P03

Probability analysis of submarine slope stability with consideration of the spatial variability of sediment strength

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Introduction

Submarine slope instability involves many factors and not all failure mechanisms are fully understood. Therefore, a probabilistic method that consider the spatial variability of soil strength was proposed in this study to evaluate the stability of submarine slopes while considering uncertainties. In this study, the spatial variability of the sediments strength is described by means of stationary and non-stationary random fields (RFs) using the Karhunen-Loève (K-L) expansion. The limit equilibrium method (LEM) along with RFs is used to evaluate the stability of the submarine slope. Then the failure probability of the submarine slope is effectively obtained from Monte Carlo simulation (MCS) with a novel Gaussian process regression (GPR)-based surrogate model.

Random fields simulation

In nature, soil properties vary from point to point over space as the result of geologic processes. It is commonly recognized that marine sediments possess inherent spatial variability. Within the framework of RFs, the 2-D Gaussian autocorrelation function used in this study is expressed as:

$$\rho[(x_1,y_1),(x_2,y_2)] = \exp(-(\frac{x_1-x_2}{l_h})^2 - (\frac{y_1-y_2}{l_v})^2) \quad (1)$$

The K-L expansion of an RF is a series-expansion method based on the spectral decomposition of its autocorrelation function. In most cases, soil shear strength is simulated with a stationary RF, which means that the average value and standard deviation (SD) of the shear strength are constant with depth. The stationary Gaussian RF with mean μ, SD σ can be expressed by the truncated K-L expansion as

$$\tilde{\boldsymbol{H}}(x,\theta) = \mu + \sum_{i=1}^{N} \sigma \sqrt{\lambda_i} f_i(x) \xi_i(\theta) \quad (2)$$

The non-Gaussian RFs and non-stationary RFs can be transformed from stationary Gaussian RFs. One simulation of the one-D RFs including stationary and non-stationary used in this study is shown in **Fig. 1**.

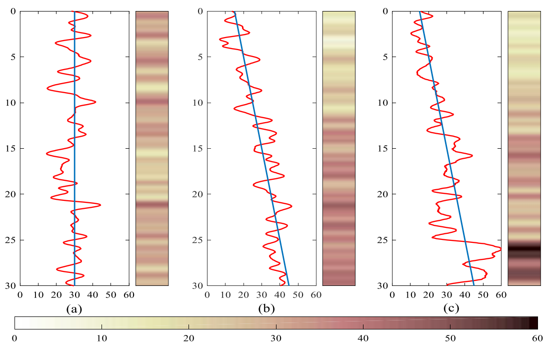

Fig. 1. Simulation of undrained shear strength of marine sediments using three types of one-D RFs.

GPR-based surrogate model

The Gaussian process method is one of the most advantageous tools among Bayesian methods. The training set including a multi-dimensional input vector $\boldsymbol{x}_i$ and the corresponding output y_i. The GPR algorithm obtains the relationship between the input and output of the training database, whereupon the distribution of the predictive function values $f^*(\boldsymbol{x}_i)$ is provided. Then the predicted output y^* can be obtained with high accuracy given a new input $\boldsymbol{x}^*$. A schematic of GPR is shown in **Fig. 2**. With the mean function $M(x)$ and Kernel function $K(x, x')$, a Gaussian process function $f(x)$ can be specified completely as:

$$f(\boldsymbol{x}) \sim GP(M(\boldsymbol{x}), K(\boldsymbol{x}, \boldsymbol{x}')) \quad (3)$$

After the GPR-based surrogate model has been built, it was used in the MCS to reduce the number of calls for direct analysis.

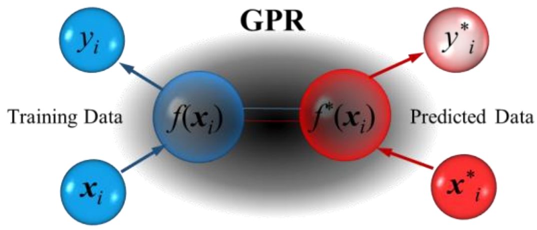

Fig. 2. Schematic of Gaussian process regression.

Reliability analysis of submarine slopes

A flowchart for both 1-D and 2-D reliability analysis of submarine slopes with spatially varying shear strength is shown in **Fig. 3**.

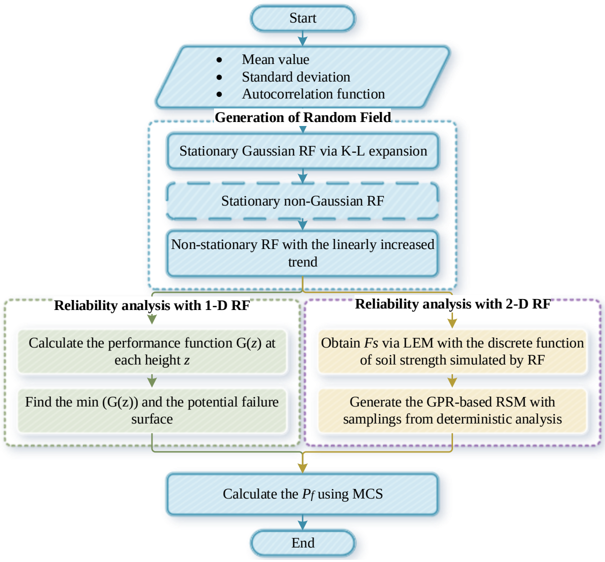

Fig. 3. Flowchart of reliability analysis of submarine slope based on random fields.

After generating the RF, we combine it with the traditional LEM to evaluate the stability of submarine slope with consideration of the spatial variability of the soil shear strength. The coupled analysis is illustrated in **Fig. 4**.

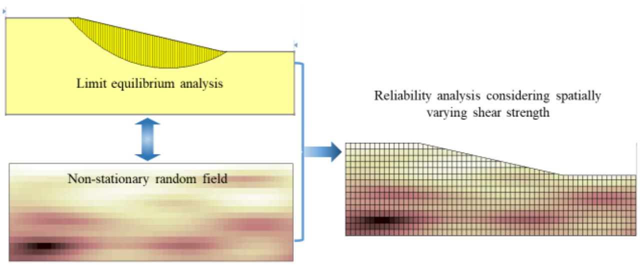

Fig. 4. Illustration of reliability analysis coupling LEM and RF.

The statistics of the slip-surface depths obtained in the infinite slope model using three types of RF are shown in **Fig. 5**.

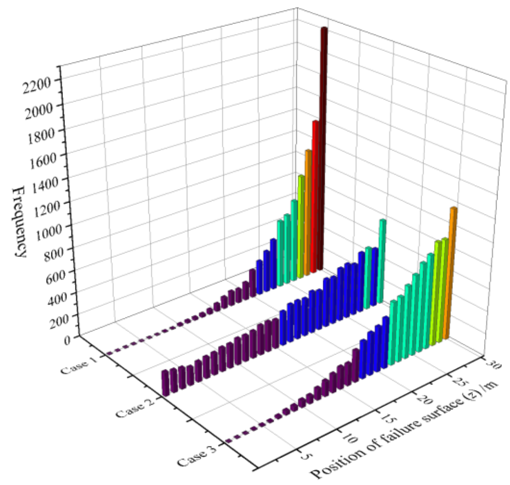

Fig. 5. Histograms of position of failure surface using three types of RF.

Conclusions

The reliability analysis was performed to evaluate the stability of submarine slopes using the LEM coupled with RFs. The GPR-based surrogate model was used in MCS. Therefore, computation associated with the analysis is decreased. The following conclusions are drawn.

(1) The spatial variability of sediment shear strength, which is commonly ignored in the traditional analysis of submarine slope, has a significant effect on the result of the stability evaluation.

(2) The failure probability of the submarine slope decreases with the vertical correlation distance and tends to converge to a certain value in the infinite slope model under both static and seismic loading.

(3) The computational efficiency is significantly increased by incorporating the GPR-based surrogate model into the reliability analysis. Therefore, the proposed GPR-based method has shown superiority and potential in the reliability analysis of submarine slope.