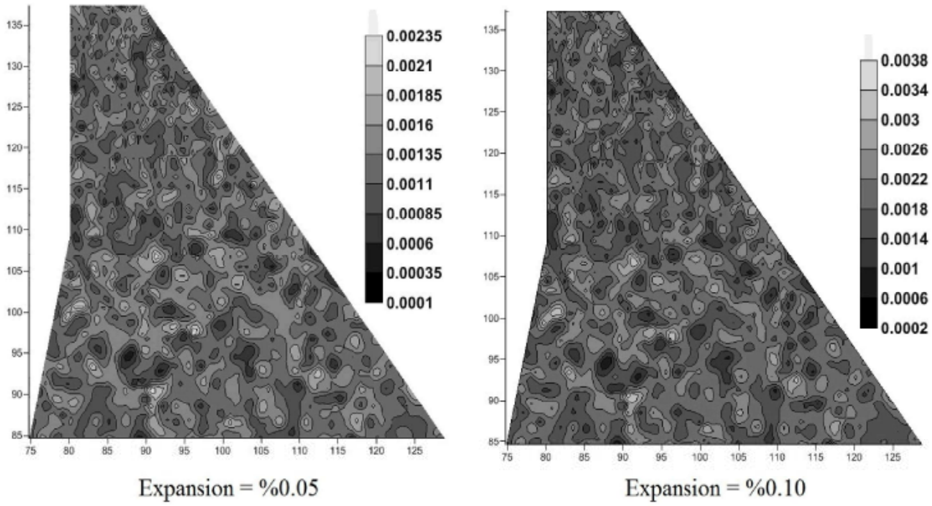


Fig. 4: Influence of expansion on the zones risk

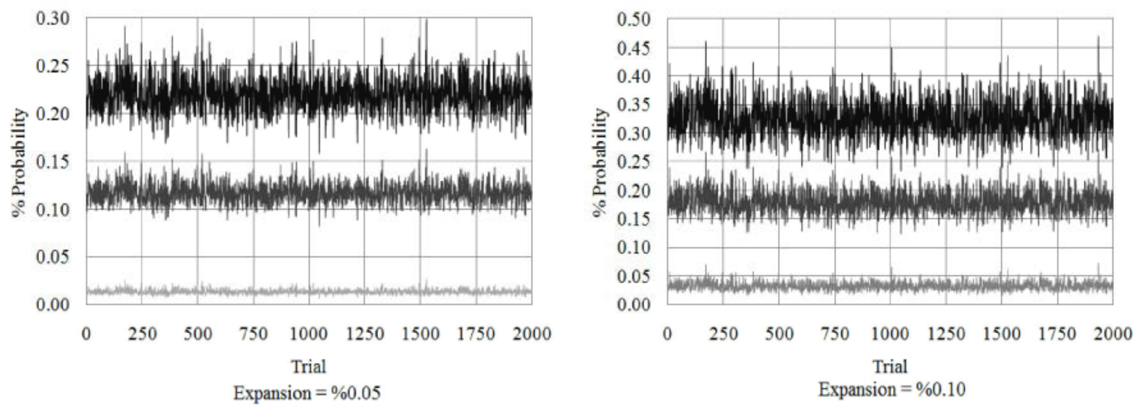


Fig. 5: Mean values of the probability and dispersion

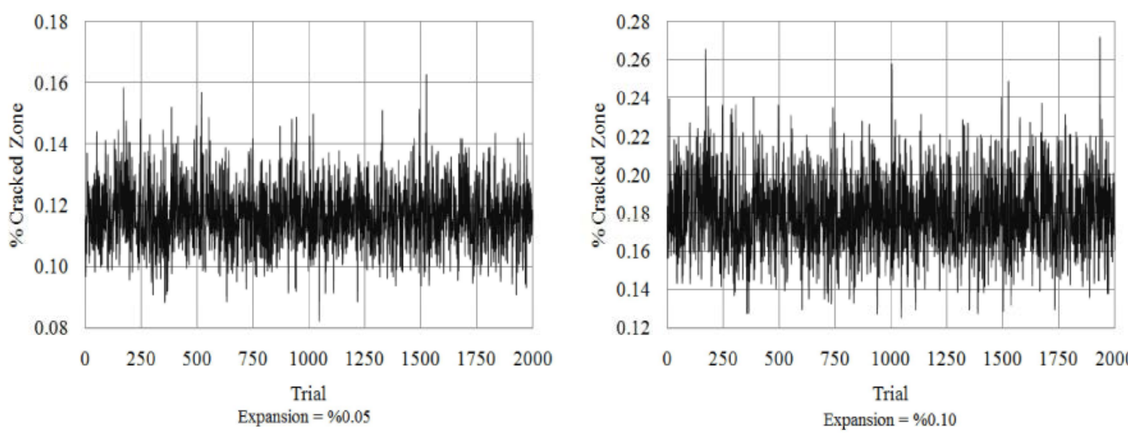
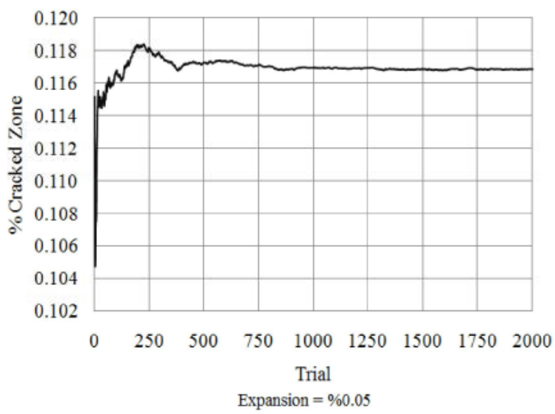


Fig. 6: Changes of the percentage of the cracked zones in each trial

Results illustrate that after 1000 trials, the crack distribution becomes steady. For example, Figure 3 shows the risk of zones after first, 20^{th} and 1000^{th} trials. This process is repeated for the other mentioned conditions and the results are shown in Figure 4. The results show that when the expansion is higher, cracked zones percentage become bigger. Also, it is clear from the findings that about%0.235 and%0.38 of dam body are cracked when expansion is%0.05 and%0.10, respectively.



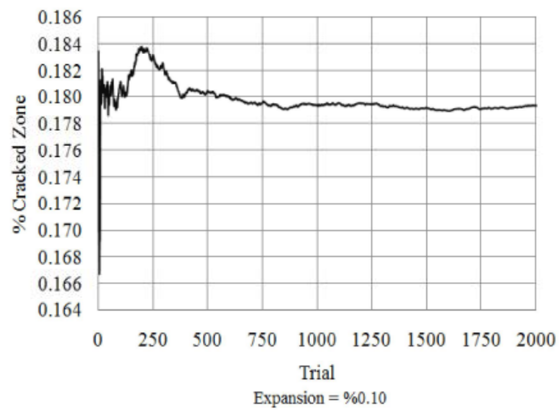


Fig. 7: Convergence of the crakes zones percentage

The expansion due to Normal Alkali Silica Reaction influences the probability and the percentage of the cracked zones. The mean values and the dispersion of the probability in *each trial* are illustrated in Figure 5. Also, Figure 6 shows the percentage of the cracked zones in *each trial*. As it can be seen from Figure 5 and 6, there is good agreement between the mean values of probability of the crack distribution and the percentage of the cracked zones in *each trial* and they are approximately equal. Figure 5 shows that the dispersion of probability varies from%0.01 to%0.40 for NASR.

Figure 7 illustrates the converged percentage of the cracked zone when expansion varies from%0.117 to%0.181. It is clear from Figure 7 that after 1000 trials, the percentage of the cracked zones becomes steady.

CONCLUSION

The Alkali Silica Reaction frequently poses challenges in areas of science and engineering and dealing with this type of problem is really challengeable. ASR is a stochastic problem. The exact place of the reaction is not definite; therefore, it is perplexing to anticipate.

Monte Carlo method relies on repeated random sampling to compute the results. Because of reliance on repeated computation of random numbers, it is especially useful in studying systems with significant uncertainty in inputs such as ASR.

In this article, using Monte Carlo method as an alternative approach for stochastic problems, the study of risky zones and the percentage of the cracked zones due to Normal Alkali Silica Reaction (NASR) in a sample dam body are investigated. The results show that:

- There is good agreement between the mean values of probability of the crack distribution and the percentage of the cracked zones in *each trial* and they are approximately equal.
- The influence of the expansion on the percentage of the cracked zones increases when the expansion becomes higher.
- When the expansion is normal (expansion lower than%0.10) the percentage of the cracked zone is lower than%20.
- For the normal expansion (expansion between%0 to%0.10) the probability of distribution varies from%0.01 to%0.40.
- And also, contours of risky alkali silica zone due to NASR were presented.

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