Supplementary Materials

Machine learning based on hybrid optimization algorithm for the prediction and risk assessment of rock tunnel lining displacement

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Table S1. Descriptive statistics of the monitoring variables used for model development.

Variable	Unit	Mean	Standard deviation	Minimum	Maximum	Missing rate (%)
External strain	με	572.619	31.823	520.923	619.244	0.000
Internal strain	με	572.973	31.779	520.830	619.352	0.000
Stress	MPa	-3.349	1.864	-6.369	0.379	0.000
Temperature	°C	11.988	6.348	2.180	21.363	0.000
Displacement	mm	-3.987	1.601	-9.798	1.824	0.000

Note: All variables were obtained from monitoring node 8 located at the tunnel vault. The dataset had undergone quality control and preprocessing in the original study, and no missing values were present in the data used herein.

Representative diagnostic results are provided in the Supplementary Materials. Figure S1 presents the training and validation RMSE curves of PSO-Peephole-LSTM, while Figure S2 compares the residual distributions of the Peephole-LSTM model family. These diagnostics are intended as illustrative evidence for the selected model and its related variants, rather than as exhaustive evidence that all 16 models are free from overfitting. The temporal robustness of all candidate models was evaluated separately using the common rolling-validation procedure.

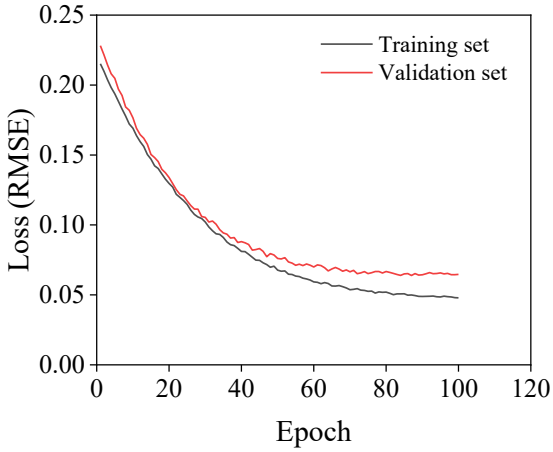


Figure S1. Training and validation RMSE curves of PSO-Peephole-LSTM.

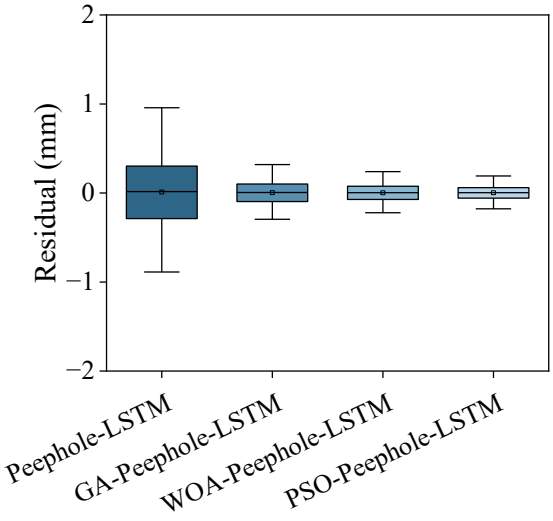


Figure S2. Residual distributions of Peephole-LSTM and its GA-, WOA-, and PSO-optimized variants.

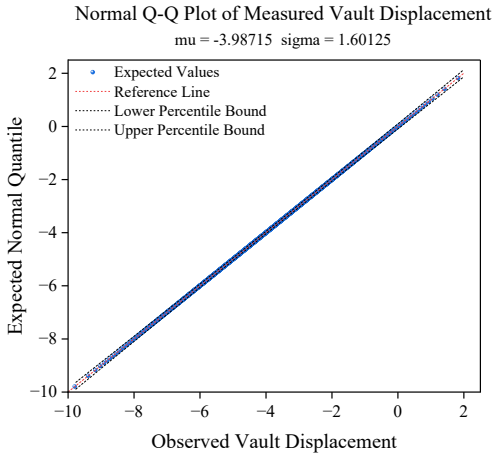


Figure S3. Normal Q–Q plot of the tunnel vault displacement observations used for LHS parameter estimation.