The new Bugis Station and associated tunnels for the Singapore MRT

Métro de Singapour : nouvelle station Bugis et tunnels associés

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ABSTRACT: The construction of the new Bugis Station and associated tunnels presented a number of interesting challenges all of which are linked to the building of new infrastructure in mature urban environments. The story of Mass Rapid Transit in Singapore is not at all old, with the first lines only operating for little over 25 years. However, the City State now finds that new lines are increasingly interlacing with existing underground assets, with unique problems presenting themselves. This, together with a more sophisticated population which demands greater respect for the built environment with inconvenience along with noise, dust and water pollution all being subject to greater scrutiny and demands for the Client and Contractor alike to deliver projects according to the highest international standards.

RÉSUMÉ : La construction de la nouvelle station Bugis et des tunnels associés a présenté plusieurs défis intéressants, tous liés à la construction d'infrastructures nouvelles dans un environnement urbain dense. L'histoire du métro de Singapour est récente, puisque les premières lignes sont en exploitation depuis un peu plus de 25 ans. Cependant, l'Etat de Singapour est maintenant confronté au fait que les tracés des nouvelles lignes rencontrent des ouvrages souterrains existants, ce qui génère des problèmes uniques. S'ajoutent à cela plusieurs facteurs qui rendent les projets de nouvelles lignes particulièrement complexes : une population plus sophistiquée qui demande un plus grand respect de l'environnement existant, une attention croissante portée aux nuisances (bruit, poussière, eau), et des demandes au client et à l'entreprise de se conformer aux normes internationales les plus exigeantes.

KEYWORDS: tunnel, station, underground, top down, bottom up, mining.

1 INTRODUCTION

The Singapore Mass Rapid Transit (MRT) system started operational service on the 7 November 1987. The decision to proceed with a Rapid Transit System was only taken after extensive studies and consideration of a bus only system. Given the land-scarce country's other priorities and with 10% of the available land already taken up by roads and related facilities the decision was taken to construct an extensive MRT network starting with the 45km North South Line initially comprising 20 stations. A further 21 stations were subsequently added with the opening of the East West Line in July 1990.

The MRT has continued its expansion with the extension of the existing lines and the construction of new lines such as the North East Line and the Circle Line and this has been complemented with Light Rail systems at Bukit Panjang, Sengkang and Punggol feeding the main MRT system.

Following publication by the Singapore Land Transport Authority (LTA) of a White Paper titled "A World Class Land Transportation System" in 1996 an extensive expansion of this network was confirmed and is now proceeding apace. The comprehensive rail network will become the backbone of an integrated public transportation system catering for a growing population.

Whilst the early lines mixed underground and overhead sections the new lines are entirely underground. The 16 station, North East Line and 28 station Circle Line are fully underground and these will be followed by the 34 station Downtown Line, 22 station Thomson Line and the future Eastern Region and Cross Island Lines.

This major expansion in a mature urban environment brings with it many challenges some of which are addressed in this paper.

Figure 1. General view of Bugis station.

2 DOWNTOWN LINE

The LTA announced the construction of the Downtown Line in June 2005. The stage one of the project was initially referred to as the Downtown Extension of the Circle Line but as planning evolved this became the first of three phases to complete the whole Downtown Line which will be the fifth metro line to be constructed in Singapore and is due to be fully open by 2016.

2.1. *Presentation of the Downtown Line (DTL)*

Serving the expanding business district of Marina Bay along with the new Marina Bay Sands Integrated Resort and through to the North-Western and Eastern areas of the island the line will comprise 34 stations over its 42km length. As mentioned above, the whole line will be underground. More than half a million commuters are expected daily on this line.

The three stages will have a staggered opening with stage one (DTL1) to be completed by 2013 followed by DTL2 in 2015 and DTL3 in 2017. Stage One incorporates the stations in the existing Central Business District through the New Downtown to the Bugis district and will have four interchange stations linking into three different underground lines: North East Line at Chinatown; the East West Line at Bugis; the Circle Line at Bayfront and Promenade Stations. Construction of this line started early in 2008.

2.2. *DTL1 C903 Bugis Station and Associated Tunnels*

Contract 903, Bugis Station and Associated Tunnels, was awarded in November 2008 to Soletanche Bachy as main contractor, and leader of the Joint Venture with local company Koh Brothers. It was the last contract awarded on DTL1 and is a Construct Only contract with the design being undertaken by Arup on behalf of the LTA. At the time, it was the largest rail project ever awarded by the LTA at S$582 million (360m euros at current exchange rates). The new Bugis Station will be the terminus for Stage One of Downtown Line (DTL1) and was therefore a critical section as the crossover and overrun was integrated within this contract.

The Bugis area is an important commercial centre, historically linked to seaborne trading but now a thriving area with private and public housing, major shopping and commercial complexes along with a large private hospital. Bugis is surrounded by the tourist areas of Little India and Kampong Glam. The new station was to be build partially below Rochor Road and adjacent open land, whilst the cut and cover tunnels were built below the heavily traffic Rochor Road. Indeed Rochor Road is one of two principal arteries into central Singapore from the South and the first when coming from the airport via the busy East Coast Parkway.

The project extends over 600m with four major road crossings at Beach Road, North Bridge Road, Victoria Street and Queen Street. The Victoria Street crossing is further complicated due to the existing Bugis MRT Station running below the street and across the alignment of the new tunnels. At Beach Road and Queen Street numerous utilities ran below the surface.

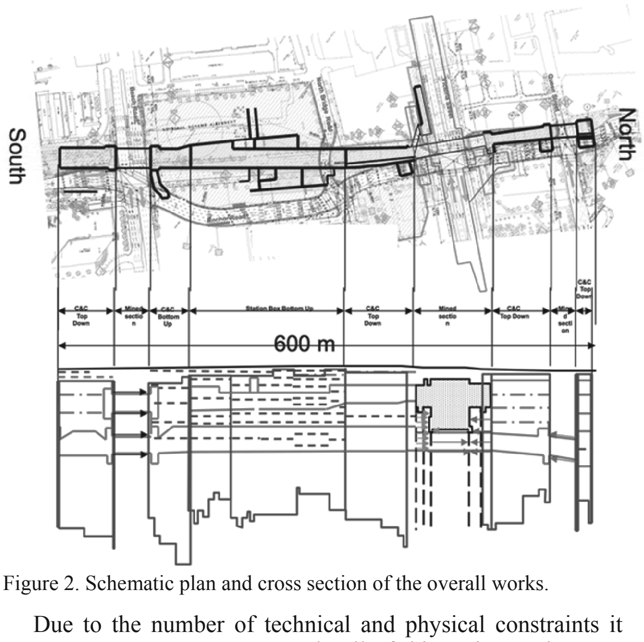

Figure 2. Schematic plan and cross section of the overall works.

Due to the number of technical and physical constraints it was necessary to construct nearly all of this entire section as a cut and cover. At the Southern end the crossover precluded bored tunneling and beyond the station the physical constraints going below the existing Bugis Station and the narrow horizontal footprint meant a cut and cover tunnel was the only solution until after Queen Street. Furthermore, the connection tunnels from the new to the existing station would also mean significant works below Rochor Road.

At either end of the project, bored tunnels would make the connection to the adjacent stations. At the Southern end a temporary access shaft was constructed by the neighbouring contractor to launch their TBM's towards Promenade Station and at the North end a receiving shaft was built to reception the TBM's coming from Rochor Station, the first DTL2 station.

The excavation depth for the station and tunnels varies along the alignment but was generally 27m below ground level with the deepest section at the Queen Street receiving shaft.

The geology in this area of Singapore is essentially 3 to 5m of fill/sand overlaying 20 to 30m of Marine Clay above Old Alluvium.

All the major retaining walls were constructed using the diaphragm wall technique and barrette piles were used for the foundations. The excavation depth and the stiffness required to avoid settlement and movement to the surrounding assets meant that a robust earth retention system was required over the full length of the project. Due to the very soft clays overlying the founding Old Alluvium, additional strengthening of the ground was required prior to bulk excavation to minimise deflection of the retaining walls. This was carried out using two different techniques. In areas where utilities and obstructions were expected, one or two jet grouted slabs were installed to improve horizontal restraint. In more open areas such as the station, cross walls were constructed between the two retaining walls built using the same equipment as the diaphragm walling. Soletanche Bachy were able to propose a value engineering scheme where a significant section of jet grouting was replaced by cross walls. In addition to being a more robust solution, there was a benefit to the programme as the same equipment could be used reducing congestion on the working platforms and as importantly no additional materials testing regime was required such as the lengthy coring of the jet grouted slab to ensure compliance with the specifications.

As explained below a three principal construction methods were necessary to overcome the environment that the physical constraints imposed over the length of the site. These were using the Bottom Up and Top Down Methods for cut and cover construction and mined tunnels where existing infrastructure precluded open excavation.

3 CONSTRUCTION BY BOTTOM UP METHOD

The Bottom Up method was applied in the central area of the site between Beach Road and North Bridge Road. This area had less physical constraints and the Contractor had the space to move Rochor Road to either side of the excavation during the construction.

Once the diaphragm wall was constructed the bulk excavation could commence. Up to 9 layers of steel struts were installed to support the retaining walls as the excavation proceeded to a depth of 27m. A total of 20,000 tonnes of steel struts were installed for the whole site (nearly three times the Eiffel Tower's 7,300 tonnes!). Once the excavation reached the formation level, the base slab is poured and the structure built from the bottom back up to the roof slab. As the reinforced concrete structure is built and the walls braced by the inner structure, the temporary steel struts can be removed.

Figure 3. A view of the Station area showing the bottom up excavation and the Rochor Road diversion around the site.

Figure 4. A picture from inside the Station showing the struting required for the bottom up excavation.

4 CONSTRUCTION BY TOP DOWN METHOD

The Top Down method was used primarily in areas where it was essential to reinstate the Rochor Road to maintain traffic flow along this busy route. In general, the retaining walls, jet grouting or cross walls and roof slab were done in two phases by shifting the road alignment slightly to create space to work on one side of the tunnel at any one time.

The top down sections are South of Beach Road and from North Bridge Road right to the Northern end of the site after Queen Street. The corridor for the tunnels at these locations was very tight and with buildings very close to the alignment of the tunnels the top down method also afforded a very stiff structure to be built minimising settlements and therefore potential damage to the adjacent assets. It was especially the case in the section in front of the Bugis Village, a row of heritage shop houses fronting Rochor Road between Victoria Street and Queen Street.

To facilitate the bulk excavation, 'off line' shafts were constructed at several locations to allow the removal of the excavated material. Towards the Northern end of the site adjacent to the Rochor Centre a public housing complex, noise mitigation measures were required around the shaft prevent nuisance to the neighbours.

Indeed for much of the diaphragm wall, cross wall and barrette foundation work, noise mitigation measures were normal practice. A large acoustic screen was erected at the beginning of the Contract between the Station site area and a row of private houses and Soletanche Bachy developed a special sound proofing around the excavation cranes. Baptised the 'Ninja Turtle', the sound enclosure incorporated cameras to ensure that the operators vision was not impaired and also a air conditioning system to prevent overheating of the machines. This was one of the innovative ideas that were put into practice on the site which won an award from the Singapore Workplace Safety & Health Council.

Figure 5. The acoustic enclosure around the top down access shaft adjacent to the Rochor Centre.

Figure 6. Excavation for the diaphragm walls in front of Bugis Village. Note the green 'Ninja Turtle' enclosure around the two excavation cranes.

With the walls and roof of the top down section cast and the road reinstated above, the excavation continued by 'mining' below the roof slab and then constructing temporary supports (generally, reinforced concrete struts) or the definitive reinforced concrete slabs. Once the overall structure was complete and waterproofed, the voids between the tunnels and the surface were backfilled using a self compacting 'liquid soil' material.

Figure 7. A view of the excavation in a 'top down' section, working below the roof slab.

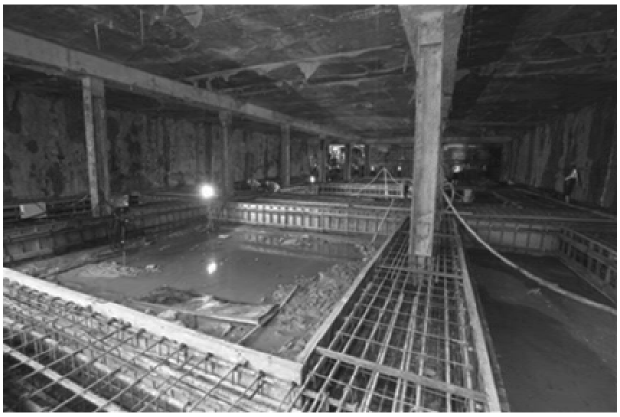

Figure 8. Preparation to casting the reinforced concrete struts in a 'top down' section of the project.

5 CONSTRUCTION BY MINING

Of all the different methods used on this project, the three mining sections were by far the most challenging. At Beach Road, two mined tunnels were constructed, the larger one for the railway and a second, smaller, pedestrian tunnel for a future development link. The large cross section of the rail tunnel at Beach Road was necessary as the crossover was situated at this location between the end of the bored tunnel section and the station platforms. At Queen Street a similar mined tunnel was required for the rail albeit with a smaller cross section. The mined tunnel below the existing Bugis Station was an entirely different proposition. Fully 80m long it stretched below the entrance structures and the central platform section with the operating railway running for the whole duration of the works.

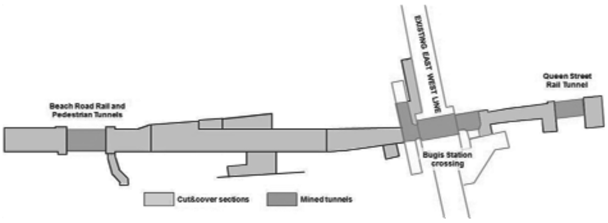

Figure 9. C903 Bugis station and associated tunnels layout.

5.1. *Beach Road and Queen Street tunnels*

These two lengths of 30m and 40m tunnels of a large sectional area (7.5mx22m and 7mx15m) are entirely excavated in the very soft marine clay layer and require extensive preliminary works. To prevent any instability during the excavation, the whole area was improved by jet grouting. Deep columns (>30m) were installed from the surface for a total of 29,000m3. The retaining structure was made of horizontal pipe piles (600mm and 900mm diameters) installed from the cut and cover areas by pipe ramming method.

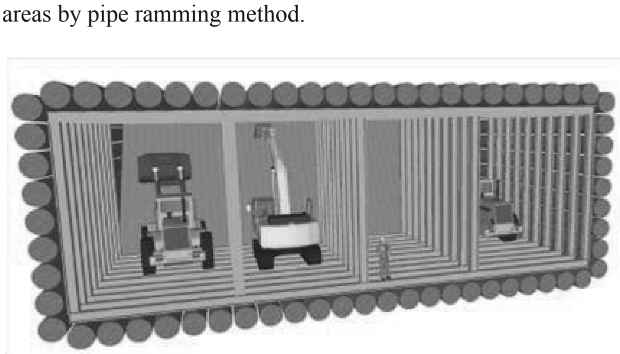

Figure 10. Schematic view of the excavation method for Beach Road and Queen Street tunnels.

The diaphragm wall was opened by stitch coring to allow the pipe pile installation. At 30m below ground level, the risk of water seepage was high and at some locations, additional grouting was carried out to ensure these openings were watertight. The cut section of wall was supported by steel propping in the temporary stage.

Figure 11. Setting up and welding – Beach Road rail tunnel.

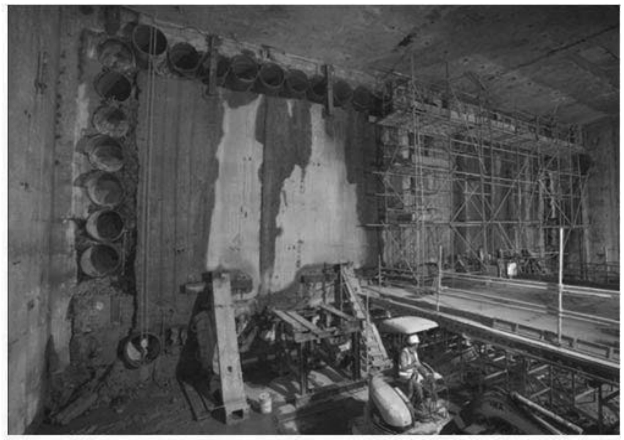

Figure 12. Temporary propping to support diaphragm wall.

The pipes were driven with two types of hammers operated by compressed air. Due to the restricted working space and the ongoing structural works in the vicinity, the pipes were installed in short sections and welded together. Depending on the area, Soletanche Bachy were able to use either 4m or 6m lengths of pipe. In some areas where access and the working area were severely restricted (40m long pipe pile installation for the Central Mining through an additional small shaft), the hammer was installed directly within the pipe to minimize the overall length.

Even with this powerful tool, hardened soil by Jet Grouting or obstructions caused refusal of the pipe driving. In such instances an auger was used to clean the pipe before resuming pipe ramming. Once completed, the pipes were fully cleaned out using the auger and the pipes cast with self-compacting concrete. For the last stage, the excavation of the tunnels was carried out using traditional methods with the installation of steel frames at regular intervals to support the pipes. At peak production 70 welders were required for pipe and steel frames installation.

5.2. *Mining under existing Bugis Station*

By comparison to the Beach Road and Queen Street tunnels, the Bugis Station mined tunnel posed different problems and represented the most sensitive part of the overall project. Tubular piles (600mm and 900mm diameter) acting as retaining walls were installed after a complex phase of works (bulk excavation, soil treatment, micropiles, Berlin wall, and strutting).

Soletanche Bachy had been aware of the presence of old king posts which had been used as temporary supports during the construction of the 1985 station and left in place. The accurate position of these obstructions were unknown and a detailed working procedure for the removal of these obstructions was put in place covering safe access lighting and air supply. When a King Post was encountered during pipe ramming, the auger was used to clean the pipe and the steel profile exposed. Following strict safety procedures, a worker was sent into the pipe to clean around the profile and it was then cut into smaller pieces for removal back through the pipe.

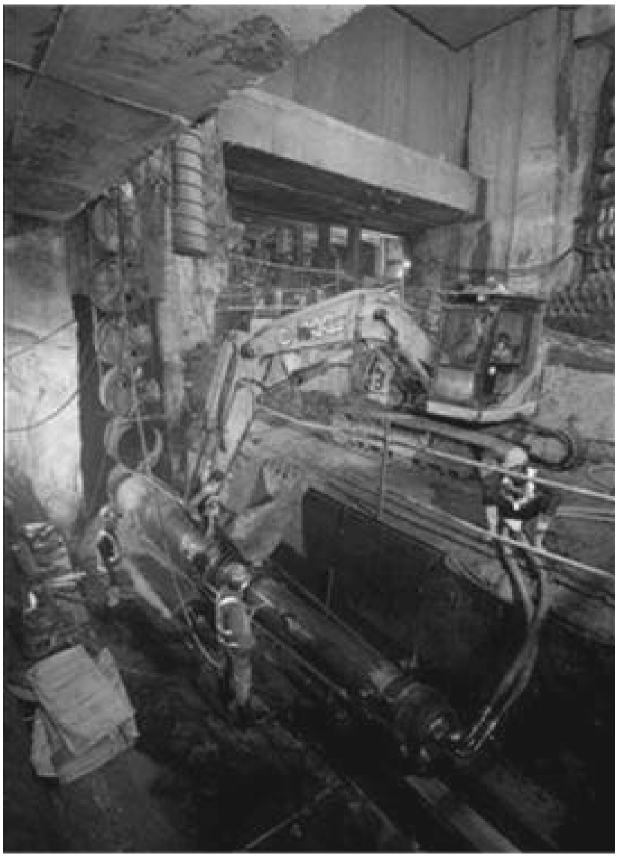

Figure 13. Pipe jacking and mining – South Wing.

Under the station, all the pipes were driven to the existing diaphragm walls and had to be anchored into them. The initial design indicated the pipes being driven 500mm into the opposing wall. However, as well as the impracticalities of doing so, the Authorities had rejected this scheme through concern for damage to the existing structure.

Soletanche Bachy proposed to tie in the pipes, using drilled reinforcement bars. An innovative system was developed by Soletanche Bachy. A guide was fabricated and inserted into the pipe. This guide was positioned at the end of the pipe up against the opposing wall and cores were then drilled into the diaphragm wall using the guide to ensure accurate positioning of the dowel bars which were sealed using an adhesive capsule.

Figure 14. The "Gun" for the Ø600 pipes.

Figure 15. Drilling in the soil nails using the Springsol.

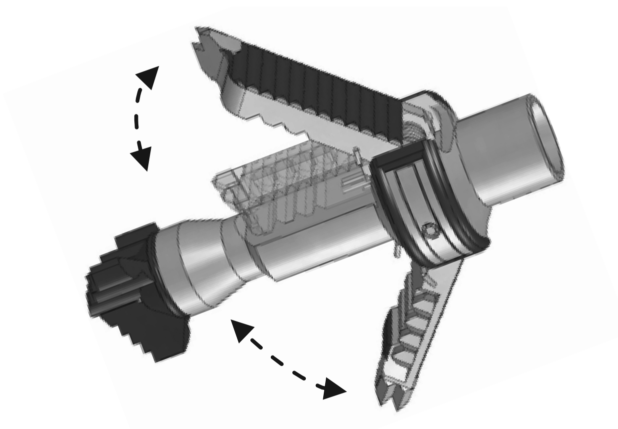

Figure 16. The Springsol tool, unfolded.

The Client had been concerned about the strength of the Marine Clay below the existing station and it had been impossible to carry out a soil investigation campaign at this location. 'Soil improvement' in advance of the mining works had therefore been specified but left to the Contractor to determine although ground freezing or horizontal jet grouting had been mooted. Soletanche Bachy shared the Client's concerned about the use of ground freezing or horizontal jet grouting around such sensitive structures and so proposed a combination of two soil improvement methods; using Springsol and fibreglass soil nails.

Initially developed to strengthen the ground below existing railway tracks, the Springsol method uses a foldable tool, developed by the Soletanche Bachy, and is able to install 400mm or 600mm diameter soil mixed columns through a small opening of only 162mm diameter.

The innovative horizontal application of this method proved highly efficient at improving the Marine Clays before the diaphragm wall was opened fully and also allowed the efficient installation of the fibreglass soil nails.

On completion of the soil improvement, the diaphragm wall could be cut and the excavation started using the soffit of the existing station base slab as the roof of the tunnel. Heavy steel frames (up to 551kg/m) were then installed as the excavation advanced. These frames were pre-fabricated at a workshop and assembled off site to ensure everything fitted when installed in the restricted mining area. In some areas, with a working headroom of only 2m, the use of heavy machines was impossible and here most of the frames were installed manually using chain blocks. The steel work installation in such confined spaces brought specific safety issues and the whole workforce were subject to targeted safety training and more regular safety talks to achieve our goal of zero accidents.

Figure 17. Central mining invert– Excavation and frames installation.

Once the bulk excavation work was complete, micropiles were installed to support the base slab for the new line. A permanent lining with waterproofing was installed and the temporary frames removed leaving the tunnel available for the system wide contractors to complete the last part of the job for the opening of the line in late 2013.

Figure 18. North Wing top heading -Roof pipes and heavy frames.

6 CONCLUSION

The successful completion of the mining sections of the contract were undoubtedly the key to overall performance of the works. They required the mobilisation of significant resources and considerable preparation. In total 7,400m of 600mm and 900mm diameter steel pipes were driven in the three locations with 2,200t of steel frames positioned to support the excavation using a total of 130,000 bolts. With soil improvement comprising 29,000m3 of Jet Grouting, 930 Springsol columns which incorporated 4,400m fibreglass soil nails.