GPR と応答曲面法による降雨時ため池破堤確率の予測
Prediction of breach in earth-fill dams due to heavy rain by GPR and RSM

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1. Background

For deteriorated so many earth-fill dams existing all over Japan, it is necessary to study the damage to earth-fill dams during heavy rainfall events. In this study, a total of 244 earth-fill dams in Okayama and Hiroshima prefectures are selected for the research object. The peak flood discharge for each earth-fill dam is initially computed using the response surface method. Next, the peak flood discharge and design flood flow are used as feature values to evaluate the probability of failure utilizing the GPR method.

2. Calculating probability of failure using response surface method

In our previous study, we first calculated the actual damage cost using the manual of Ministry of Land, Infrastructure, Transport and Tourism, and selected parameters based on sensitivity analysis. A simpler calculation of the damage cost was proposed using the response surface method[1].

In this study, we aim to develop response equations for the probability of destruction utilizing the response surface method. The response surface equation for peak flood discharge has been developed. According to the theoretical equation (Eq. 1), catchment area, maximum rainfall intensity, and water storage, are selected as parameters. The response equation (Eq. 2) is obtained through regression.

$$Q_P = \frac{1}{3.6} \cdot Q_L \cdot A \tag{1}$$

Q_L: direct outflow (m^3/s)

A: catchment area(km^2)

$$Q_{pRS} = -4.896 + 8.493\mathrm{A} + 1.947\times10^{-5} V + 0.1247 R_p \tag{2}$$

As shown in Fig.1a, a good correlation was established by comparing the actual values with the values derived from the equation.

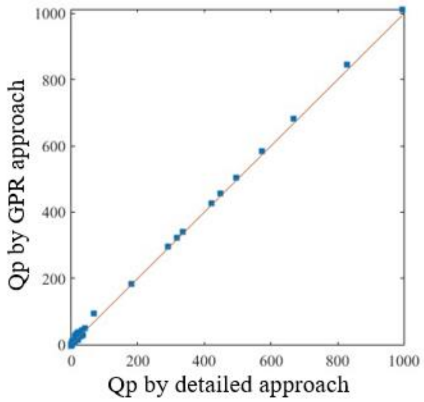

Fig.1a Comparison between detail and RSM.

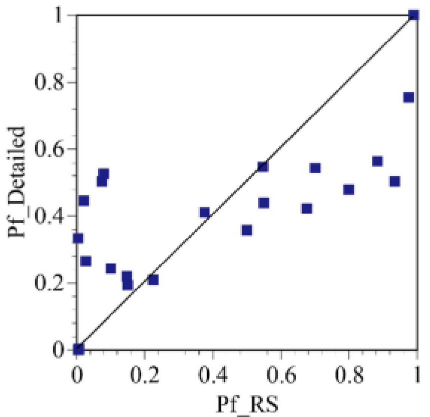

Fig.1b Comparison between detail and RSM.

Since an embankment breach occurs when the peak flood discharge Q_p exceeds the design flood flow Q_d, we chose both as parameters and the probability of failure as the target variable for regression

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analysis and obtained a new response equation (Eq.3). As shown in the figure 1b, the two did not fit well, so we decided to choose the GPR method and analyze the data.

$$P_{fRS} = 0.4613 - 0.0933 Q_{pRS} + 0.001215 {Q_d}^2 \quad (3)$$

3. Calculating probability of failure using GPR method

GPR (gaussian process regression), is a Bayesian-based approach, a nonparametric model based on kernel functions that can be used to model the non-linear relationship between inputs and outputs, and finally to predict output data.

As with the response surface method, the peak and design flood discharge calculated by the response equation are selected, namely Q_p and Q_d as the feature vectors, and the probability of failure, P_f as the output vector. 200 of these data are used as training data and 24 as test data.

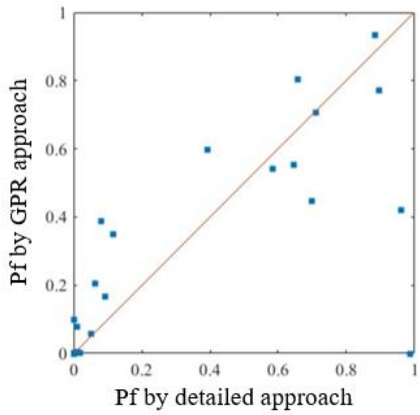

Fig.2. Comparison between detail and GPR.

The choice of kernel function plays a key role in GPR since it measures the similarity between input vectors. In this study, we choose the Matérn kernel function for computing the covariance matrix with isotropic distance measure. The expression is shown in equation 4.

$$k(x,z) = {\sigma_f}^2 f(\sqrt{d}r)\exp(-\sqrt{d}r) \quad (4)$$

Where x and z refer to vectors of Q_d and Q_p, σ_f is signal variance, r is Euclidean distance.

$r = \sqrt{(x-z)^T P^{-1} (x-z)}$, $P = ell \cdot I$ I: unit matrix

d=2.5, ell=0.12, σ_f=0.38: hyperparameters

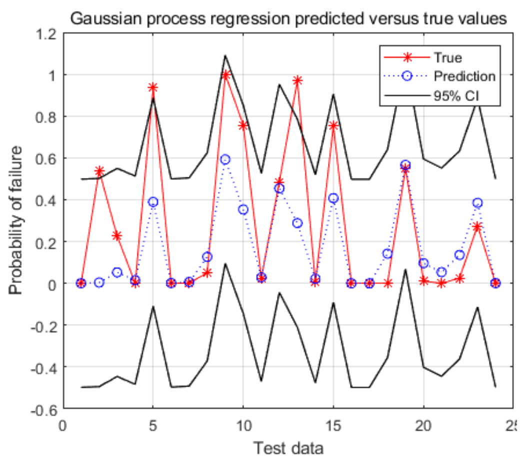

Fig.3. Predicting of probability using GPR method with 95% CI.

The results in Figures 2 and 3 show a significant reduction in prediction error compared to the RSM. MSE (Mean squared error) =0.066189, R^2=0.80.

4. Conclusion

In this study, we want to find a suitable method for predicting the probability of failure of earth-fill dams in heavy rainfall events. We first use the response surface method to construct a regression equation, but the results are not satisfactory. Next, a GPR method, using the Matérn kernel function optimizes the hyperparameters to complete the prediction of the probability of failure. From the results, GPR showed a better fit than RSM.

Reference

1) Zheng S, Nishimura S, Shuku T, Shibata T, Tateishi T. Risk evaluation for earth-fill dams due to heavy rains by response surface method. Georisk. 2023. doi: 10.1080/17499518.2023.2164901