Reliability Analysis of Underground Structures Using Metamodels and FORM

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1 Abstract

An engineering reliability analysis method of underground structures using metamodels and a first-order reliability method (FORM) was studied. Surrogate models, or metamodels are approximate models that can be constructed to replace implicit response functions that involve finite element analyses. The radial basis functions (RBFs) are suitable for creating metamodels for general linear or nonlinear responses and they are locally and globally adaptive. After a performance function was replaced by an augmented RBF metamodel, an alternative FORM was applied. The method was tested using mathematical functions and applied to a tunnel engineering example. Different numbers of samples were tested and reliability analyses were performed. The failure probabilities and reliability indices were found to have a good accuracy. The proposed method combining RBFs and FORM is useful for practical engineering problems involving expensive response simulations.

Keywords: engineering reliability analysis; underground structures; reliability index; metamodels; first-order reliability method (FORM).

2 Introduction

In an engineering reliability analysis, the failure probability of an engineering system or component is determined as [1,2]

$$P_F \equiv P(\mathrm{g}(\mathbf{x}) \leq 0) = \int_{\mathrm{g}(\mathbf{x})\leq 0} p_X(\mathbf{x}) d\mathbf{x} \qquad (1)$$

where $\mathrm{g}(\mathbf{x})$ is a performance function of random variable vector $\mathbf{x}$. Traditional reliability analysis methods of practical engineering problems include first-order/second-order reliability methods (FORM/SORM) [3-6]. The FORM/SORM methods are based on the concept of the most probable point (MPP) or design point. These methods require the derivatives of system responses, and the implementation of these methods for complex engineering problems is not straightforward. In addition to the MPP-based methods, direct sampling methods are available [7, 8]. In these methods, sensitivity analysis of the performance function is not required. However these methods are generally computationally very expensive, especially when the failure probability is small. For practical engineering applications that require expensive response simulations such as finite element (FE) analyses, approximate methods have been developed so that implicit response functions

https://doi.org/10.2749/newyork.2019.1163

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