Multiple-deck-charge blasting with electronic detonator at DTL2 C915 in Singapore




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1. Introduction

Downtown Line Stage 2 (DTL2) is a 16.6 km-long, underground subway system in Singapore, consisting of one depot and 12 stations including 3 interchange stations, and is scheduled to be completed by 2015. Contract 915 (C915) comprises twin-bored Tunnel Boring Machine (TBM) tunnels between the Beauty World and Hillview stations, 9 cross passages and cut and cover structures. Figure 1 shows the location

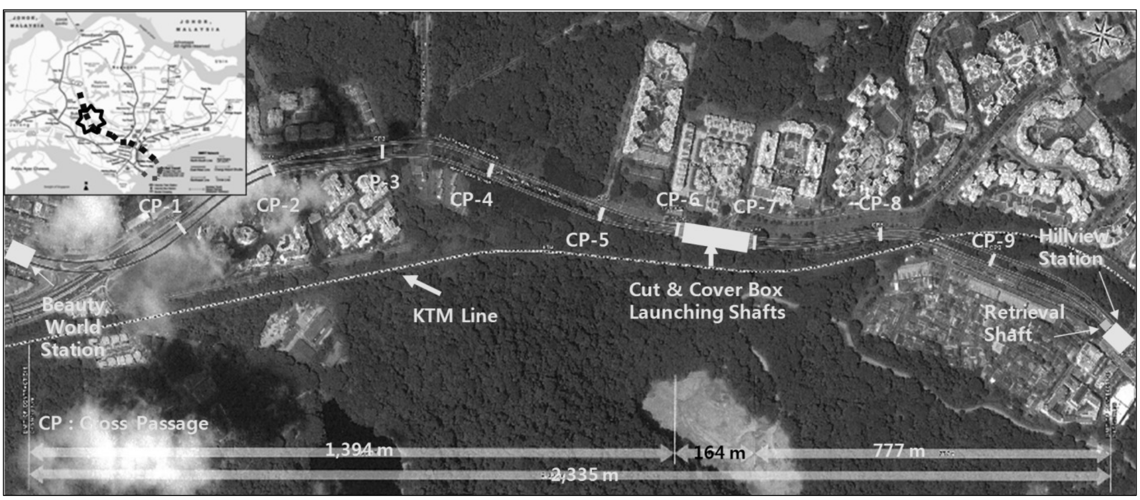


Fig. 1. Location of the DTL2 C915 site

of the DTL2 C915 construction site. Because the tunneling routes are located in typical mixed ground conditions, three slurry TBMs with very high capacity are used to overcome mixed ground problems.

Cut and cover structures at the C915 consist of 2 TBM launching shafts and a cut and cover box. Since cut and cover structures have thick Bukit Timah granite layer, lots of rock blasting work is required for rock excavation. Since construction-related blasting activities are not common in Singapore, rock blasting in urban area is regarded as a special and difficult construction activity. Most blasting works use conventional electric detonators and Ammonium Nitrate Fuel Oil (ANFO) as blasting agents, therefore blast performance and vibration control are unfavorable.

This paper presents a blasting method of multiple-deck blasts with electronic detonators and cartridge emulsion explosives to overcome construction constraints and show how the new method can improve blast performance in urban environment.

2. TBM Launching Shaft B

Figure 2 shows the plan view of the cut and cover Earth Retaining or Stabilizing Structure (ERSS) in C915 site. Cut and cover structures consist of Secant Bored Pile (SBP) wall, king post, diagonal strut, horizontal strut, and metro deck. The TBM launching shaft B is located in the left side of the Figure 2. The dimensions of TBM launching shaft B are 31.2 m (width) × 25.7 m (length) × 26.2 m (height).

Geological formation at the C915 site composed of residual soil and Bukit Timah granite. As shown in

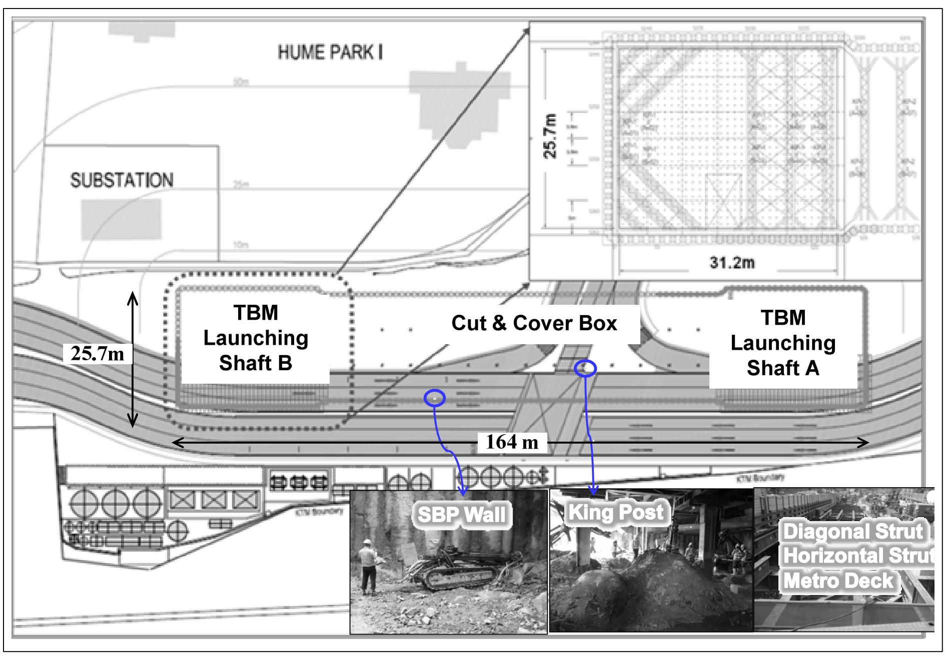
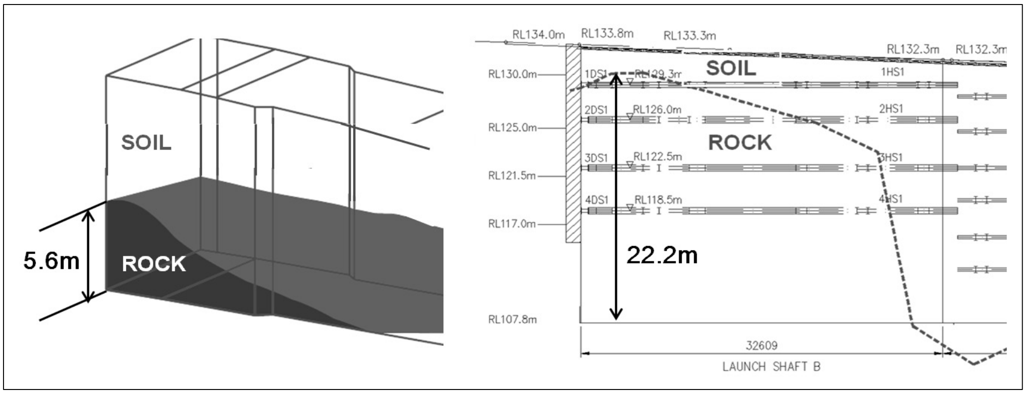


Fig. 2. Plan view of cut and cover structures at the C915 site



(a) Estimated rock cover at tender stage (b) Real rock cover after additional site investigation

Fig. 3. Rock cover thickness estimated at tender stage and after additional site investigation

Figure 3, launching shaft B has thick Bukit Timah granite layer with a uni-axial compressive strength of 200 MPa.

At the tender stage, the excavation rock volume of the TBM launching shaft B is estimated at about 10,504 cubic meters and the maximum rock thickness from the bottom was estimated to be about 5.6 m. However, the maximum rock thickness was found to be 22.2 m after additional site investigation during the construction.

3. Original Blast Design

The construction of cut and cover ERSS involves stages of excavation, mucking out and support (strutting). Excavation in rock was originally planned using electric detonator and ANFO, which are conventionally used in Singapore.

DTL2 C915 site has very strict blasting regulations. Only two blasts per day are allowed and allowable peak particle velocity is 30 cm/sec for the ERSS and 1.5 cm/sec for residential buildings. No explosives shall be kept or stored in any place at the blasting site. Also the required quantity of detonators and explosives should be ordered at least 2 days before since there is no magazine at the C915 site.

An original blast design involved the electric detonator and ANFO explosive consisting of 30 holes per one blast with 1.5 m depth of drilling hole to satisfy vibration limits. To minimize flyrock, soil covering with thickness of 2~3 m was suggested.

Figure 4 shows the layout of blasting area at the TBM launching shaft B. Excavation area of the TBM launching shaft B was divided into 24 sectors. The dimensions of one sector were 4 m (width) × 8 m (length). One strut level had the height of 4.5 m and the total TBM launching shaft B required 5 levels of strut. Since drilling length per round was 1.5 m, 3 steps were needed to excavate a depth of one strut level.

Since two blast-rounds per day are allowed, two sectors could be blasted. It would take 12 days to excavate the depth of one step and 36 days per one

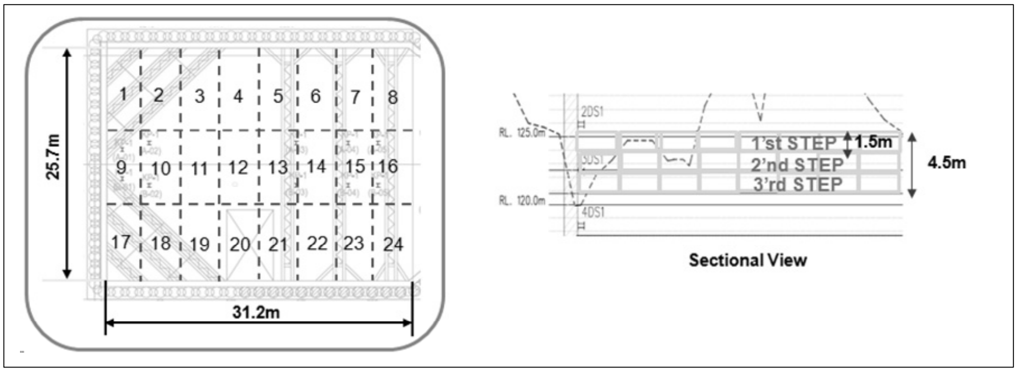


Fig. 4. Layout of blasting area at the TBM launching shaft B in the original blast design

strut level except for strutting time were needed. Considering 6 days of strutting time, a total of 42 days were required to excavate one strut level. Since a total of 5 strut levels existed in the TBM launching shaft B, 210 days were needed to excavate the whole volume.

Based on careful analysis with the above data and the whole construction schedule, delayed work progress was expected due to low blast performance. Shaft sinking activity is one of the critical paths to fulfill planned construction schedule because of highly mixed ground condition for tunneling. Thus, an efficient blast method which can improve blast performance and also satisfy vibration limit was required to overcome schedule constraint.

4. Revised Blast Design

The original blast design causes delayed work progress and it is hard to keep the construction schedule. It was concluded that rock blasting works would affect the delay of construction and subsequent tunneling works significantly. The following problems were found:

- Limitation of the number of electric detonators (maximum 30 detonators per blast) to satisfy vibration restriction
- Large ground vibration due to ANFO characteristics
- Less efficient work sequence in limited area

The following factors were considered in selecting the revised blast design to improve the above problems and blast performance.

- Delay periods and charge weight for one blast per day
- Maximum hole depth per one blast
- The number of decks for blasting efficiency
- Selection of detonators for precision blast
- Selection of explosives for vibration control
- Cover system to reduce flyrock
- Drilling rigs to improve efficiency

After considering the above factors, a revised blast design was proposed using multiple-deck blasts with electronic detonators and cartridge emulsion

Table 1 Advantages and disadvantages of each blasting design

Blasting design	Original blasting design	Revised blasting design
Advantages	Conventionally used method in Singapore	Increase in the number of blast holes per one blast Reduction of ground vibration Increase in blasting efficiency
Disadvantages	Limits in the number of blast holes per one blast (30 holes per one blast)	First time use in Singapore More costly (expensive)

explosives based on contemporary state-of-the-art of blasting technology.

In order to improve rock blasting efficiency, multiple-deck charge blasting method was suggested for increasing the number of holes and volume of shot rock per one blast. Also electronic detonator was chosen to increase efficiency of deck blasting by accurate control of the delaying.

As drilling length is increased with deck blasting, more powerful explosives are required to overcome rock confinement condition. Therefore, cartridge emulsion explosives were selected. Cartridge emulsion type explosive has higher strength and efficiency than ANFO and has the additional advantage of reducing ground vibration (Olofsson, 1988).

To minimize flyrock, soil covering with thickness of 2~3 m was suggested at initial stage. However, blasting mats consisting of Tatami (rice straw) mat and rubber tire mat were used to reduce time in covering works during the blasting cycle.

Table 1 shows the advantages and disadvantages of each blasting design.

4.1 Electronic detonator system

The most widely used explosives in construction site are dynamite, emulsion and ANFO. These explosives need detonator (blasting caps) to blast. There are three types of detonators according to firing methods: electric detonator, non-electric detonator and electronic detonator (Figure 5).

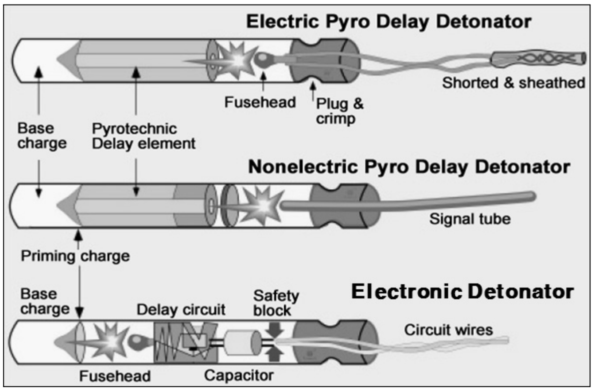


Fig. 5. Three types of detonators (After Miller & Martin, 2007)

Recently developed electronic detonators, having itself electronic chip and control device, can deliver a variety of benefits in accuracy and precision. The delay of an electronic detonator is controlled by a quartz clock within a central processing unit on the electronic chip. This allows an electronic detonator to fire as accurately as 0.01% of its nominated delay time (Miller & Martin, 2007). All other delay detonators employ pyrotechnic delay elements that depend on a burning powder train for their delay.

The introduction of electronic detonation revolutionizes rock blasting technique, making it possible

Table 2 Characteristics of electronic detonators

Detonator shell	Copper
System operating temperature	−20 ~ +50 degrees centigrade
Maximum delay	30,000ms
Step of programming	1 ms
Accuracy	0.01% (+/− 0.5 ms)
Maximum surface wire length	2.5 km

to overcome the problems with ground vibration and increase the number of blast holes per one blast (Persson et al., 1993). Table 2 summarizes the characteristics of an electronic detonator.

4.2 Multiple–deck charge blast

The revised blasting design is composed of triple–deck charge blasts with electronic detonators and cartridge emulsion explosives, and it is suggested for improving construction productivity and maintaining stability of retaining walls and support structures. A deck charge is an explosive charge separated by from the each charge by inert stemming. The drilling length per round was determined to be 4.5 m considering the height between struts and working spaces. The number of decks was selected to be 3

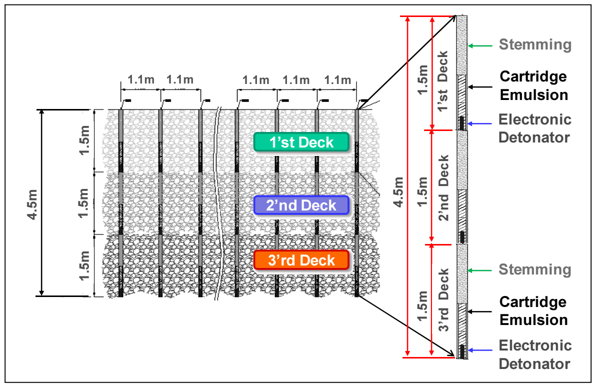


Fig. 6. Schematic illustration of triple–deck charge blasting pattern

based on test blasting results to satisfy vibration limits. Figure 6 shows the schematic illustration of triple–deck charge blasting pattern. The height of one deck was 1.5 m and the burden and spacing was set to be 1.1 m. The material of stemming was sand and aggregate. The charge weight of each deck was selected to be 0.8 kg. Three vertical decks are blasted sequentially in one blast round by very accurate control of delay with electronic detonator.

The number of blast holes was determined to be 233 for considering time in charging and installation of blasting mats. The cut and cover section were divided into 3 zones as shown in Figure 7 and each

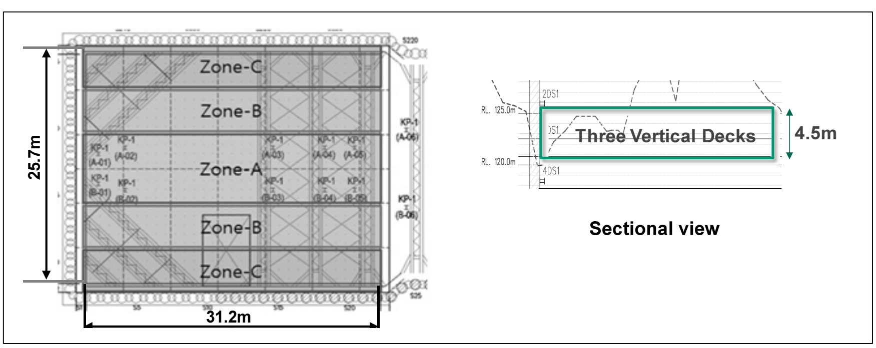


Fig. 7. Layout of blasting area at the TBM launching shaft B in the revised blast design

Table 3 Comparison of the original and revised blast design

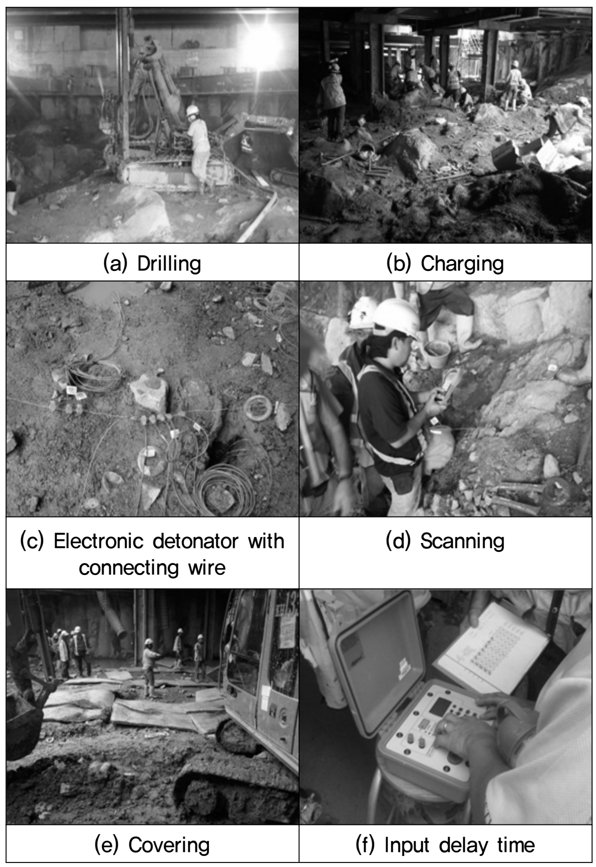
Blasting design		Original method	Revised method
Excavation	Area	24 m × 32 m	24 m × 32 m
	Depth	4.5 m	4.5 m
Drilling depth per round		1.5 m / step	4.5 m / step
Burden and spacing		1.1 m	1.1 m
Required sector		24	3
Total number of blast holes		2097 (699 ea × 3 steps)	699
Total number of detonators		2097 (699 ea × 3 steps)	2097 (699 ea × 3 decks)
Total drilling length		3145.5 m	3145.5 m
Max. number of blast holes per round		30	233
Max. number of detonators per round		30	699 (233ea × 3 decks)

zone was blasted alternately. Table 3 summarizes the comparison of the original and revised blast design. Figure 8 shows work sequences for triple-deck charge blast preparation.

4.3 Theoretical comparison of cycle time

In the revised blast design, cycle time was estimated to be 3 days per zone except for mucking and strutting time. As the whole blast area at the TBM launching shaft B consists of 3 zones, it would take 9 days to excavate one strut level depth. Considering 12 days of mucking and strutting time, 21 days were required to excavate one strut level. Since a total of 5 strut levels exist, 105 days were needed to excavate the whole TBM launching shaft B.

The revised blast method is able to reduce 21 days in excavation time for depth of 4.5 m at the TBM launching shaft B. If it is assumed that both blasting designs have the same mucking out time, the revised method can save about 105 days in the whole excavation of TBM launching shaft B with 5 strut levels.



(a) Drilling | (b) Charging | (c) Electronic detonator with connecting wire | (d) Scanning | (e) Covering | (f) Input delay time

Fig. 8. Work sequences for the revised blasting method at the TBM launching shaft B.

Table 4 Theoretical comparison of cycle time for a strut layer

Blasting design		Original method	Revised method
Total number of drilling holes		2,097 (699ea × 3 steps) ; 1.5 m	699 ea ; 4.5 m
Total blasting sector (zone)		72 (24 sectors × 3 steps)	3
Drilling length		1.5 m	4.5 m
1 Blast	Max. number of blast holes	30	233
	Drilling time	0.25 days	1.5 days
	Charging time	0.125 days	1.0 days
	Blasting time (including covering and ventilation time)	0.125 days	0.5 days
	Sum	0.5 days	3.0 days
Total	Blasting	36 days (0.5 days × 72 sectors)	9 days(3 days × 3 zones)
	Mucking		6 days
	Strutting	6 days	6 days
	Cycle time per a strut level	42 days	21 days

This construction site is subjected to restricted working and vibration regulations such as two blasts per one day only and strict vibration limits control. Such restrictions can make big difference in construction time when electronic detonators are used.

Also, soil covering method with thickness of 2~3 m was changed to blasting mats consisted of Tatami (rice straw) mat and rubber tire mat to reduce significant time in covering works.

Table 4 shows theoretical comparison of cycle time in each blast design to excavate rocks with depth of 4.5 m between two methods.

5. Conclusion

This paper presents a case study involving the application of revised blasting method to overcome low productivity and schedule constraint during the shaft sinking at DTL2 C915.

The revised blast design applied to the work can be summarized as follows;

1) In order to improve construction productivity under restrictive vibration regulations (two blasts per one day and strict vibration limits), triple-deck charge blasts with electronic detonators are proposed. The revised blast design can reduce 21 days in excavation time for a depth of 4.5 m at the TBM launching shaft B and save about 105 days in the whole excavation of TBM launching shaft B with 5 strut levels.
2) The drilling length is determined to 4.5 m based on the height between struts and working spaces. The number of decks is selected to be 3 through test blasting results.

3) As drilling length is increased with deck blasting, more powerful explosives are required to overcome rock confinement. So, cartridge emulsion explosives are selected instead of ANFO.
4) In order to prevent flyrock, soil covering with thickness of 2~3 m was initially considered. However, this was later changed to blasting mats consisting of Tatami (rice straw) and rubber tire mat to reduce time in covering works.

A lot of blasting works are anticipated for future MRTs, tunnel and cavern projects in Singapore. New and efficient blasting methodology should be applied to enhance the productivity of the blasting works. The method applied to C915 site can provide a good start pointing for such efforts.

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