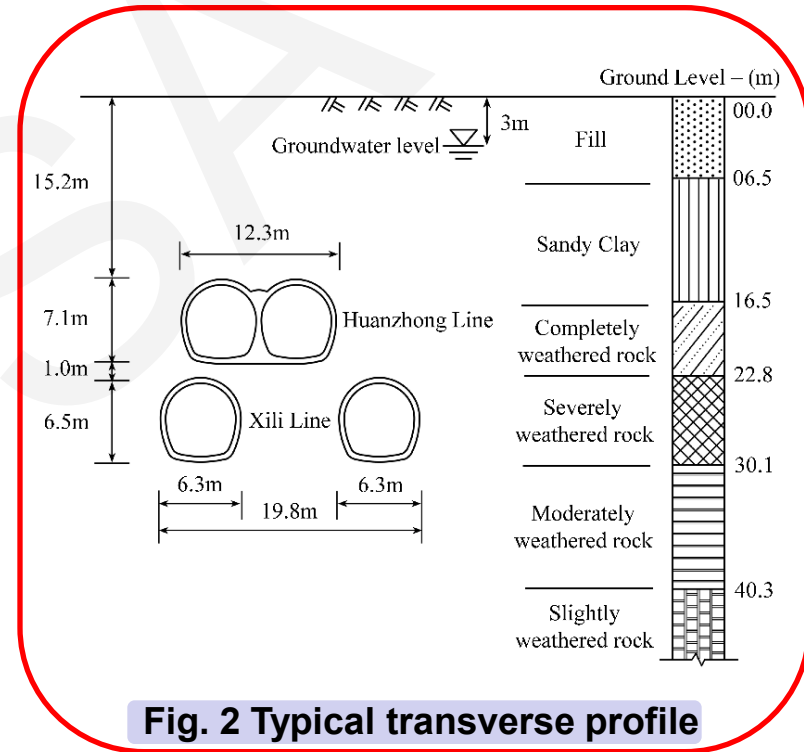
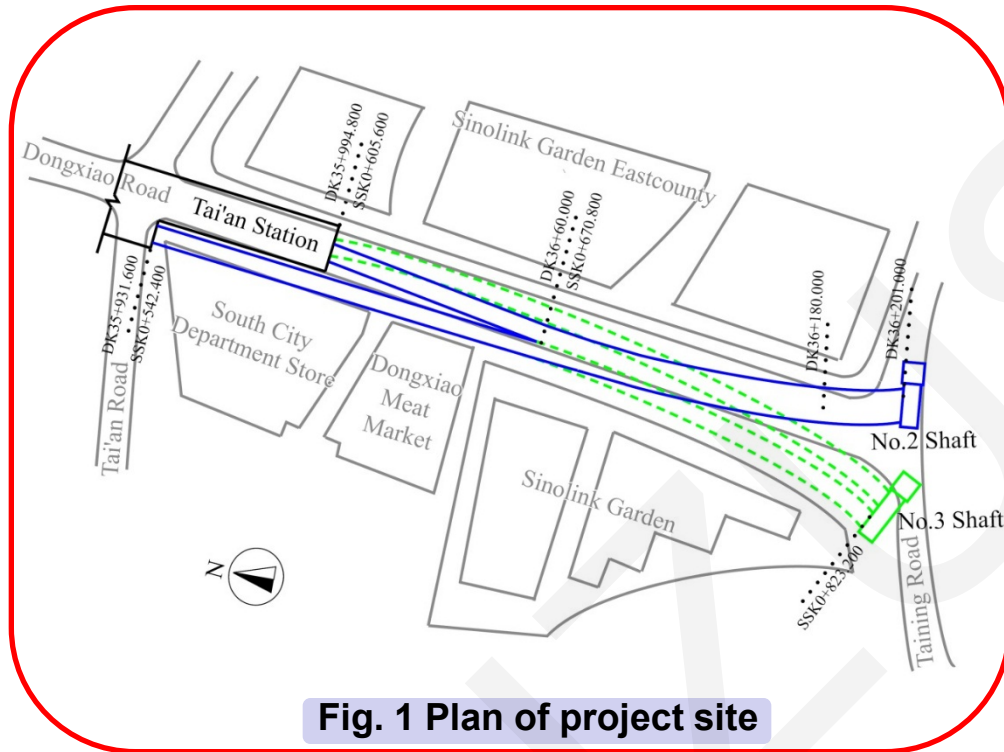


# Surface settlements induced by tunneling in permeable strata: a case history of Shenzhen Metro

Cite this as: Xiao-wu TANG, Peng-lu GAN, Wei LIU, Yu ZHAO, 2017. Surface settlements induced by tunneling in permeable strata: a case history of Shenzhen Metro. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 18(10):757-775. <http://dx.doi.org/10.1631/jzus.A1600522>

# Project Background

## Overlapped metro lines excavated in permeable strata



Soil type	$\gamma$ (kN/m <sup>3</sup> )	$n$	$E$ (MPa)	$\nu$	$c'$ (kPa)	$\phi'$ ( $^{\circ}$ )	$\psi$ ( $^{\circ}$ )	$k$ (m/s)
1 Fill	18.1	0.40	5	0.20	17.6	18.2	0	$6.5 \times 10^{-6}$
2 Sandy clay	18.9	0.45	8	0.31	26.9	23.0	0	$4.6 \times 10^{-7}$
3 Completely weathered rock	19.1	0.43	12	0.30	28.0	24.5	0	$3.8 \times 10^{-6}$
4 Severely weathered rock	19.2	0.41	30	0.27	29.0	27.2	0	$1.2 \times 10^{-6}$
5 Moderately weathered rock	24.8	0.30	60	0.30	60.0	35.0	5	$8.7 \times 10^{-7}$
6 Slightly weathered rock	26.6	0.15	120	0.30	100.0	40.0	10	$4.0 \times 10^{-8}$

# Construction Schemes

## ■ Simultaneous tunneling using STM

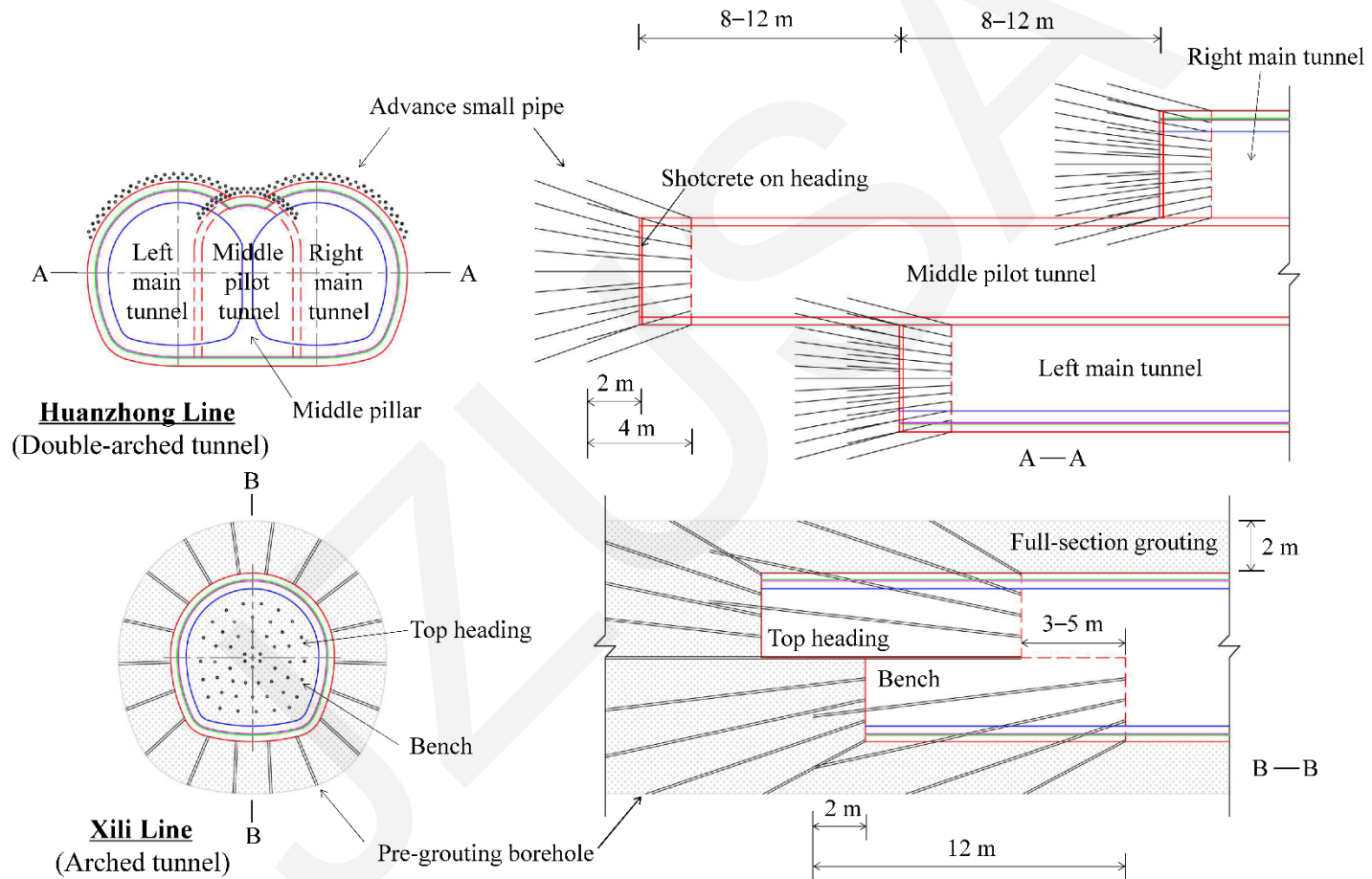
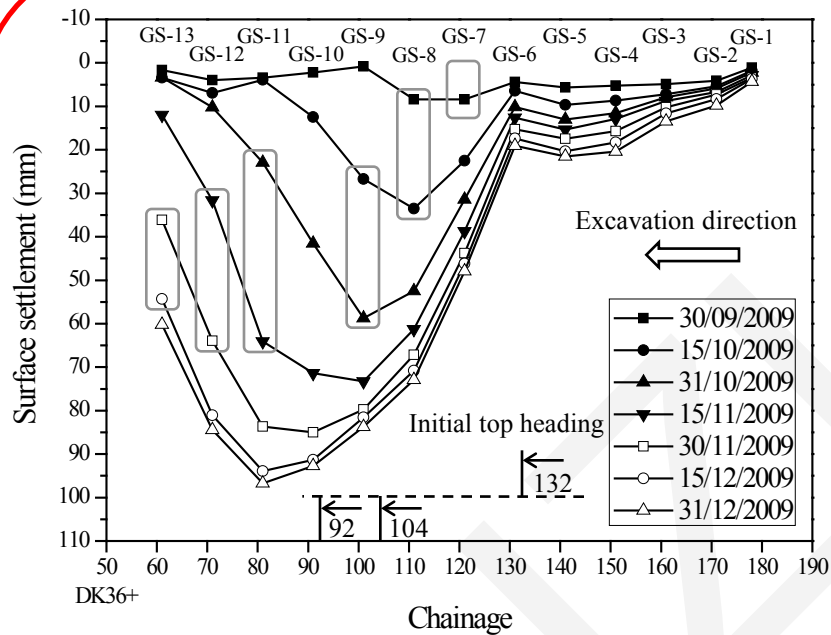


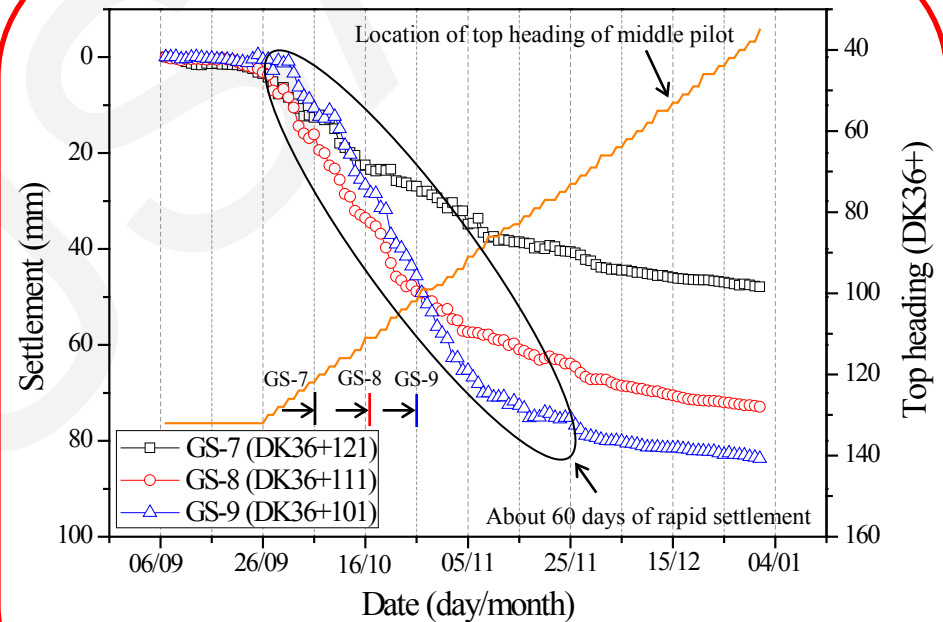
Fig. 3 Construction patterns

# 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

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

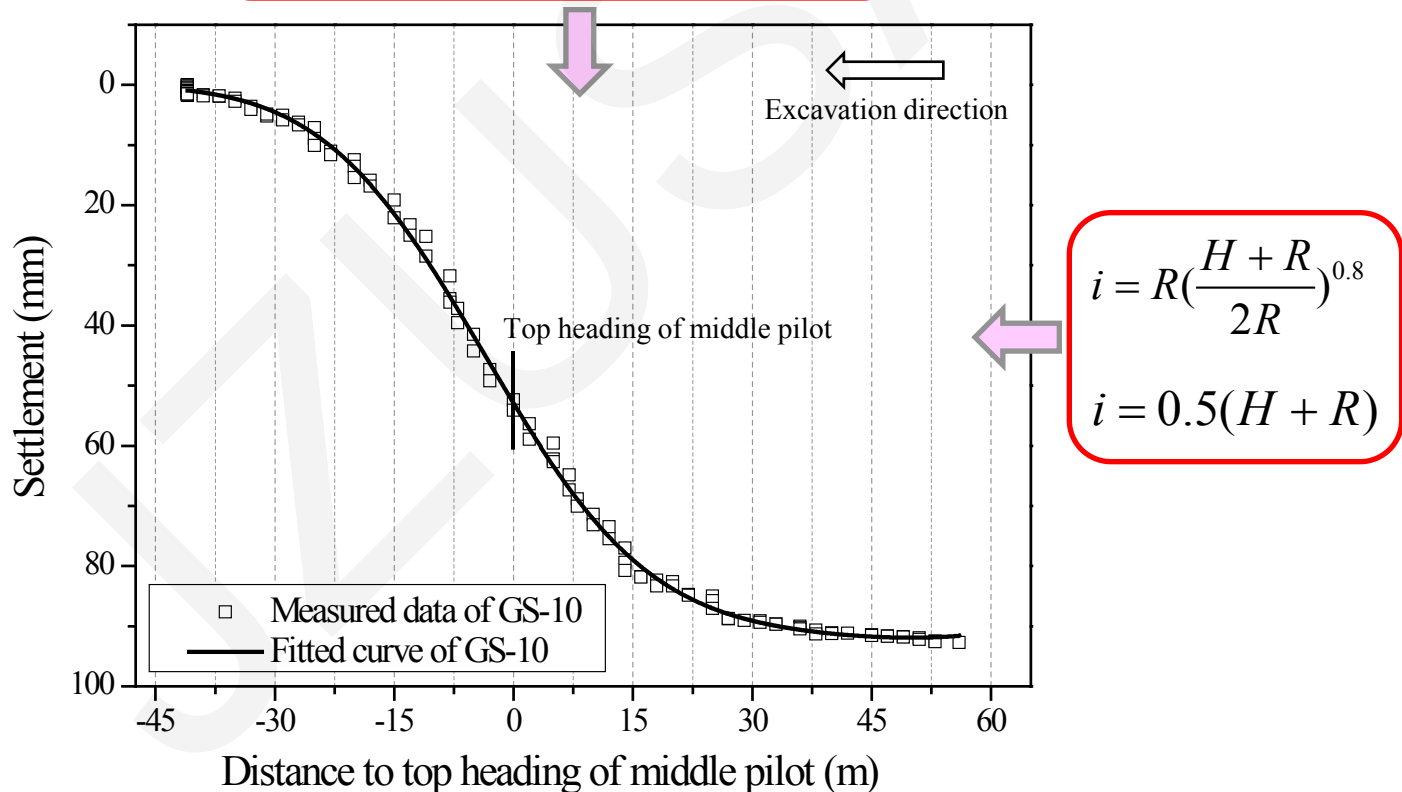


Fig. 6 Curve fitting for settlement history of GS-10

# Finite Difference Analysis

## Simulation of actual tunneling process

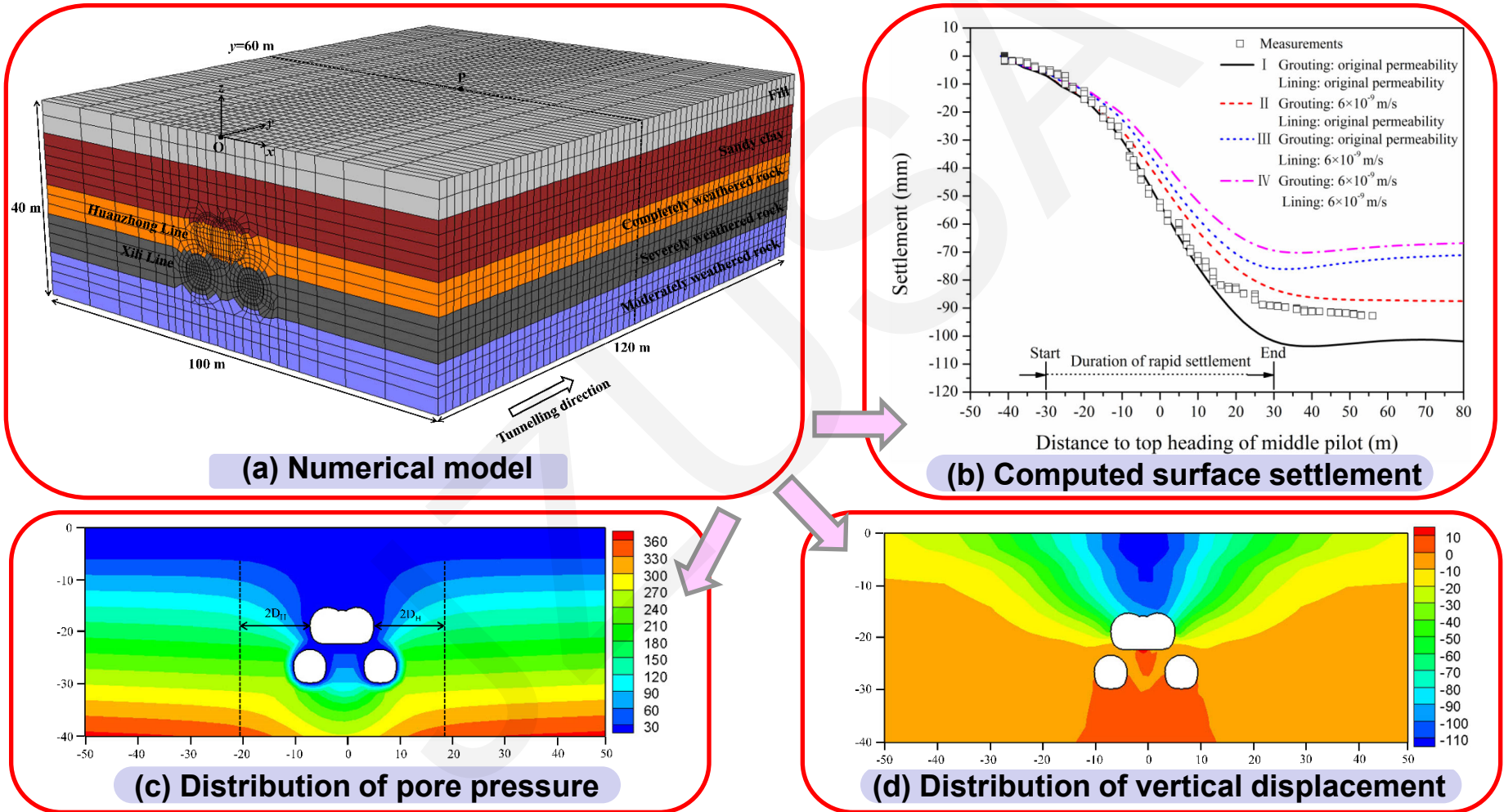
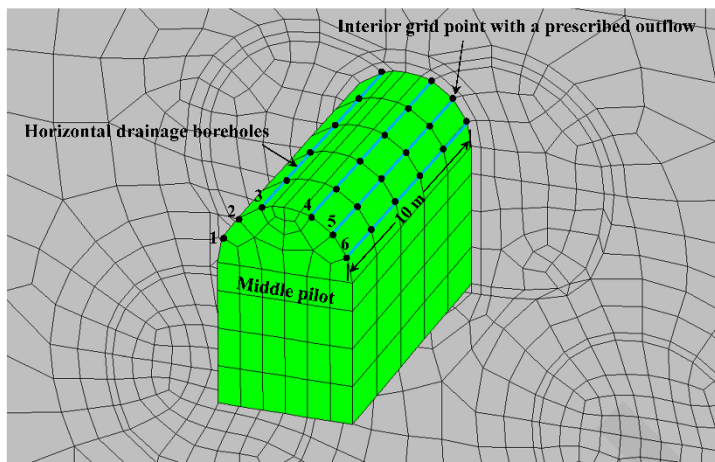


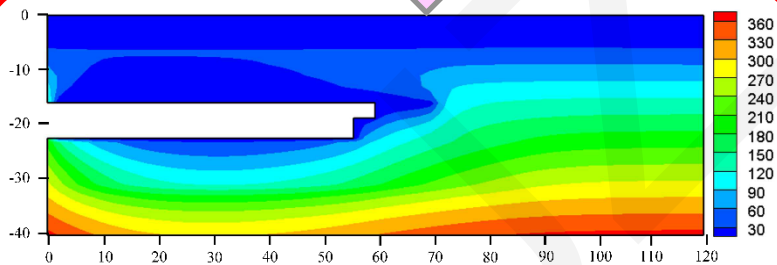
Fig. 7 Finite difference analysis

# Effect of Advance Drainage

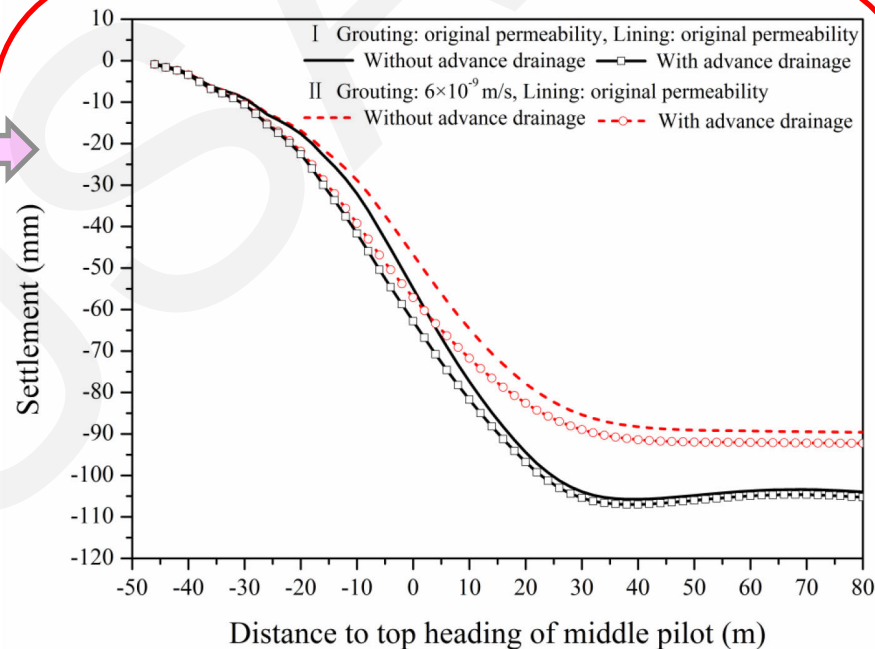
## Simulation of horizontal drainage boreholes



(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.