

Risk Management of the Restoration of Shanghai Metro Line 4

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ABSTRACT: Risk management will be more widely adopted in China with strong pushes from the academics, engineers as well as the government. After the huge accident involving Metro Line No. 4 in Shanghai, all key projects in Shanghai now requires implementation of risk management. This paper briefly introduces the collapse of One section of Shanghai Metro Line 4 and the restoration plan. Through the successfully application of risk management in the restoration of Shanghai Metro Line 4, It is confirmed that risk management is very vital for the large engineerings.

1 INTRODUCTION

Part of the Shanghai Metro Line 4 construction require twin bored tunnel of about 2km to be built between South Putong Road Station and Nanpu Bridge Station. The main tunnels were completed successfully including the 440m section under the Huangpu River. During the construction of the cross passage using frozen method on 1st July 2003, excessive ground loss into the excavating face occurred and a stretch of the completed tunnels were damaged as a result. Adjacent buildings were also adversely affected. As an immediate measure to limit damage to other sections of the tunnel due to unbalance load after the collapse, the twin tunnels were filled with water. Cavity filling using grout and concrete was also carried out after the collapse as part of the damage control measures.

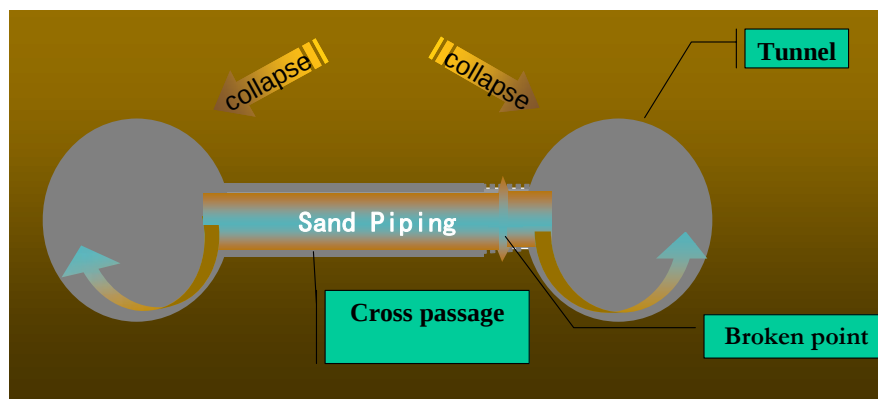


Fig.1 Sand piping accident

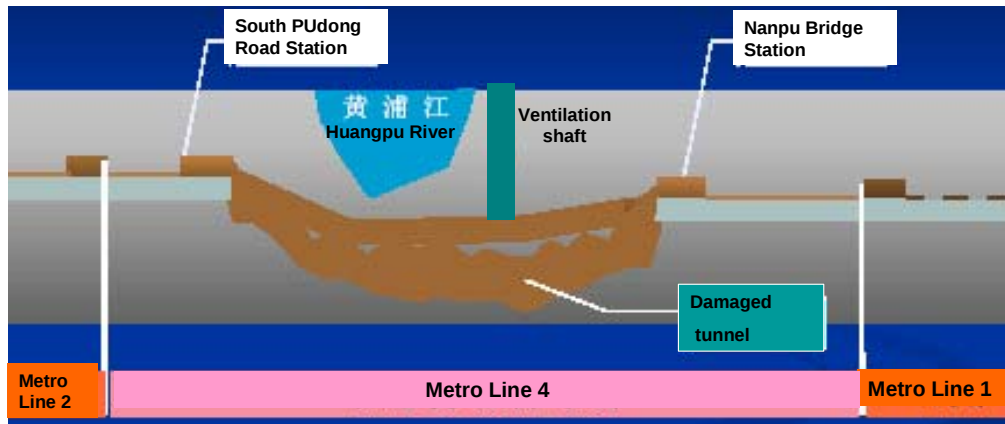


Fig.2 Section of the collapse



Fig.3 Crack of adjacent road and inclination of the adjacent pump room

After the incident, a Technical Committee was set up to evaluate and determine the feasible remedial solutions for the damaged tunnels. Detailed site investigation was carried out and various experts were consulted. The feasibility of each remedial solution was debated and the associated risk was carefully evaluated. The options for the repair works deliberated can be categorized into two broad categories:

- keeping the existing line and repair the damaged section of the tunnels
- tunnel re-alignment

Many factors had considered in selecting the remedial solution including the environment impact, the risk and difficulties, re-construction duration and cost effectiveness etc.

After detailed consideration, it was decided to adopt the first method-keeping the existing line and repair the damaged section of the tunnels.

2 RESTORATION OF SHANGHAI METRO LINE 4

2.1 Geology

After the accident, the soil of this site has been severely disturbed, and there are some obstacles buried there. The obstacles includes the underground utilities, ventilation shaft structures, ground freezing facilities, rail system which were buried up to 40m below ground.

As the Fig.4 shows that the soil has been moved down after collapse.

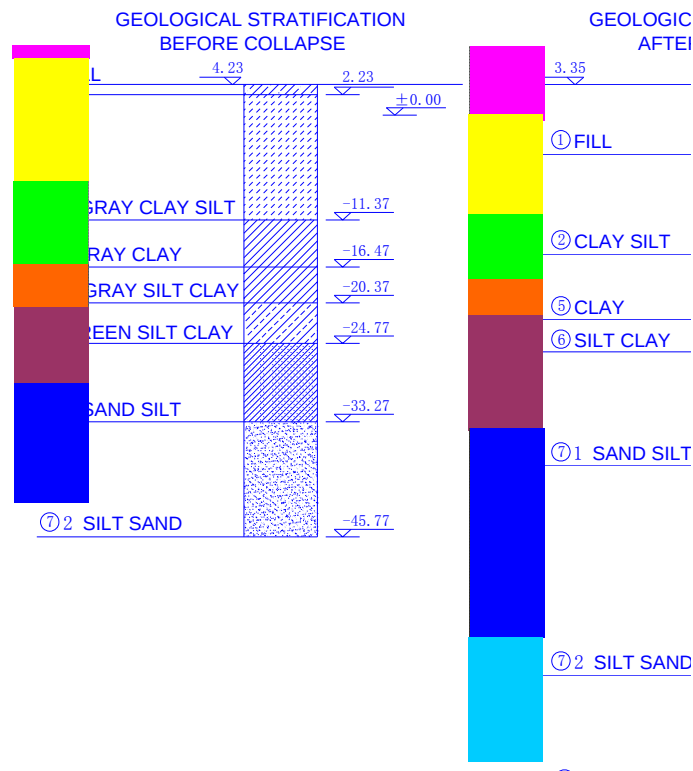


Fig.4 Geological stratification of the site

2.2 Introduction of the Restoration of Shanghai Metro Line 4

The restoration works can be divided into three parts:

- Part one: using cut and cover method to excavate the damaged tunnel and construct the new tunnel.
- Part two: dewatering and cleaning up the sound tunnels.
- Part three: connecting the new tunnels and existing ones using boring method

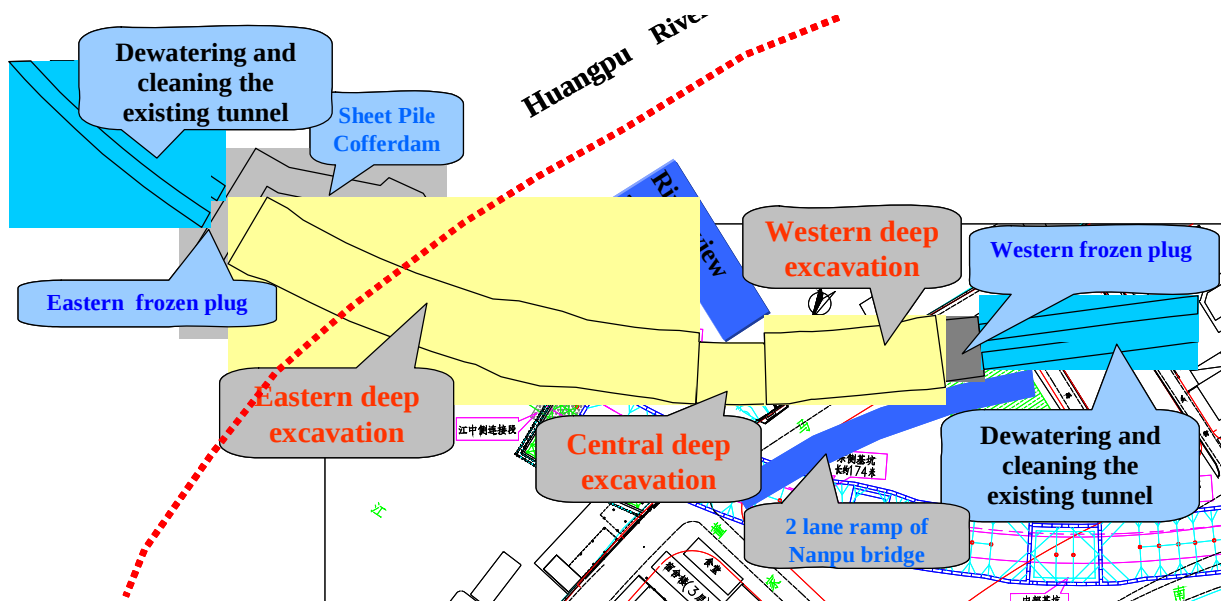


Fig.5 The Plan of the restoration work

2.2.1 Sheet pile cofferdam

As the Fig 5 show, at the eastern side where the damaged tunnel of some 60m was built under the river,

a steel platform will be erected in combination with the sheet pile cofferdam to facilitate the excavation works.

2.2.2 Obstacles cleaning

As lots of obstacles existing in the deep ground, the serious problem is the installation of the deep diaphragm walls. To resolve this problem, 360° rotation drilling and cutting machine of high accuracy is chosen to cut the debris into manageable sizes for removal.



Fig.6 360° rotation drilling and cutting machine



Fig.7 Removal tunnel segment

2.2.3 Protection of existing tunnels

To complete the repair works, the damaged tunnel will be reconstructed and connected to the existing tunnels which are structurally intact after the collapse. Therefore, treatment at the interface between the damaged tunnels and the intact one is complex and crucial. During the 360° rotation drilling and cutting machine cleaning the tunnel segment, some measures should be taken to protect the intact tunnel. So, before the machine drilling and cutting, the interface between the damaged and the sound tunnel will be backfilled and followed by ground freezing to form a tunnel plug to protect the sound tunnels.

2.2.4 Connection to the New Tunnel

The connection of the newly constructed tunnel to the existing sound tunnel is another challenge that requires careful planning and execution. The connection will be carried out upon the completion of the new tunnel as well as the clearing of the existing sound tunnel. Ground freezing has been adopted to address the concern of the ingress of water and soil at the interface during excavation. The connection will be completed by in-situ lining.

2.2.5 Tunnel dewatering and cleaning of existing tunnel

Because of the collapse and immediate measures, the tunnel were backfilled with water and materials. After the small section between the damaged tunnel and the sound one has been backfilled and frozen, The existing tunnel began to dewater and clean, the compressed air facilities has been on standby in the event.

2.2.6 Deep excavation

As the damaged tunnel and other obstacles being buried deeply, the restoration work takes the cut and cover method to excavate the damaged tunnel and build the new one.

According to the condition of the environment nearby, the whole pit has been divided into three parts: eastern pit, central pit and the western pit.

The whole excavation has been constructed along side the damaged tunnels for 263m in length, the width of the excavation is 23m and depth is about 38m., near the two interfaces, the excavating depth measure up to 41.2m.

The diaphragm wall design chooses comprise of 1.2m thick with JGP at the panel joint for enhance water tightness. 9 levels Reinforced concrete strutting system has been adopted to increase the rigidity of the retaining system. Sacrificial JGP layers below the strut level and below the formation level has

been installed to reduce wall deflection and enhance safety against basal heave. In order to reduce the water pressure and safeguard the surrounding structure, after so many times discussions , the work finally takes the dewater system inside the pit.

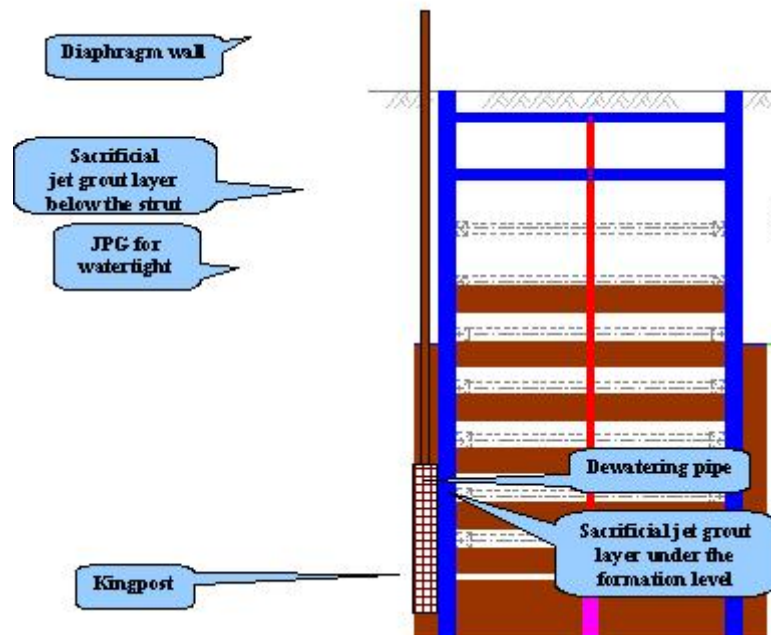


Fig.8 Section of deep excavation

3 RISK MANAGEMENT OF THE RESTORATION OF SHANGHAI METRO LINE 4

After the accident of Shanghai metro line 4, underground engineers have learned so many lessons from the collapse. So, engineers have taken some effective measures to manage the risk of restoration of Metro Line 4 during the construction.

As the Fig below shows, the restoration work has many risks and full of great challenges.

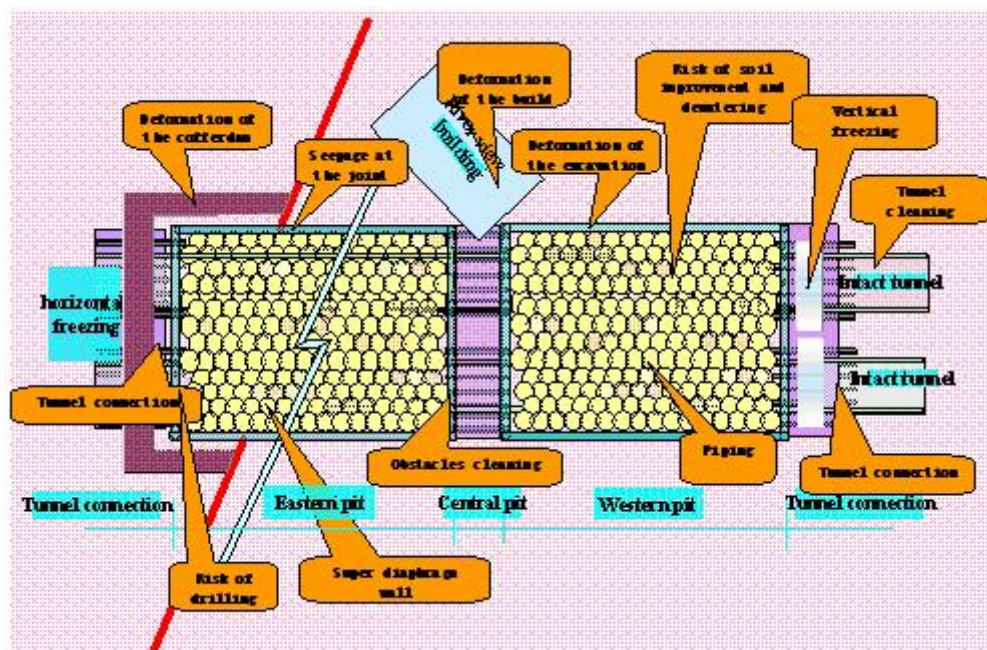


Fig.9 Risks of the restoration of Shanghai Metro Line 4

All risks can be focus on the follow aspect:

- Deep obstacles (including damaged tunnel segments) cutting and elimination;
- Construction of diaphragm wall with depth of 65.5m;
- Construction of steel platform and cofferdam in Huangpu river;
- Foundation reinforcement with jet grout with depth of 50m under complex condition;
- Decreasing high pressure water by pumping with large quantity ;
- Pit excavation with depth of 41m in soft ground;
- Joint construction with NATM after freezing consolidation;
- Congested construction site assembly and traffic organization.

Before the deep excavation, some monitoring cell have been installed to measure some characters during construction, such as the pressure of the soil, inclination of the diaphragm wall and the formation of the nearby construction, etc.

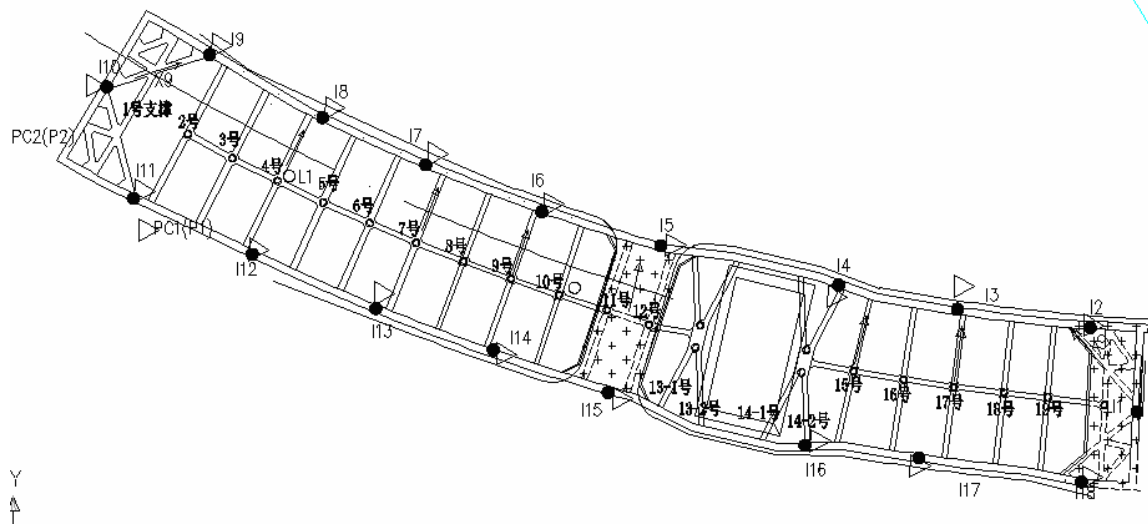


Fig.10 Place of monitoring cells

Through taking some effective risk management, the deep excavation, one of the most risk procedures, has been completed successfully. The deformation of the deep excavation and the surrounding buildings have been controlled in safe level.

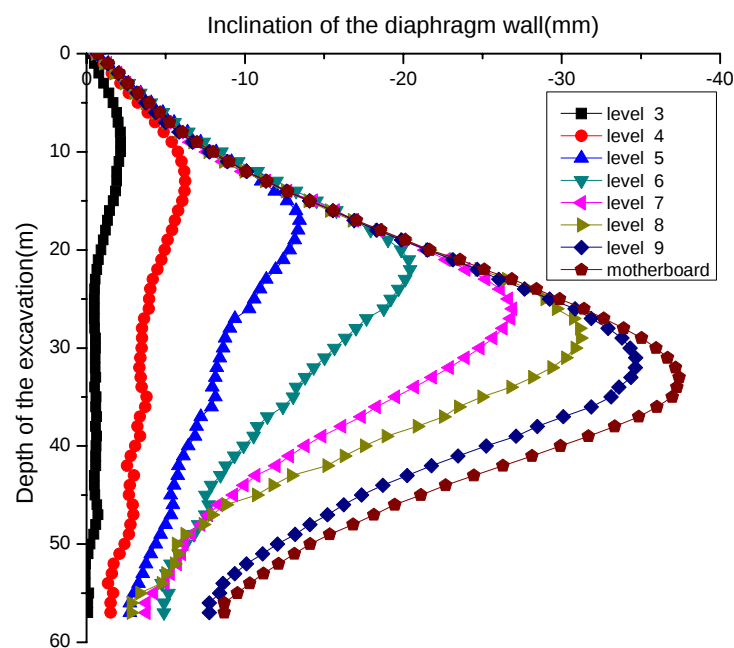


Fig.11 Inclination of the diaphragm wall



Fig.12 Deep excavation and strut system

4 CONCLUSION

The restoration of Shanghai Metro Line 4 has faced with various challenges, such as buried obstacles, severely disturbed ground, deep excavation, protection the sound tunnel, connection the damaged tunnel and the intact one, etc. various construction method has also been taken in the work including sheet pile cofferdam, JPG ground improvement, ground freezing ,dewatering and so on..

Through the risk management of the work, lots of risks have been identified and some effective measures have been taken to reduce the risk, which guards the construction successful. It is confirmed that risk management is very vital for the large engineerings.

