Surface settlements induced by tunneling in permeable strata: a case history of Shenzhen Metro

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Project Background

■ Overlapped metro lines excavated in permeable strata

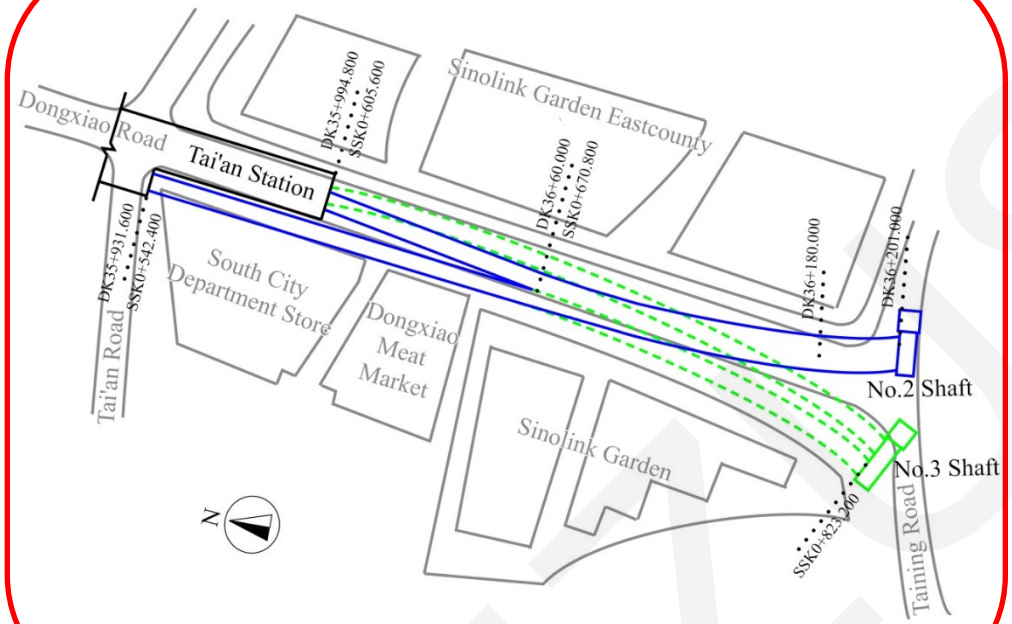


Fig. 1 Plan of project site

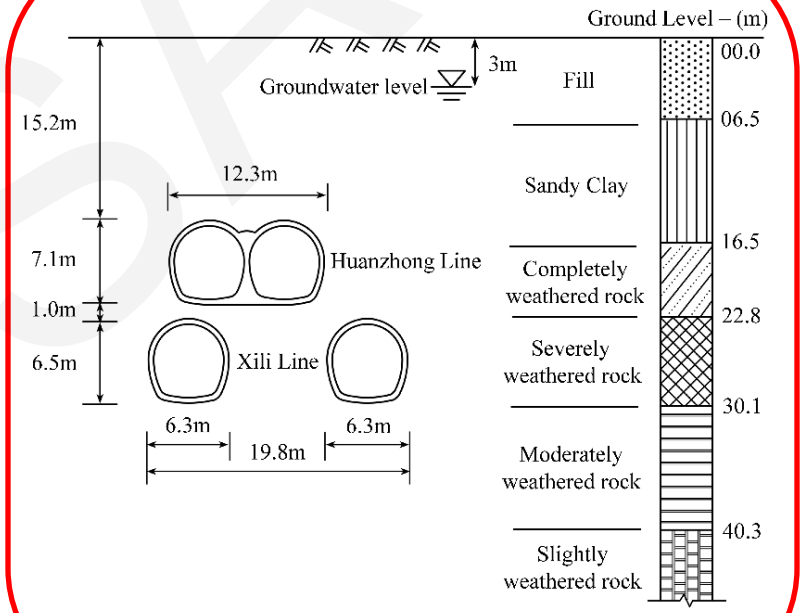


Fig. 2 Typical transverse profile

Soil type	γ (kN/m³)	n	E (MPa)	v	c′ (kPa)	φ′ (°)	ψ (°)	k (m/s)
1 Fill	18.1	0.40	5	0.20	17.6	18.2	0	6.5×10^{-6}
2 Sandy clay	18.9	0.45	8	0.31	26.9	23.0	0	4.6×10^{-7}
3 Completely weathered rock	19.1	0.43	12	0.30	28.0	24.5	0	3.8×10^{-6}
4 Severely weathered rock	19.2	0.41	30	0.27	29.0	27.2	0	1.2×10^{-6}
5 Moderately weathered rock	24.8	0.30	60	0.30	60.0	35.0	5	8.7×10^{-7}
6 Slightly weathered rock	26.6	0.15	120	0.30	100.0	40.0	10	4.0×10^{-8}

Construction Schemes

Simultaneous tunneling using STM

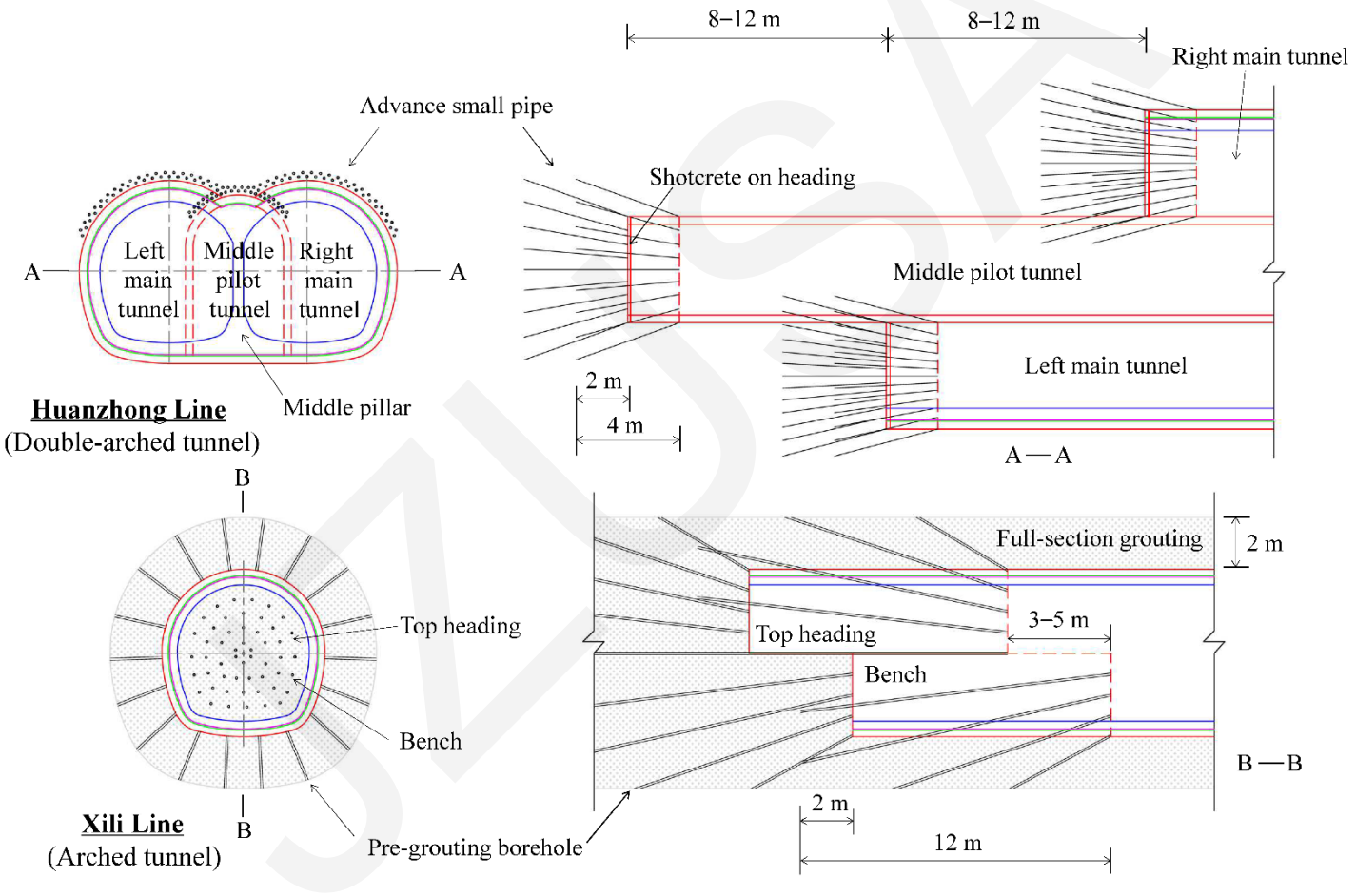


Fig. 3 Construction patterns

Settlement Measurements

■ Significant settlement induced by groundwater seepage

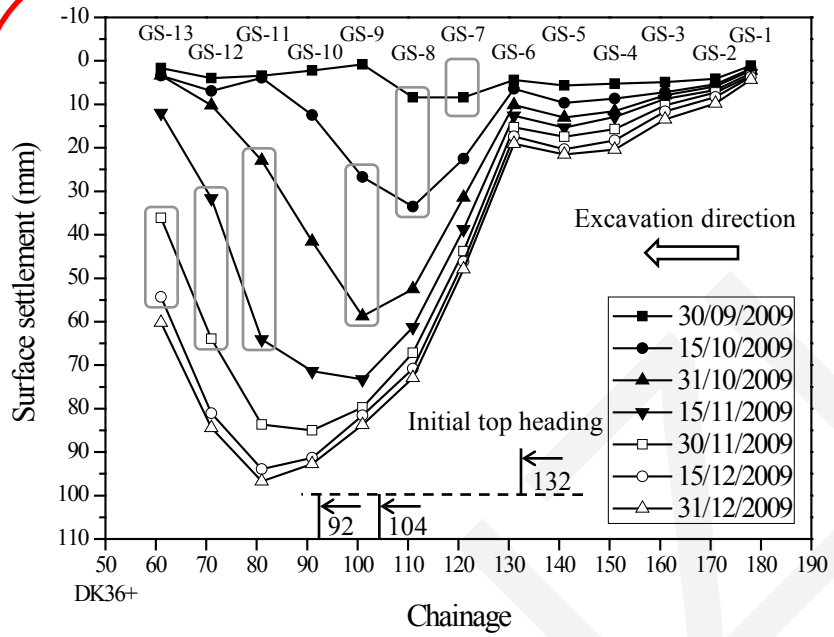


Fig. 4 Longitudinal surface settlements in every half month

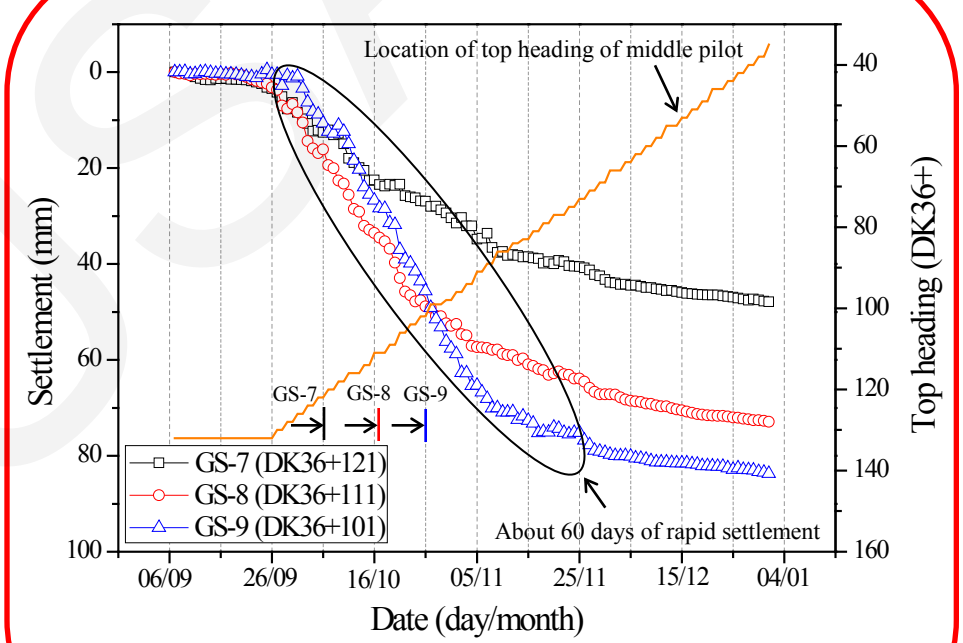
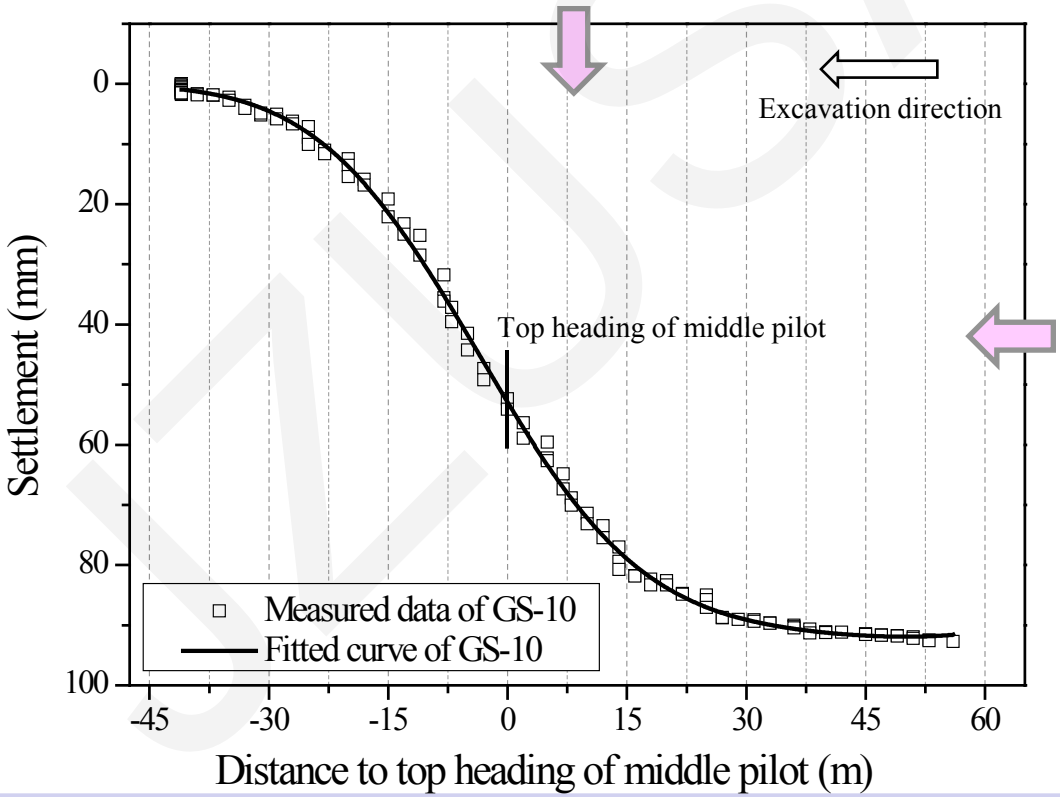


Fig. 5 Progressive development of surface settlements

Measurements Discussion

Settlement fitting with cumulative frequency function

$$W = W_{\max}\left[G\left(\frac{x - x_i}{i}\right) - G\left(\frac{x - x_f}{i}\right)\right]$$



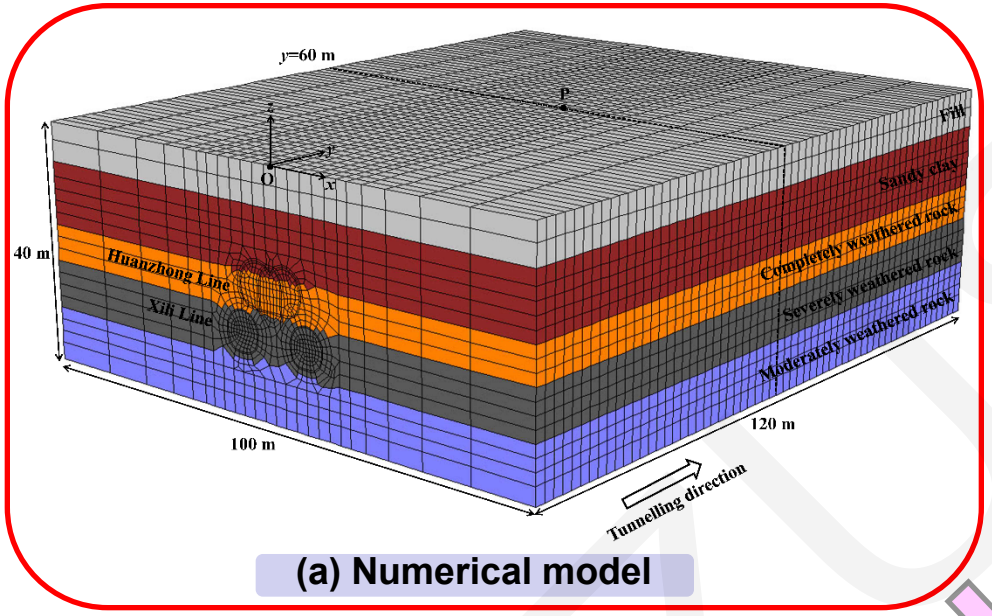
$$i = R\left(\frac{H + R}{2R}\right)^{0.8}$$

$$i = 0.5(H + R)$$

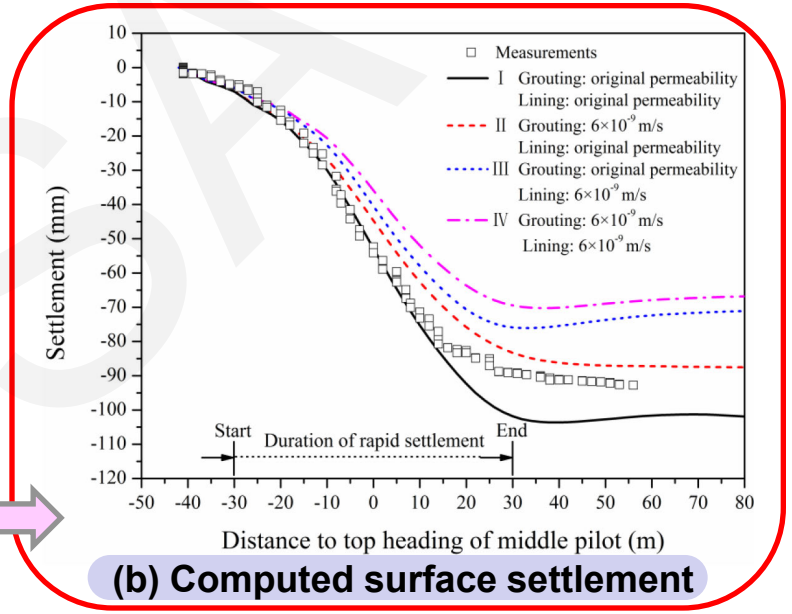
Fig. 6 Curve fitting for settlement history of GS-10

Finite Difference Analysis

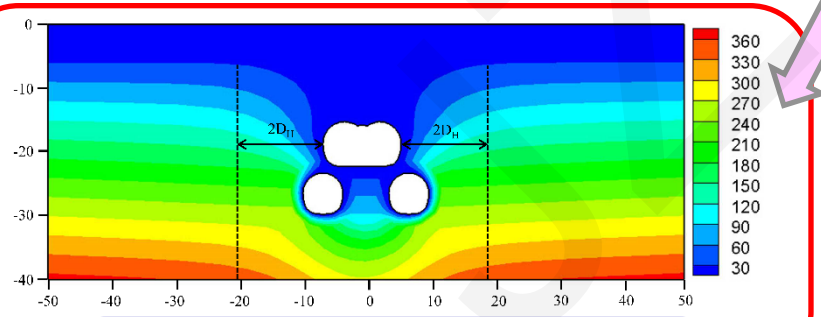
Simulation of actual tunneling process



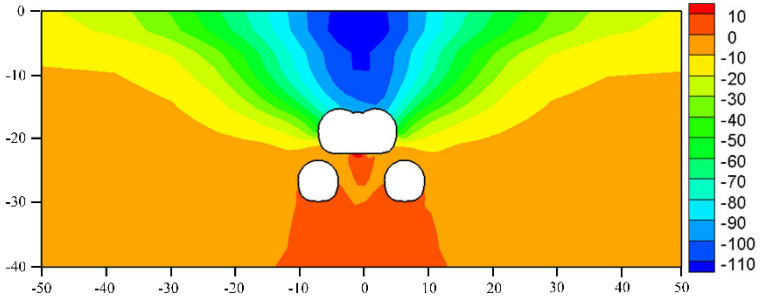
(a) Numerical model



(b) Computed surface settlement



(c) Distribution of pore pressure

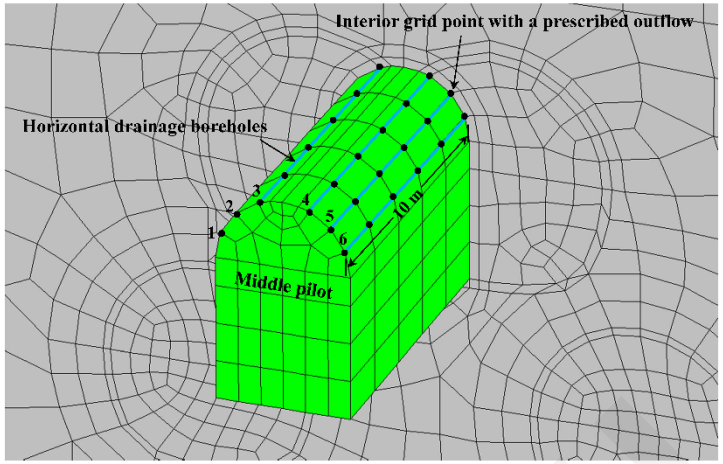


(d) Distribution of vertical displacement

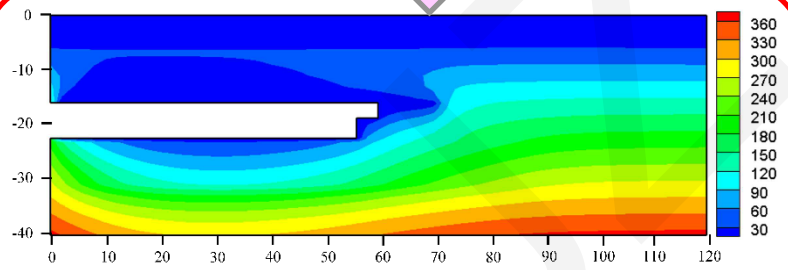
Fig. 7 Finite difference analysis

Effect of Advance Drainage

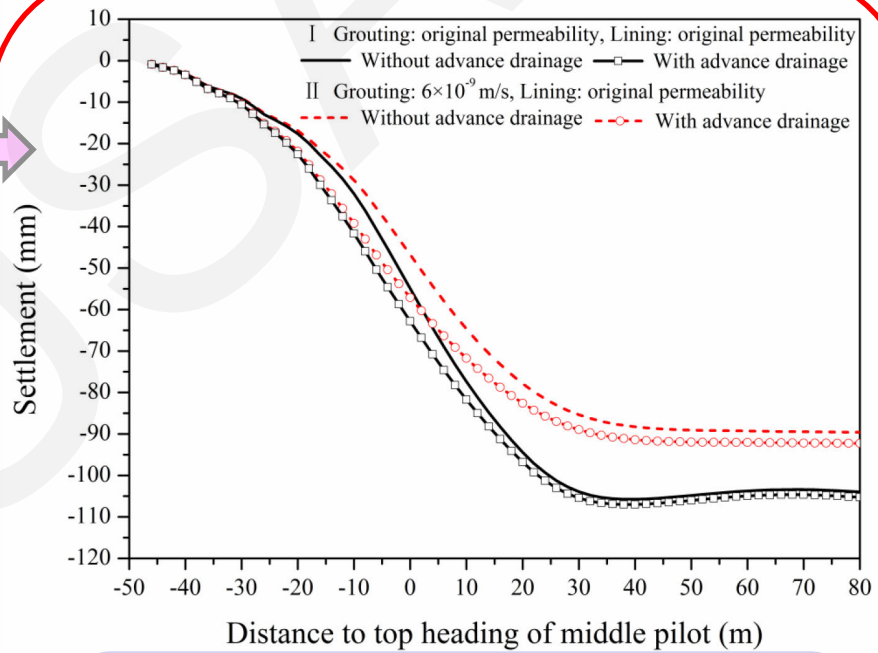
Simulation of horizontal drainage boreholes



(a) Layout of drainage boreholes



(b) Distribution of pore pressure with drainage boreholes



(c) Computed surface settlements without and with advance drainage

Fig. 8 Numerical analysis considering advance drainage boreholes

Conclusions

- A case history of remarkable surface settlement induced by simultaneous tunneling with STM in permeable strata was presented in this paper. The main conclusions are summarized as follows:

- Groundwater seepage is the main cause of the rapid increase in surface settlement. The effect of small pipe grouting is limited in avoiding excessive surface settlement, and the measure of full-section grouting is mandatory.

- The 3D numerical results demonstrate that significant surface settlement is mainly caused by groundwater seepage and is influenced by the permeability of the small pipe grouting zone and the primary lining.

- The advance drainage measure with horizontal boreholes evidently improves the safety of tunnel headings, and has limited effect on surface settlement. When full-section grouting is not available, it is an alternative measure to be adopted in combination of small pipe grouting during tunneling in permeable strata.