# Predicting initial in-situ stresses in dam sites using an advanced meta model

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## Introduction

The initial in-situ stresses in dam sites are an important factor that affects the safety of the dam, and predicting them accurately and reliably helps to understand the behaviour of the dam and its foundation. In this study, an advanced meta-modelling technique, the Polynomial Chaos Kriging (PCK) model, is used to predict the initial in-situ stresses in dam sites. The constructed PCK model not only provides higher prediction accuracy compared to traditional multiple linear regression models, but also performs parameter sensitivity analysis at near-zero cost.

## Methods

➢ **PCK**

PCE Kriging

$$Y \approx \mathcal{M}^{PCK}(X) = \sum_{w\in\Omega} \zeta_w \delta_w(X) + \sigma^2 D(x)$$

The weighted sum of orthogonal polynomials

The variance of a zero-mean stationary Gaussian process

(1) determining the truncated polynomial set
(2) calibrating the unknown Kriging hyper-parameters

In PCK, a **regression-type PCE model** is employed to capture the global behavior of the computational model, while an **interpolation-based Kriging model** is utilized to capture local variations in the computational model.

## Graphics / Images

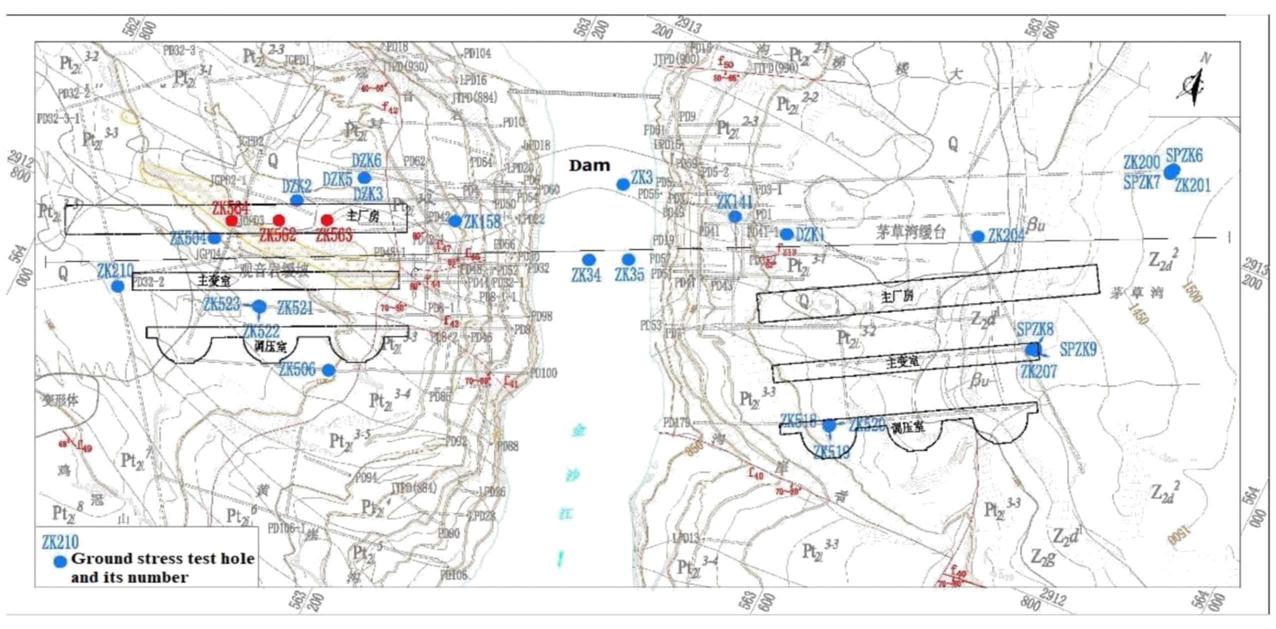


Figure 1. Graph of borehole locations for in-situ stress measurements in the dam site area

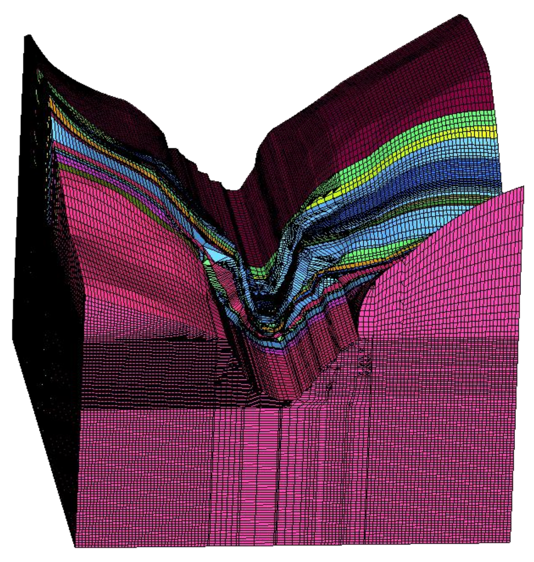

Figure 2. Finite element model of the refined dam site area

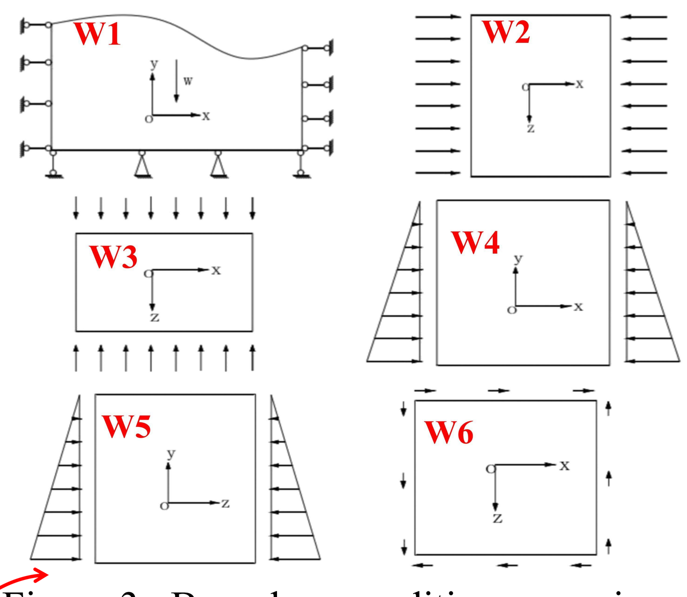


Figure 3. Boundary condition scenarios for simulating the in-situ stress field

**W1:** Self-weight
**W2:** East-West uniform extrusion structure
**W3:** North-South uniform compression structure
**W4:** East-West triangular load extrusion structure
**W5:** North-South triangular load extrusion structure
**W6:** Uniform shear tectonic stress in the horizontal plane

X1 (SX)
X2 (SY)
X3 (SXY)
X4 (SZ)
X5 (SXZ)
X6 (SYZ)

Training dataset (measurement points 1–6); Validation dataset (measurement points 7–8)

Input (W1–W6); Output (measured stress component)

| Measurement point number | | W1 | W2 | W3 | W4 | W5 | W6 | measured stress component |
|---|---|---|---|---|---|---|---|---|
| 1 | X1 (sx) | -1.6128 | -0.2486 | -1.0972 | -0.5237 | 0.4475 | 1.0973 | 3.1783 |
| | X2 (sy) | -0.8494 | -0.0898 | -6.5144 | 0.1921 | 0.1542 | 6.5144 | 5.4864 |
| | X3 (sxy) | 0.1734 | 0.0349 | 0.9284 | 0.8259 | 0.0606 | -0.9284 | 3.5209 |
| | X4 (sz) | -4.9936 | -0.1772 | 0.2820 | 0.3074 | 0.4407 | -0.2820 | 2.9267 |
| | X5 (sxz) | 1.8262 | 0.2278 | 0.0154 | 0.2967 | -0.3839 | -0.0154 | 3.2393 |
| | X6 (syz) | -0.0887 | -0.0119 | 0.9768 | -0.9924 | -0.0555 | -0.9768 | 1.8683 |
| 2 | X1 | -1.4795 | -0.2319 | -0.9458 | -0.4779 | 0.3962 | 0.9458 | 3.1601 |
| | X2 | -0.7675 | -0.0745 | -5.9629 | 0.7353 | 0.1201 | 5.9630 | 5.7890 |
| | X3 | 0.1087 | 0.0315 | 0.6732 | 0.2242 | 0.0434 | -0.6732 | 3.0480 |
| | X4 | -4.9284 | -0.1856 | 0.3095 | 0.3233 | 0.4492 | -0.3095 | 2.9542 |
| | X5 | 1.7387 | 0.2241 | -0.0008 | 0.2741 | -0.1827 | 0.0008 | 3.2202 |
| | X6 | -0.0768 | -0.0140 | 0.8628 | -0.9897 | -0.0588 | -0.8628 | 1.9139 |
| 3 | X1 | -0.1453 | -0.0226 | 0.0191 | 0.0824 | 0.0382 | -0.0191 | 3.1893 |
| | X2 | -0.4883 | -0.0018 | -4.7438 | 0.4400 | 0.0643 | 4.7438 | 5.0292 |
| | X3 | -0.2074 | -0.0119 | -0.0732 | 0.3023 | 0.0746 | 0.0732 | 3.3978 |
| | X4 | -4.1563 | -0.0531 | 0.9319 | 0.1897 | 0.4381 | -0.9319 | 2.5112 |
| | X5 | 0.9359 | 0.0298 | -0.1678 | -0.1100 | -0.1820 | 0.1678 | 3.1295 |
| | X6 | 0.2031 | 0.0254 | 0.3070 | -0.8049 | -0.0634 | -0.3070 | 2.2426 |
| 4 | X1 | -1.1459 | -0.1453 | -0.6176 | 0.1540 | -0.1131 | 0.6176 | 3.5326 |
| | X2 | -1.2806 | -0.0477 | -7.7252 | 0.0322 | 0.0085 | 7.7252 | 5.6172 |
| | X3 | -0.0031 | -0.0192 | 0.2725 | 0.6505 | -0.0989 | -0.2725 | 3.6404 |
| | X4 | -4.2457 | -0.0544 | -0.3170 | 0.0940 | 0.0113 | 0.3170 | 2.8259 |
| | X5 | 1.2999 | 0.0896 | 0.3283 | -0.0666 | -0.2731 | -0.3283 | 2.9545 |
| | X6 | -4.2457 | -0.0544 | -0.3170 | 0.0940 | 0.0113 | 0.3170 | 2.8259 |
| 5 | X1 | -0.8534 | -0.0167 | -0.9250 | -0.5679 | -0.4368 | 0.9250 | 2.7980 |
| | X2 | -0.8204 | -0.0036 | -3.8085 | 0.4712 | -0.0788 | 3.8085 | 4.7041 |
| | X3 | 0.5818 | 0.0085 | 2.5692 | -0.4763 | -0.0342 | -2.5691 | 1.8684 |
| | X4 | -4.0544 | -0.0195 | 0.2757 | -0.2390 | -0.1475 | -0.2757 | 2.2886 |
| | X5 | 1.4615 | 0.0158 | -0.8997 | 0.5871 | 0.1715 | 0.8997 | 4.1109 |
| | X6 | -0.9909 | -0.0072 | 0.9651 | -0.6424 | -0.1493 | -0.9651 | 2.0683 |
| 6 | X1 | -2.8005 | -0.2602 | -1.6605 | 0.6042 | -1.3002 | 1.6605 | 4.2528 |
| | X2 | -1.9557 | -0.1072 | -9.0918 | 0.0673 | 0.1734 | 9.0918 | 6.1141 |
| | X3 | -0.4557 | -0.0405 | -1.6619 | 0.9514 | -0.0981 | 1.6619 | 4.5379 |
| | X4 | -7.2967 | -0.1769 | -0.1703 | -0.1703 | -0.5471 | 0.1703 | 2.3256 |
| | X5 | -3.3771 | -0.2447 | -0.0698 | 0.3522 | -0.7714 | 0.0698 | 3.3944 |
| | X6 | -0.6131 | 0.0048 | 0.6831 | 1.1969 | 0.1213 | -0.6831 | 3.8907 |
| 7 | X1 | -0.7844 | -0.0168 | -0.2761 | 0.1721 | -0.2266 | 0.2761 | 3.2748 |
| | X2 | -1.1711 | -0.0143 | -7.1707 | 0.3045 | -0.0020 | 7.1707 | 5.6437 |
| | X3 | -0.3841 | -0.0037 | 0.3521 | 0.1956 | 0.0378 | -0.3521 | 3.1209 |
| | X4 | -1.9440 | -0.0133 | -0.8197 | 0.0986 | -0.1168 | 0.8197 | 3.2320 |
| | X5 | -1.0792 | -0.0089 | -0.2714 | 0.1452 | -0.1302 | 0.2714 | 3.1982 |
| | X6 | -0.9097 | -0.0053 | -0.9329 | 0.4827 | -0.0139 | 0.9329 | 3.7474 |
| 8 | X1 | -2.2451 | -0.2923 | -0.8931 | 0.0350 | -0.3269 | 0.8931 | 3.6056 |
| | X2 | -0.2025 | -0.0930 | 0.2734 | 0.8299 | -0.0761 | 10.3971 | 5.0691 |
| | X3 | -2.4786 | -0.0030 | -10.3971 | 0.0719 | 0.0571 | -0.2734 | 5.1458 |
| | X4 | -8.8984 | -0.0694 | 0.6391 | 0.1516 | -0.0717 | -0.6391 | 1.9739 |
| | X5 | -2.9343 | -0.1977 | -0.5961 | 0.0724 | -0.3572 | 0.5961 | 3.2981 |
| | X6 | -1.0427 | 0.0154 | -0.4415 | 0.7179 | 0.0446 | 0.4415 | 3.7501 |

Figure 4. Initial dataset for constructing the PCK model

- **Input: The six-direction stress components of each measured point under six different boundary condition.**
- **Output: The measured in-situ stress components of each measured point.**

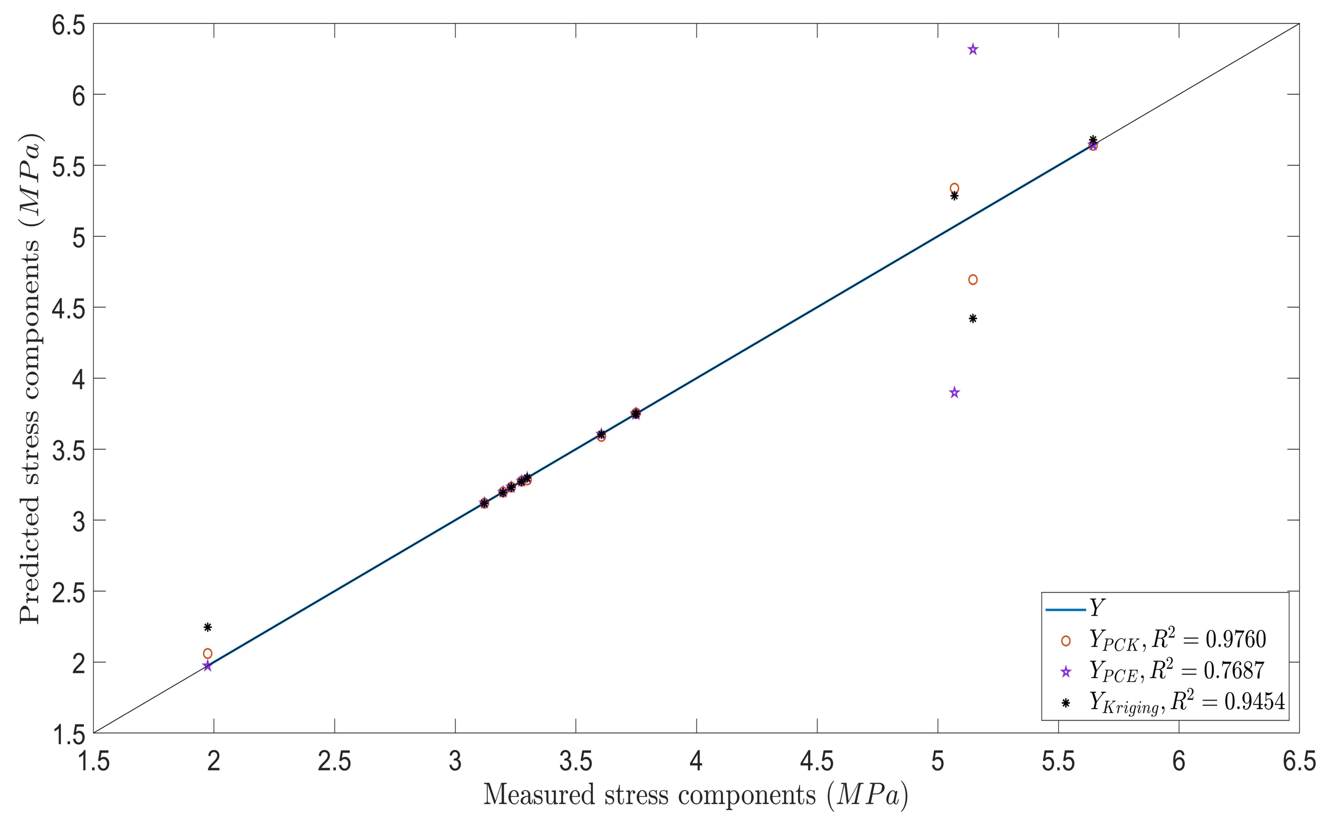


Figure 5. The predictive accuracy of in-situ stress based on the PCK model

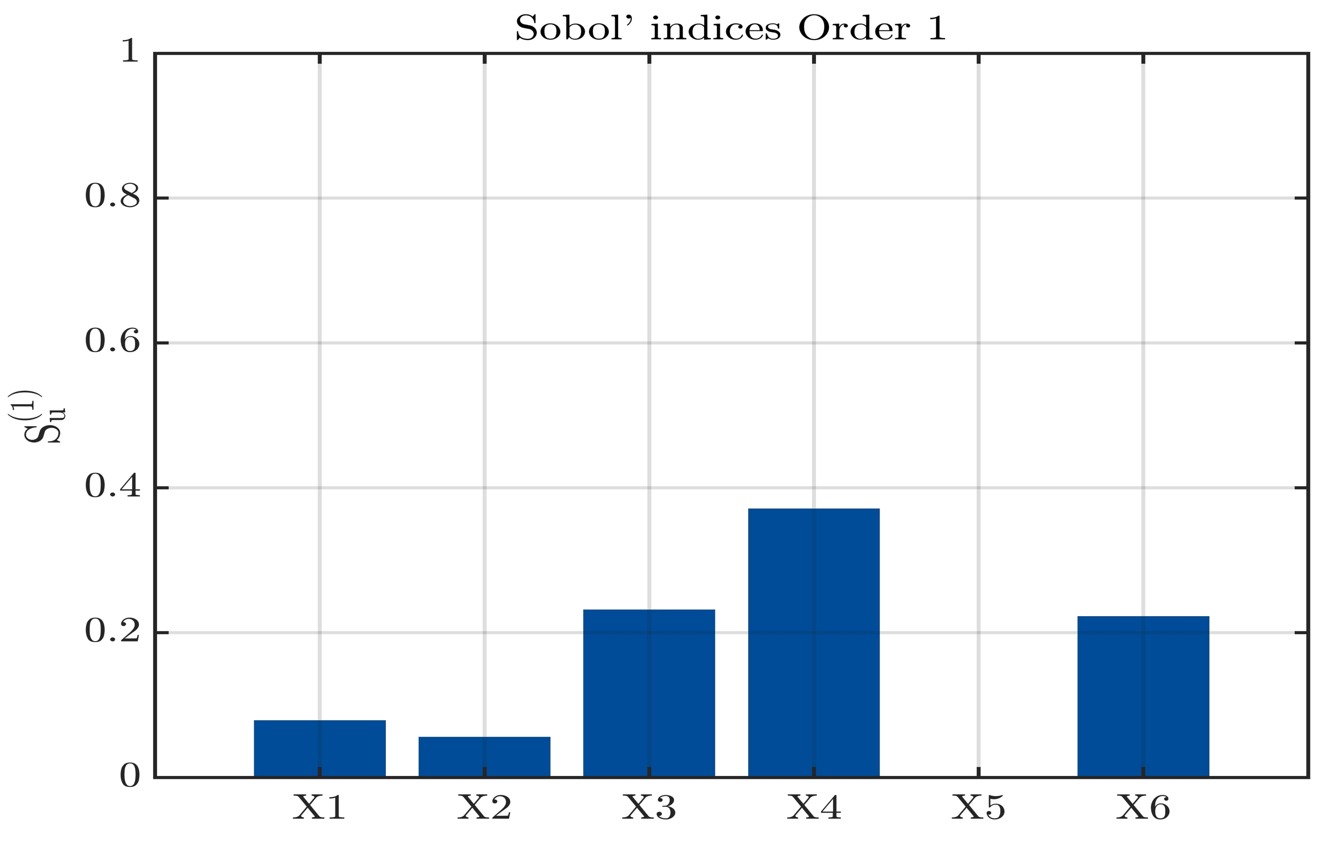


Figure 6. Sensitivity analysis of input parameters based on PCK model

## Conclusions

➢ From Figure 5, compared to the PCE and Kriging models, the PCK model demonstrates higher accuracy and stronger capability for modeling with small samples, indicating its good practicality in engineering applications.

➢ From Figure 6, according to the sensitivity analysis results, the stress component corresponding to the SZ-direction has the most significant impact on the output response. This is consistent with the fact that the initial in-situ stress is primarily influenced by self-weight.