Geo-treatments in Constructing a Tunnel in Karst Strata: Lessons Learned from the Metro Subway Project in Guangzhou, China

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Outline

- Metro Tunnel in Guangzhou
- Georisks and Construction Problems
- Recommended Solutions
- Summary
Metro Tunnel in China

- In Operation
- Under Construction
- In Planning

Map of China showing locations of metro tunnels.

Bar chart showing the number of metro tunnels by year from 2009 to 2020.

- 2009: 1011
- 2010: 1471
- 2011: 1699
- 2012: 2058
- 2013: 2518
- 2014: 2886
- 2020: 6100

Pie chart showing the distribution of tunnels:
- In Operation: 20
- Under Construction: 21
- In Planning: 5
Metro Tunnel in Guangzhou

9 lines
164 stations
260.5 km (before 2015)

17 lines
677 km (2020)
Metro Tunnel in Guangzhou

Guangzhou “Geological museum”:

Sand  Clay  Rock  Solitary stones  Ground Water  Karst  Fault

Guangzhou  Guangdong Province  Karst caves

0 50km 100km

Guangdong Province

ISSAEST, Fairbanks, AK, USA, August 2-5, 2015
Metro Tunnel in Guangzhou

Geological section: from Maanshan station to Liantangnan station

Maanshan Station  |  Liantangnan Station

- Sand 155m
- Rock 53m
- Karst 711m
- Upper-soft-lower-hard strata 666 m
- Sand 299m

98 karst caves were found along the tunnel.
Georisks and Construction Problems

Shanghai Metro line 4

- Collapsed ground
- Pumping station constructed in 2002

Ground collapse

Building destruction
Georisks and Construction Problems

Cutter wear

Foam slurry spout out

Photted during the tunneling of Ma-Lian section
Georisks and Construction Problems

- Surface Collapse
- Tunneling in Mixed Ground
- Cutter Wear

Upper-soft (clay or sand)-lower-hard (limestone) strata and karst
# Recommended Solutions

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<tr>
<th>Method</th>
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<td>Karst treatment</td>
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<tr>
<td>Tunneling in upper-soft-lower-hard strata</td>
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<tr>
<td>Tunneling in karst</td>
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<tr>
<td>Cutter treatment</td>
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Recommended Solutions

Karst cave treatment:

Survey → Determination → Treatment → Effect inspection

Geological Drilling
Rayleigh wave
CT
Geological radar

Number
Location
Filling
Treatment or not

Sleeve-valve-pipe grouting
Determine the location
Drilling
Install the grouting pipe
Grouting
Preparation of slurry
Hole sealing

Other grouting methods

Unconfined compressive strength (> 0.2 MPa)
OR
Standard penetration test blow count (> 18)
Recommended Solutions

Grouting steps

(a) Hypothetical Boundary
   Encrypting drilling hole and grouting hole (exhaust at the top)

(b) Peripheral holes

(c) Centre holes

Karst cave

Karst cave

Karst cave

Karst cave
Recommended Solutions

Tunneling in Upper-soft-lower-hard Strata

Control Points

- Volume of excavated soil
- Penetration rate
- Excavated soil sample
- Tail grouting pressure
- Immediate analysis and cutter inspection
Recommended Solutions

Tunneling in Caved Karst Strata:

1. The head of TBM remained raised to increase the lower jacking force and decrease the upper jacking force.

2. The screw was shut up to slowly drain the water.

3. Control the earth pressure to drain water and reduce excavated soil.
## Recommended Solutions

### Cutter Replacement (Ma-Lian Section):

<table>
<thead>
<tr>
<th>Technique</th>
<th>Preparation time (day)</th>
<th>Ground condition</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground improvement</td>
<td>2-3</td>
<td>Thin sand within the excavation face; cutter can go back</td>
<td>Time-efficiency</td>
<td>Unavailable when the cutter is heavily damaged</td>
</tr>
<tr>
<td>Chamber filling</td>
<td>7-10</td>
<td>Cavity in the excavation face; cutter cannot be rolled; confined water pressure</td>
<td>Stable excavation face after filling; Less disturbance on ground without disk rolling</td>
<td>Re-filling is needs once there is water leakage; disk cannot be rolled</td>
</tr>
</tbody>
</table>
Recommended Solutions

Cutter Replacement:

Photoed during the tunnelling of Ma-Lian section
Summary

1) Problems were encountered during tunneling excavation, such as karst treatment, tunneling in upper-soft-lower-hard strata, tunneling in caved karst strata, and cutter replacement. Recommended solutions are presented.

2) To make sure that the TBM could successfully pass through the caved karst strata, karst caves were explored and judged. Slurry grouting method was utilized to deal with karst caves.

3) The volume of excavated soil sample, penetration rate, tail grouting pressure, immediate analysis and cutter inspection should be controlled during tunneling in upper-soft-lower-hard strata.

4) The jacking force, screw and earth pressure should be controlled during tunneling in caved karst strata.

5) Ground improvement of grouting and chamber filling method were presented for the cutter replacement.
Thank you!

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