

Probabilistic analysis of settlement characteristics induced by shield tunnelling in sandy cobble soil considering spatial variability

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Key words:

Shield tunnels, Sandy cobble strata, Settlement characteristics, Spatial variability, Probabilistic analysis

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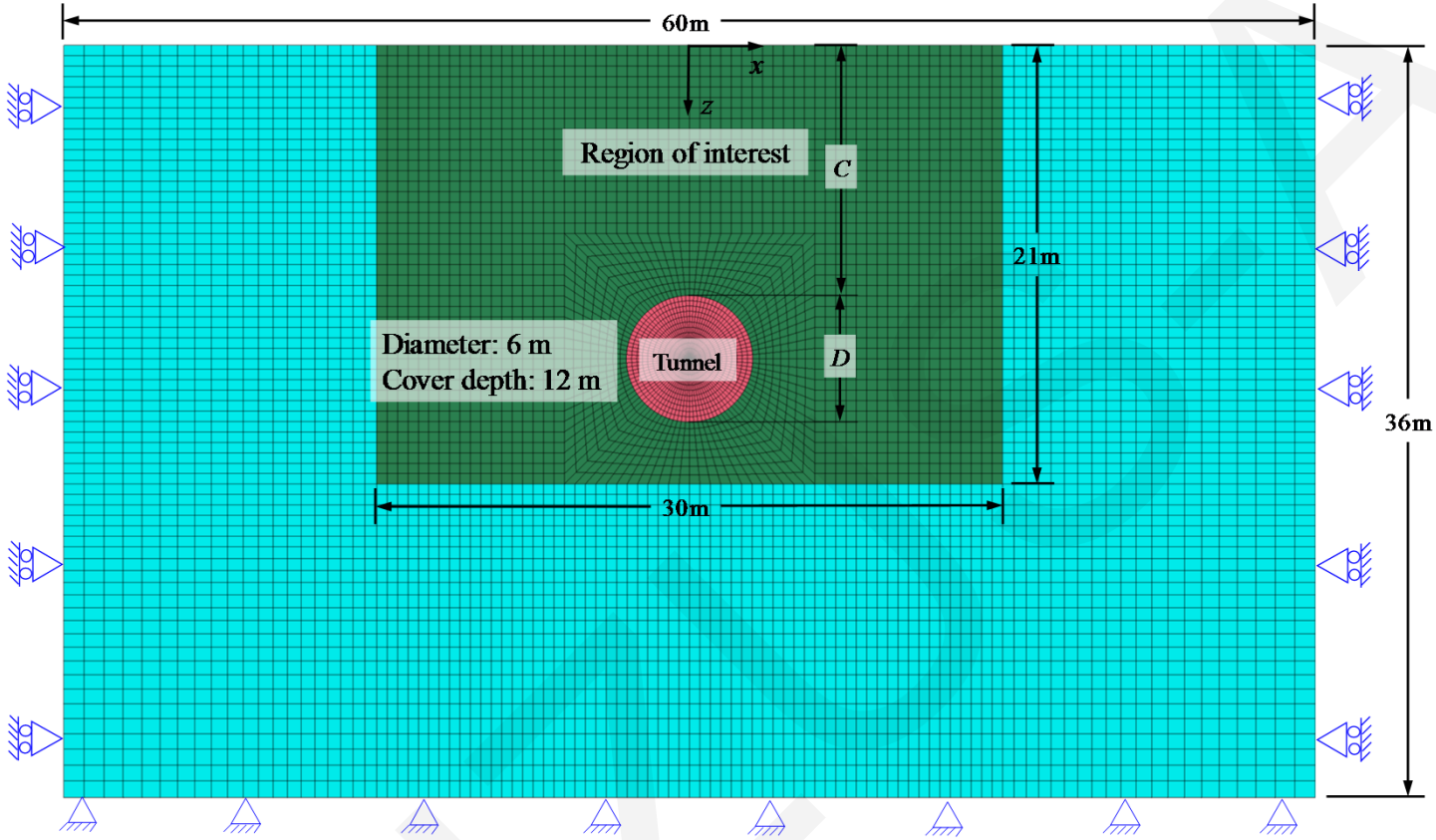
➢ Numerical modeling

Hardening-Soil constitutive model



Region of interest: assigned material parameters generated by the random field modeling

Other region: assigned the mean value of material parameters

Multi-scale numerical model

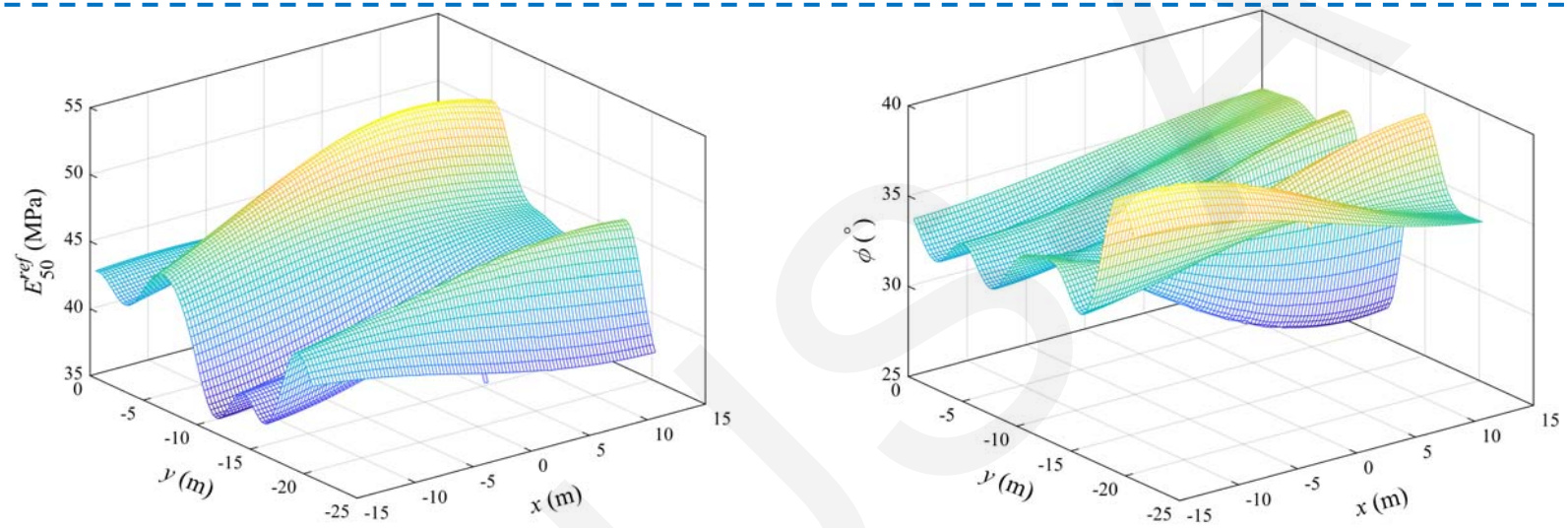
The tunnel volume loss rate (η_t) induced by the gap (g) between the excavation profile (R) and external boundary of lining (r) is simulated by applying a displacement boundary condition around the tunnel circumference.

$$g_{\max} = 2(R - r) = 2r\left(\sqrt{1+\eta_t} - 1\right)$$

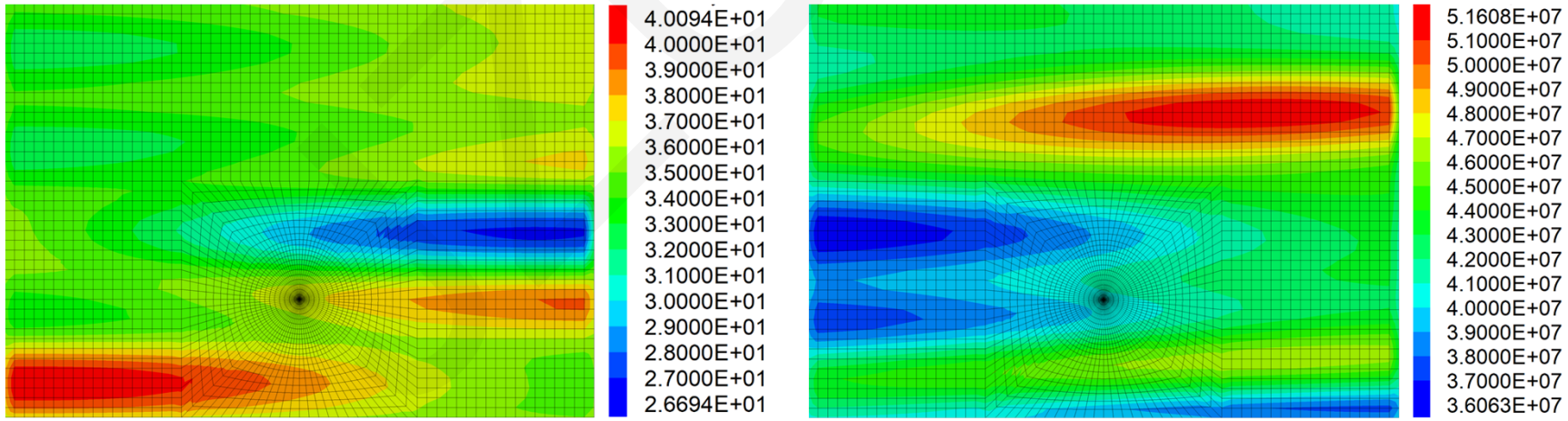
➢ Random field modeling

Spatial variability of E_{50}^{ref} and φ

Karhunen-Loève expansion method, Gaussian autocorrelation function

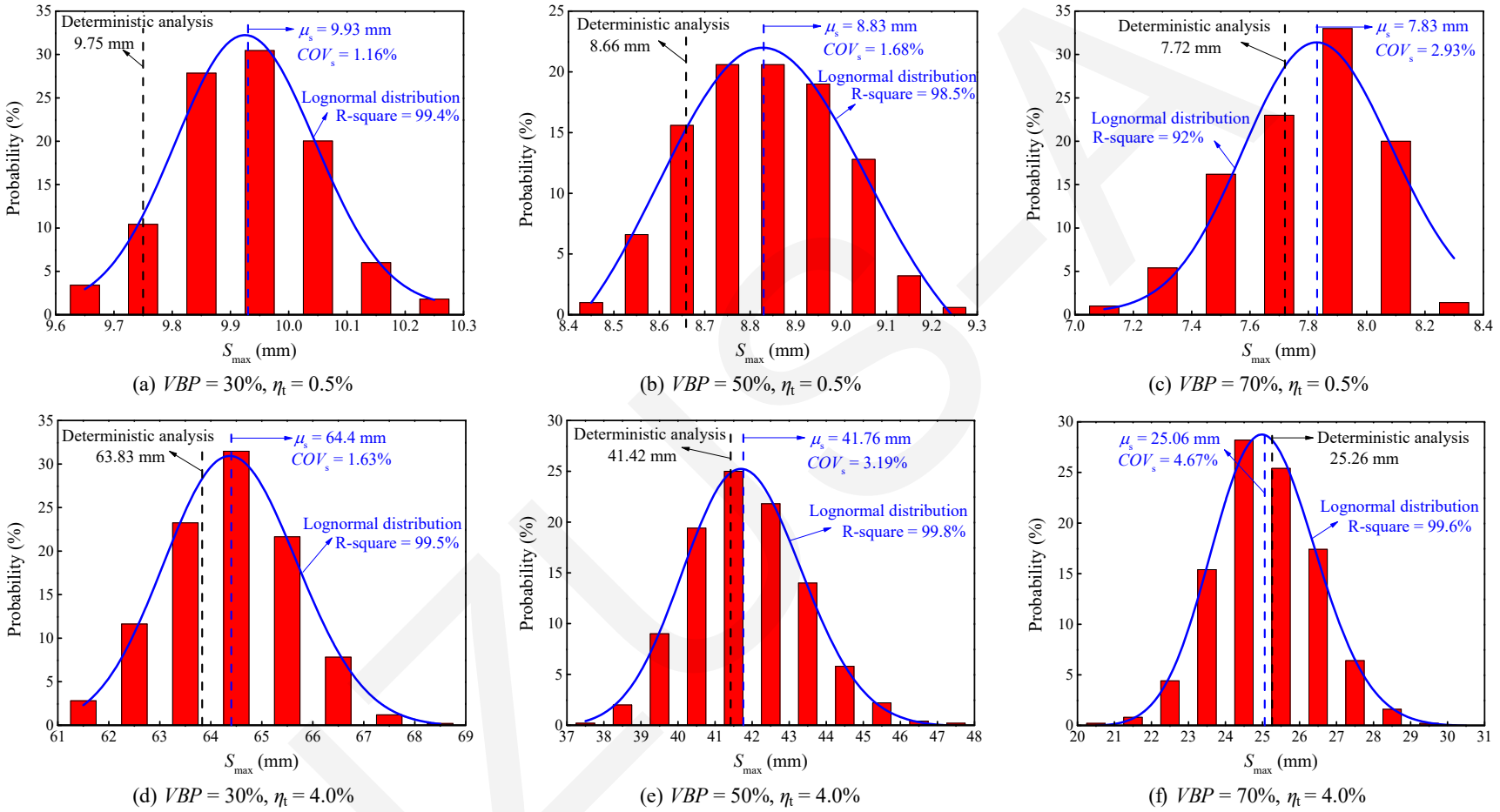


Representation in MATLAB of random field modeling for E_{50}^{ref} (left) and φ (right)



Representation in FLAC3D of random field modeling for E_{50}^{ref} (left) and φ (right)

➢ Maximum surface settlement



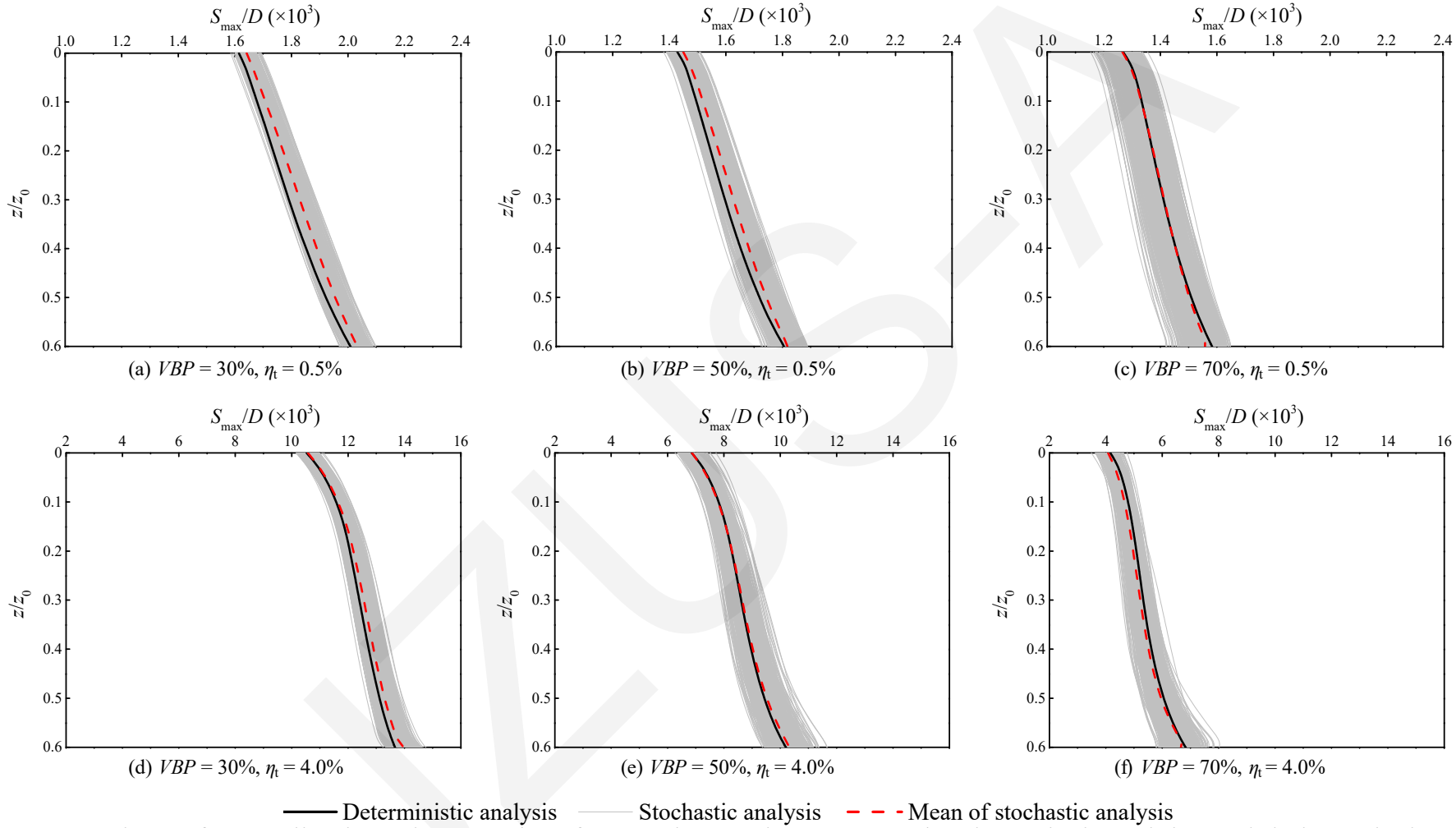
Probability histograms of the maximum surface settlement obtained by the stochastic analysis

- All the stochastic analysis results can be fitted by the probability density curves following the lognormal distribution.
- As the VBP or η_t increases, the coefficient of variation (COV_s) of S_{max} also increases, indicating a higher dispersion.

Note: All the deterministic analysis results are sourced from our previous research (Wang et al., 2024).

Fan Wang, Xiuli Du, Pengfei Li*. Prediction of subsurface settlement induced by shield tunnelling in sandy cobble stratum [J]. *Journal of Rock Mechanics and Geotechnical Engineering*, 2024, 16: 192-212.

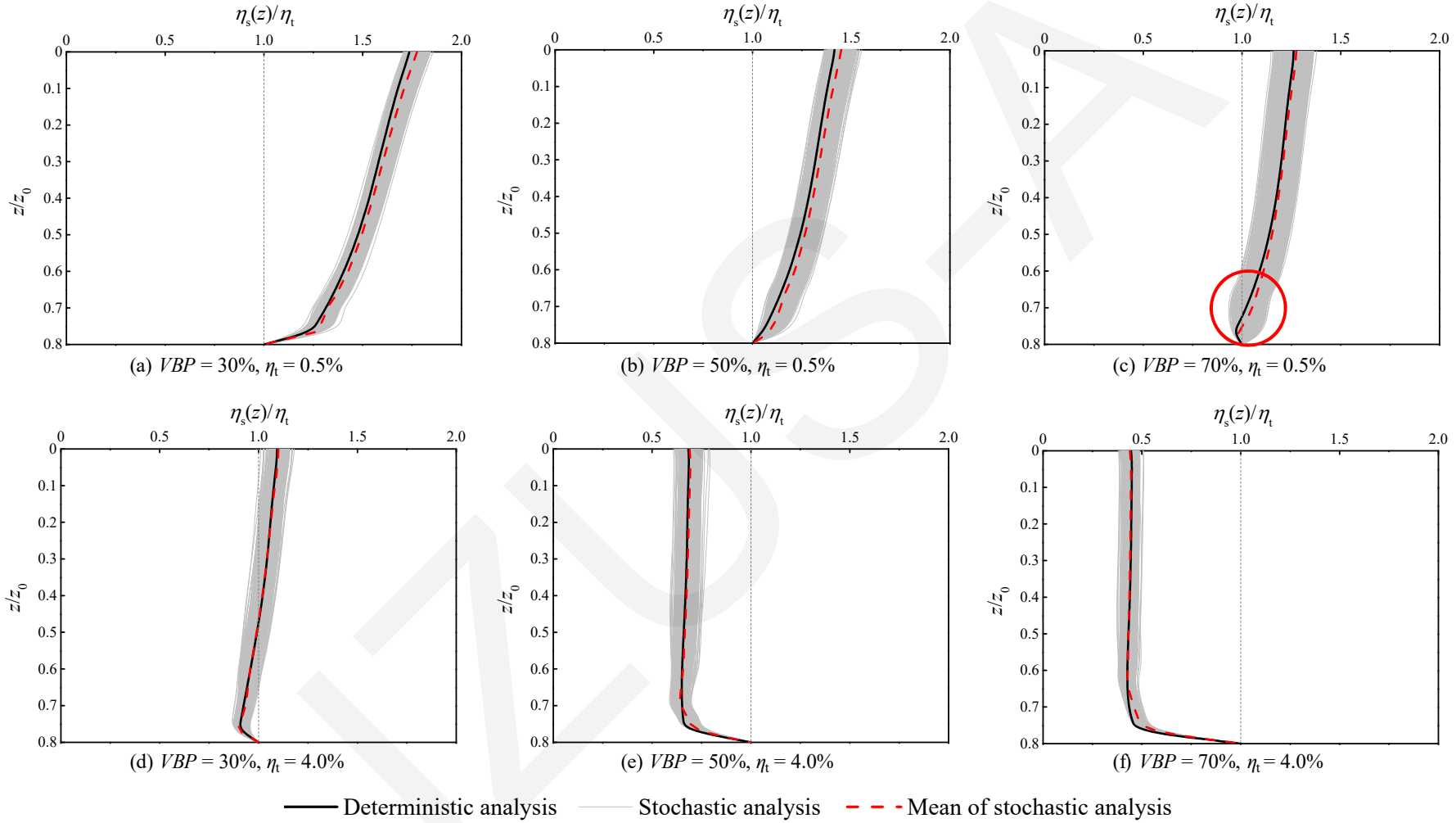
➢ Maximum subsurface settlement



Comparison of normalized maximum subsurface settlement between stochastic analysis and deterministic analysis

- For lower *VBP* or lower η_t, neglecting the spatial variability of soil properties and relying solely on the mean values of material parameters for deterministic analysis will be more likely to underestimate the subsurface settlement.
- The *COV* at the same depth increases with the *VBP*, and the *COV* for higher η_t is always greater than that of lower η_t.

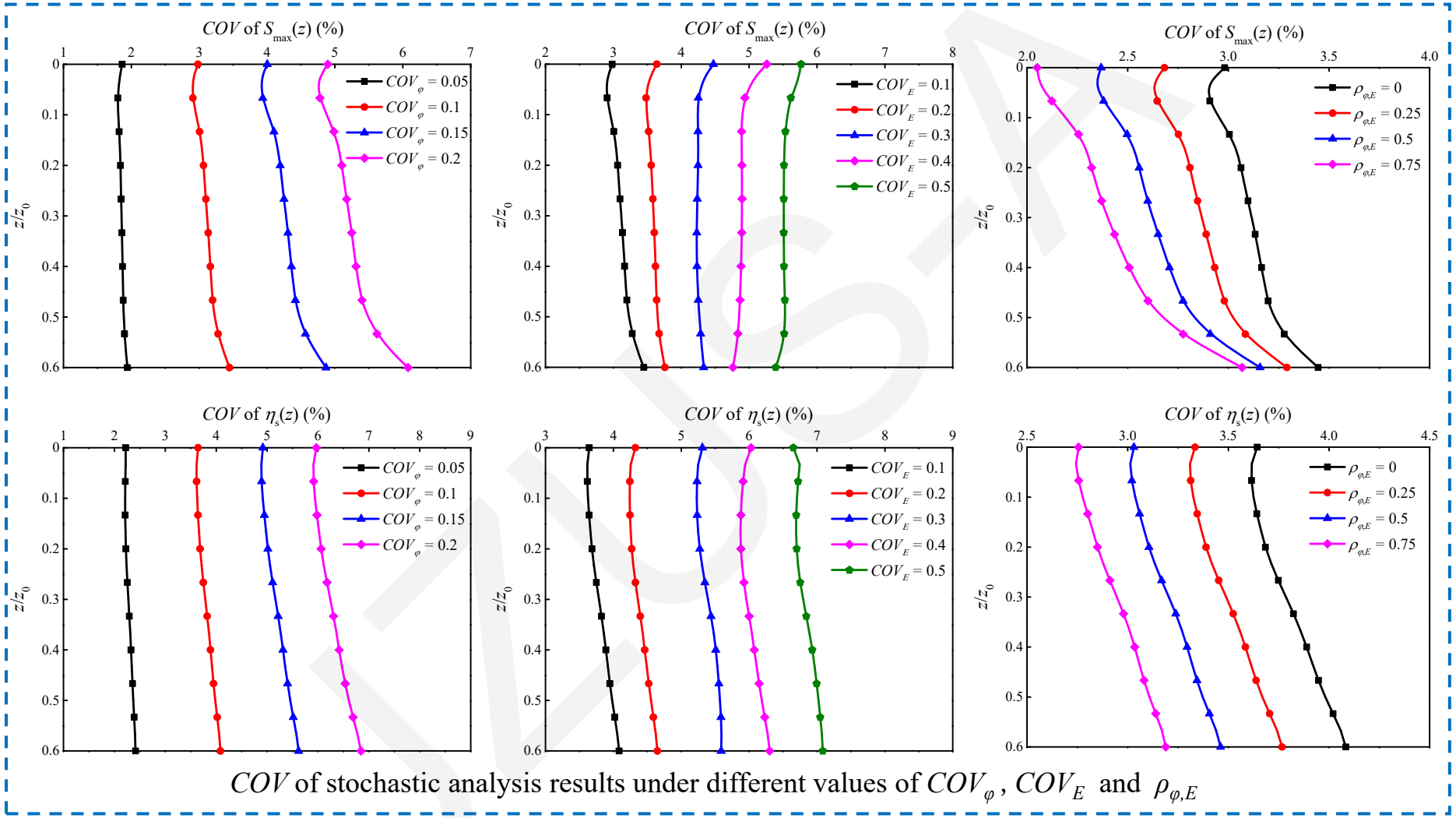
➢ Subsurface soil volume loss rate



Comparison of normalized subsurface soil volume loss rate between stochastic analysis and deterministic analysis

- Neglecting the spatial variability of soil properties and relying solely on the mean values of material parameters for deterministic analysis may not be sufficient to accurately assess the volumetric deformation mode of the soil above the tunnel crown, potentially affecting the prediction of subsurface settlement (see Fig. (c)).

➢ Effect of COV_φ, COV_E and $\rho_{\varphi,E}$



COV of stochastic analysis results under different values of COV_φ, COV_E and $\rho_{\varphi,E}$

- As the COV_φ or COV_E increases, both the *COV*s of $S_{max}(z)$ and $\eta_s(z)$ at the same depth significantly increase.
- Tunnelling-induced ground settlement is more sensitive to the variability of φ than that of E_{50}^{ref}.
- The *COV*s of both $S_{max}(z)$ and $\eta_s(z)$ at the same depth decrease with the increase of $\rho_{\varphi,E}$.

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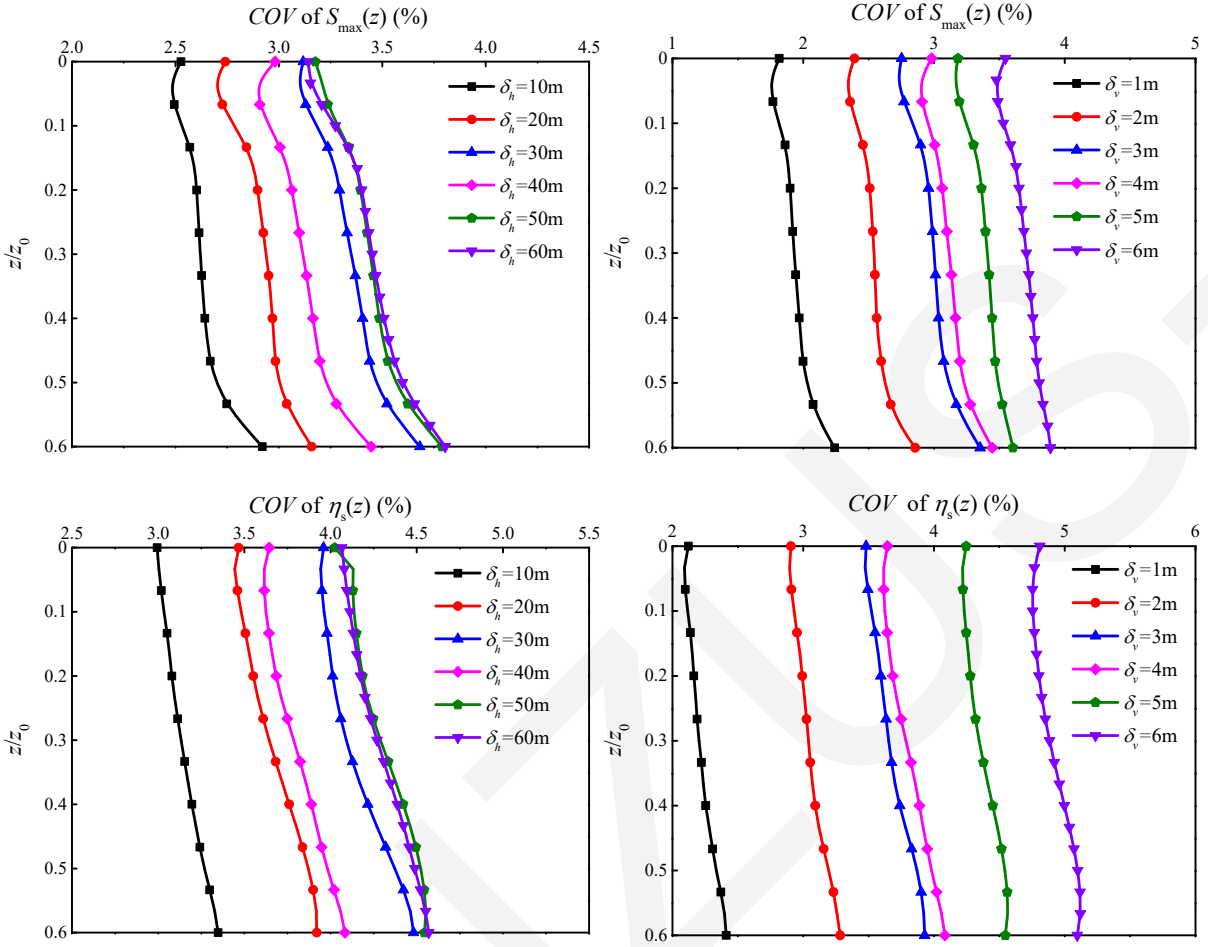
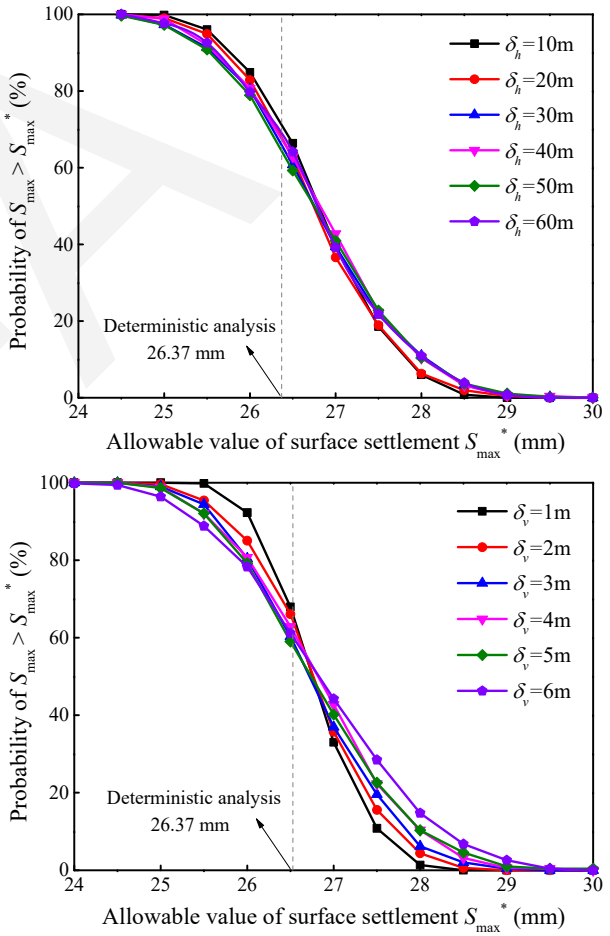
➢ Effect of δ_h and δ_v



COV of stochastic analysis results under different values of δ_h and δ_v



Effects of δ_h and δ_v on the probability of maximum surface settlements exceeding the allowable values

- Both the *COV*s of $S_{max}(z)$ and $\eta_s(z)$ at the same depth increase gradually with δ_h; after the δ_h reaches 30 m (five times the tunnel diameter), the *COV* no longer increases significantly but fluctuates within a small range.
- Both the *COV*s of $S_{max}(z)$ and $\eta_s(z)$ at the same depth significantly increase with the increase of δ_v.
- δ_v has a more pronounced effect on the probabilistic characteristics of surface settlement than δ_h.