Blasting in a Rail Protection Zone in Singapore

Filippos I. Manolas[a]* and ThamilArusu[a]

[a]*Asia Tunnelling& Construction Pte Ltd, Singapore*
* contact@asiatunnelling.com

Abstract

Tunnelling and underground infrastructures are increasingly in demand around the world nowadays to improve the transport network in densely populated and urban areas. This portends that construction sites will be placed near existing metro stations, highways, buildings etc. and therefore the strict tolerance limits of environmental impacts have to be observed.Very often, we encountered hard rock regions in the geology of the proposed area which requires rock removal by blasting. The Railway Protection Zone (RPZ) code classifies blasting operations as restricted, but can be performed successfully under controlled conditions.

In the Singapore MRT Project Downtown Line (DTL) Stage 2, Asia Tunnelling& Construction Pte Ltd (ATC P/L) was engaged by main contractors in several contracts to carry out blasting of the rock profile in the access shafts and the station boxes; one of them was partially inside the RPZ. This paper discusses the rock blasting process within the RPZ and evaluates the blast performance in the restricted area which was key in managing vibration levels and eliminating/minimizing fly rock incidents. Furthermore, this paper examines the risk management strategies of the blasting process and highlights the key success factors.

Keywords: Drill&Blast,Rail Protection Zone,Vibration, Fly rock, Singapore Downtown Line.

1. Introduction

The Singapore's Land Transport Master Plan (LTMP) outlines the plans for upgrading and nearly doubling the existing Mass Rapid Transit (MRT) network throughout the island, mainly going underground to make space for the valuable land surface for other high valued development. In 2014, Singapore already has five MRT lines under the Land Transport Authority (LTA), while just recently the construction of a new Thomson line was launched. The new Thomson Line will have 22 stations and 6 interchange stations which will be linked to the other five existing MRT lines and of which, three of these interchange stations lay within the Bukit Timah Granite formation. Extracting rock from its natural location is a difficult task which gets even more challenging when having to do so in a rail protective zone.

From geological approach the presence of hard rock is usually gladly welcomed by geotechnical engineers and geologists but the tasks become complicated when project sites are in close proximity with existing buildings, highways or in this case within the rail protected zone.

Rock blasting is restricted in Rail Protection Zones but the limited alternative choices for removing the rock (rock hacking and splitting, breaking rock with chemical means) are usually time consuming, costly or have insufficient results. Usually, the solution would be a combination of these methods, where possible, in which themajority of the rock is extracted with the Drill & Blast (D&B) method.

2. Rail Protection Zone

A Rail Protection Zone is defined by the Rapid Transit System Regulation (Railway Protection, Restricted Activities) as the part of the land or area which is within 40m from the outermost edge of any part of the railway that is on, above or below the ground.The RPZ area is then divided in sectors which are the 1st reserve line, 2nd reserve line and 3rd reserve line and refers to the areas which are within 6m, 20m and 40m respectively from the outermost edge of the railway (Fig.1). Furthermore, a Railway Safety Zone is outlined (usually 20m from the 3rd reserve line) to delineate the Railway Protection Zone. The use of explosive material for purpose of blasting, demolition or removal of rocks is not permitted within the RPZ.

However, in special cases LTA could allow blasting using explosives within the RPZ but only if certain conditions are complied. Summarized, these conditions include a detailed proposal for the blasting works including blast designs and calculations of induced vibrations, a vibration monitoring plan and precautionary measures and safety control including measures to prevent fly rock incidents.

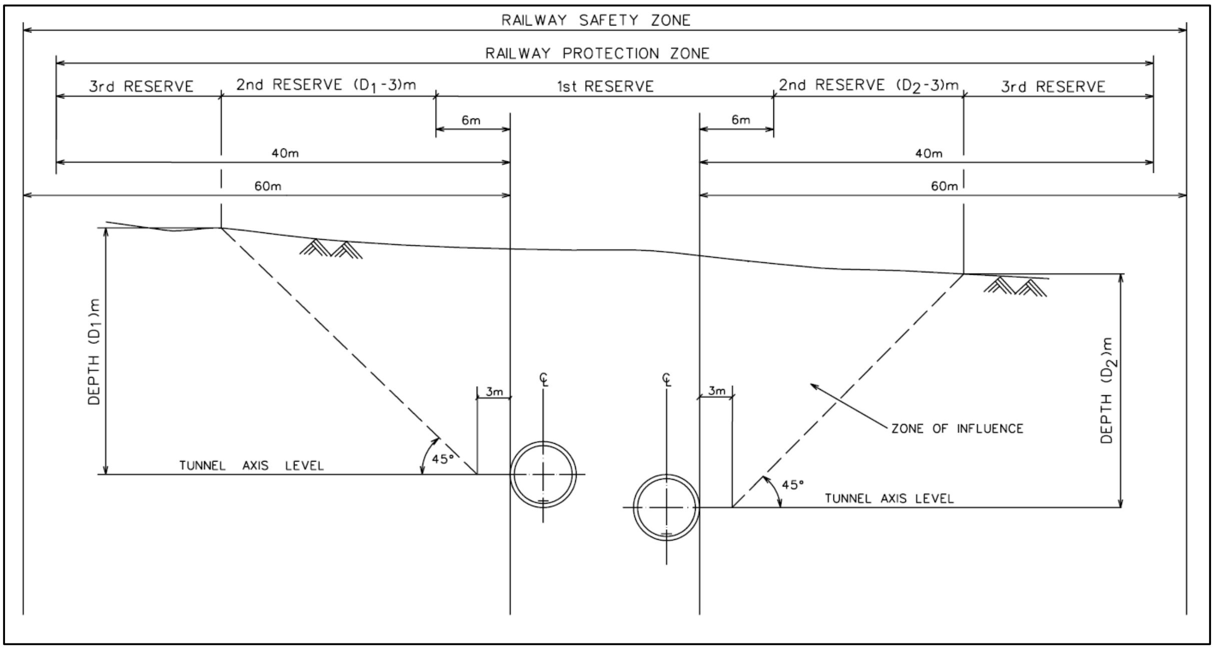

Figure 1. Definitions of reserve lines and zone of influence

3. Case study – Downtown Line C919 Botanic Gardens interchange station

The construction of the interchange station at the Botanic Gardens, Singapore (Contract 919) required the removal of approximately 30,000 m^3 of rock. The station excavation comprises excavation works in soil and rock until reaching the required formation level which is approximately 34m below surface level. Botanic Gardens Interchange Station is one of the 12 stations of the MRT Downtown line Stage 2 project and Sembawang Engineers and Constructors was appointed as the

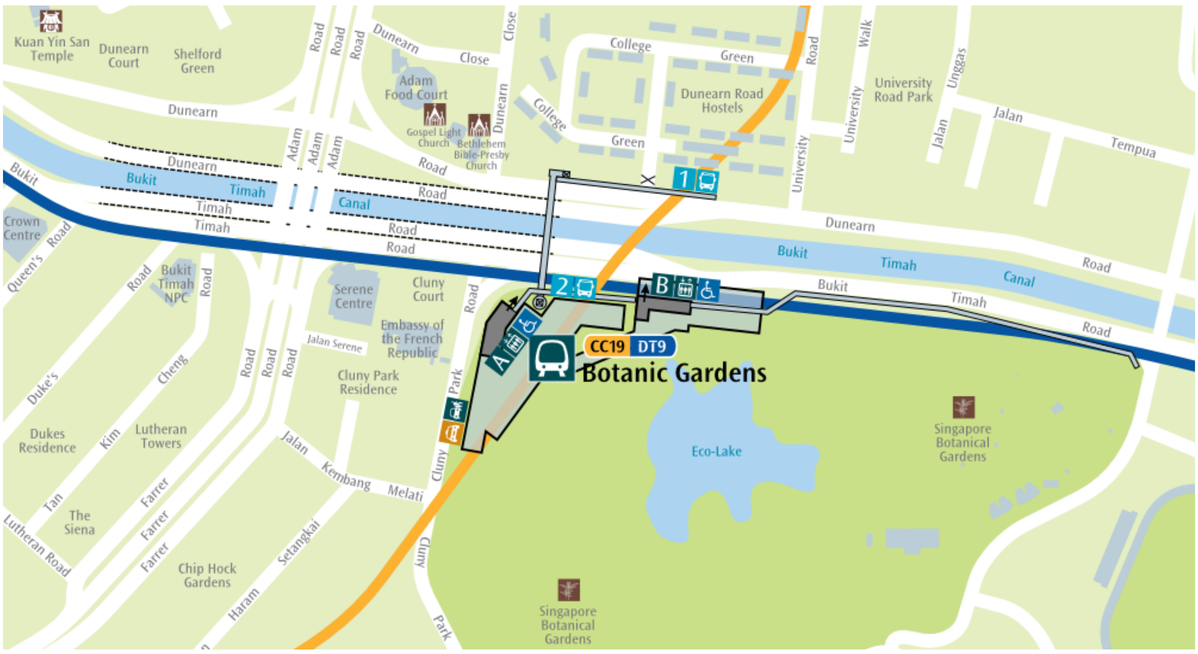

Fig.2. Botanic Gardens interchange station. The existing station (CC19) and tunnels (in yellow) together with the new station (DT9) and tunnels (in blue) can be seen.

Main Contractor.

Upon completion of the S5 strutting works which constitutes part of the Earth Retaining Stabilizing Structures (ERSS), bedrock which was already anticipated had to be extracted in order to advance lower tocomplete the station excavation works. The excavation had hit rock at a depth of 23m below the ground level and another 11m had to be excavated in order to reach the formation level. The challenge was to ensure the blast vibration level were kept below 15mm/sec which was a pre-requisite in an urban area where infrastructures and utilities were in close proximity to the project site. To add to the complexity and challenges of the task, the site was sitting parallel to a busy road (Bukit Timah Road), a canal on one side and the much visited touristic Botanic Gardens. Furthermore, the proposed station was being constructed just next to the existing Botanic Gardens Station (Circle Line). Most of the bedrock mass was within the RPZ from the existing MRT station and a few meters away from the active bored tunnels. In addition services such as gas pipes, telecom cables, electricity cables, sewer and water pipes were around the perimeter of the station box.

Blasting rock in such a sensitive area whilst maintain ground vibrations to a specified limit and ensuring public safety has its risks and challenges. The concerns about blast induced ground vibration and fly rock due to close proximity to the roads, the pedestrian side walk, the buildings and structures were a challenge that required extensive planning and design for a safe and efficient blasting operation. To top it all, the ERSS had to be taken into account as the diaphragm wall, kingpost and the struts that support the station box construction and the permanent concourse slabs that were already casted could not be subjected to extensive impact by the blasting works. In addition the blasting had to fragmentize the rock to a manageable size to muck without further secondary breaking with rock splitters which would delay the whole blasting cycle and the excavation in general.

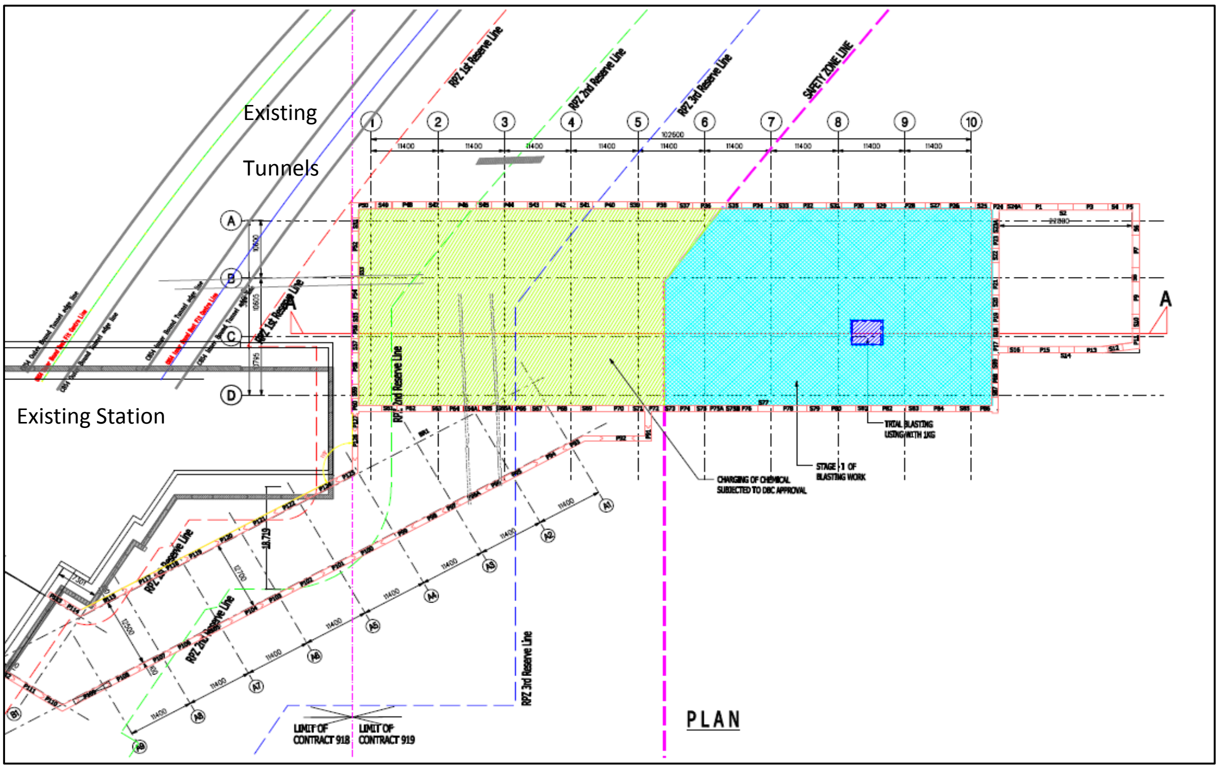

Fig. 3. Plan view of construction site and Rail Protection Zone Sections

4. Environmental hazards involved in blasting

4.1 Ground Vibration

With increasing mining and construction activities in areas close to human settlements, ground vibration has become a critical environmental issue as it can cause human annoyance and structural damage. Generally when blasting in urban areas is proposed as a rock removal method, ground vibration is the key element that raises the alarm from residents and tenants. Ground vibrations are an unavoidable environmental effect of urban blasting and may cause annoyance to residents of nearby buildings both directly and via generated structure-borne interior noise. Very strong ground vibrations may even cause structural damage to very close buildings or services located close to the blasting area.

Magnitudes of ground vibrations are usually described in terms of particle vibration velocity and are measured in mm/s.

The ground vibration measured at a location is influenced by a number of parameters. Some of them like blast geometry, charging patterns, initiation sequence, explosive characteristics and delay timing are controllable while others like rock properties, blast distance to the structure, geology surrounding the blast site are uncontrollable. The degree to which each of these parameters has influence on ground vibration,has to be established so that the blast design can be tailored to control ground vibration.

4.2 Fly rock

Fly rock is generally perceived as the rock propelled by the blast beyond the boundaries of the blast area. Flying rock generated by a blast is a very dangerous hazard which can result serious injuries or even fatalities to those being in the wider blasting area and certainly cause structural damages tofacilities, equipment and vehicles from the impact of the throw. It is very difficult to predict the amount of fly rock and the direction of the flying rock debris, therefore the risk has to be eliminated or minimized to a strict minimum to ensure the safety of the people around the blasting area. Blast protection system and Safety measures and techniques that will ensure the prevention of fly rock have to be strictly followed on site to avoid accidents or near miss incidents.

Basically, flyrock is caused by a mismatch of the explosive energy with the geo-mechanical strength of the rock mass surrounding the explosive charge. Factors responsible for this mismatch include abrupt decrease in rock resistance (geological faults, voids, fracture planes, etc.), high explosive concentration, inadequate delays between blastholes, inappropriate blast design, deviation of blast holes from its intended directions, insufficient burden and stemming and improper loading and firing practice.

Apart from the technical issues behind fly rock incidents, there are factors involved in causing injuries or damages due to lack of blast area security which are:

- failure to evacuate the blast area by employees and visitors
- failure to understand the instructions of the blaster or supervisors
- inadequate guarding of the access roads leading to the blast area, or the secured area
- taking shelter at an unsafe location, or inside a weak structure.

These accidents are preventable with good in-site regulations, training and communications.

5. Rock blasting proposal in RPZ

5.1 Sequence of works – Blasting operation procedure

Based on the location of the proposed blasting operation, which was within the critical Rail Protection Zone, a detailed blasting proposal had to be submitted to LTA and Development & Building Control (DBC) for approval before the rock excavation works could commence. The blasting proposal was divided into three phases.

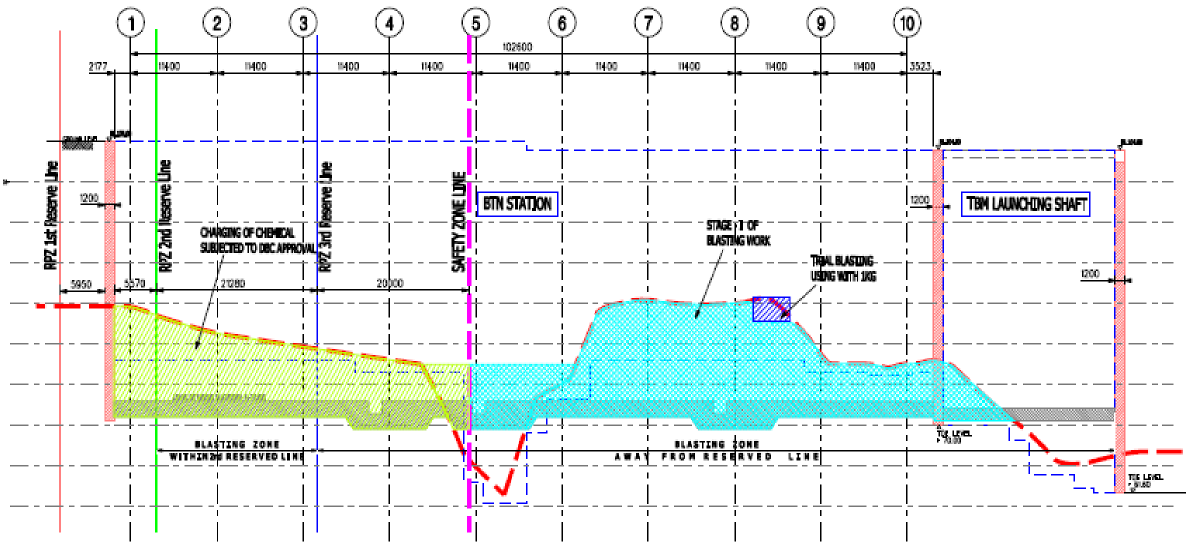

Figure 4. Section view of the proposed station were rockhead level is shown

Phase one was to start the removal of rock from the other end of the station box which was outside the RPZ using the drill and blast method and monitoring the vibration levels at the closest point of the Rail Protection Zone which was in the existing station. The operation would commence with a trial blast within the station but outside the RPZ to get some data of the vibration levels, if any, transferred to the existing bored tunnels and station as well as other locations close to the site. After receiving the seismographs data and while maintaining the vibration limit below 15mm/sec the blasting would continue until all rock outside the 60m Rail Safety Zone would be removed.Additionally, vibration would be closely monitored and if the PPV recordings would exceed the allowable level even before reaching the RPZ then all blasting operations would cease and rock splitting and hacking would take over the removal of the affected area. Vibrations readings within the Rail Safety Zone are shown in Table 2.

Phase two. All data from the trial blast and the subsequent blasts were compiled and compared with vibration data from other DTL 2 projects in similar rock conditions. This enabled the blasting engineers to develop a conservative blast design for 2nd and 3rd reserve areas only.The challenge was to ensure the vibration limits were not breached. An independent third party monitoring was undertaken over the period of the blasting within the existing station and all readings were kept within the stipulated 15mm/sec and are shown in Table 3.

Phase three involved the blasting of a small area but still within the 1st and 2nd reserve line. The permission for blasting was granted after a detailed blasting report and blasting design were submitted. Finally, the rock was removed from the proposed station using the drill and blast method without breaching the vibration limit. Table 4 shows the vibration readings from this area.

5.2 Influential parameters during blast design

Designing a blast requires understanding the site conditions, evaluating the post blast data and geology around the blast site together with reviewing all the controllable parameters in order to achieve a blast with the minimal possible ground vibration,good fragmentation taking into account the mucking equipment used due to the limited head room and acceptable rock profile.

5.2.1 Free face creation

It is known from the crater theory that, if a charge is deeply buried with no free face nearby, the rock is not adequately broken and most of the energy goes into the generation of seismic waves. When it is buried at shallow depth, the same charge may break the rock properly while producing lower ground vibration. In case of bench blasting which normally has one or more free faces, vibration should decrease as the number of free face increases. Free faces located at optimum distance from the blasthole enable the explosives energy to perform the greatest amount of work on the rock mass. Therefore, a blast will be more efficient if it has more than one free faces available.

5.2.2 Delay interval

The influence of delay interval between charges plays a significant role in rock blasting. The “ideal” delay between adjacent blastholeswould ensure that stress waves from each detonation interact positively with fractures produced by the adjacent charge that has fired at an earlier time, before the rock is dislodged, which plays a key role in ground vibration generated a generallyaccepted practise that the delay of 25 ms between blastholes initiation time will provide good fragmentation of the rock and generate lower vibration readings.

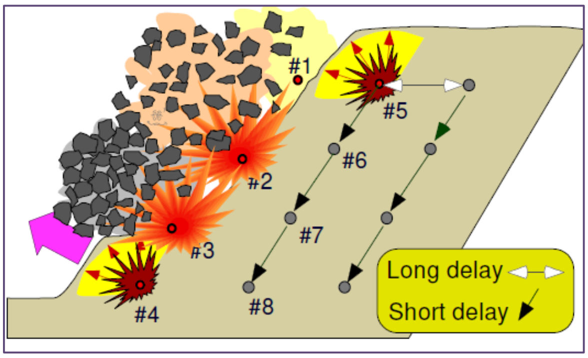

Fig.5 Blast holes detonating sequence

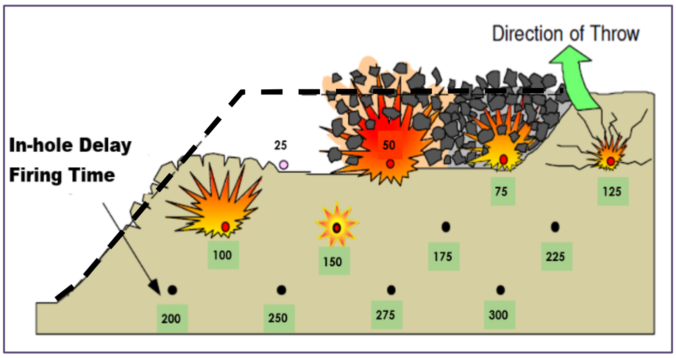

Fig.6Controlled blasting sequence with two free faces

5.2.3 Explosives types

It has been found that the type of explosives has significant influence on ground vibration. After several researches it is commonly agreed that explosives with lower detonation velocity will generate lower ground vibrations. As the shock energy component of an explosive gives rise to unwanted vibrations explosives having larger portion of gaseous energy should be preferred.

5.2.4 Maximum charge per delay

The total amount of explosives used in a blast has minor influence on ground vibration given that the charging pattern and delays are designed in such a way that the correct firing sequence will be achieved by avoiding having more than the desired charges firing in any given instant.

5.3 Blasting design and plan

In order to comply with the strict vibration limits the blasting design had to be strictly followed. The design initially was rather conservative to ensure that vibrations would be kept to a minimum until more data from the post blast about the ground parameters would be obtained. The strict control of charge weights and their initiation times were the top priority of the operation. Furthermore, the execution of the drilling pattern was critical as it had to follow in line with the design criteria on the drilled depths, spacing and burden. The blast direction was always directed away from the RPZ to release the explosives energy towards free faces and minimize the stress induced towards the restricted area. Additionally, there was a preference of choosing the next blasting area in order to exploit the use of the free faces created in previous blasts. The daily operation consisted of blasting areas with not more than 30 blast holes per round. The diameter of the blast holes was 64mm and the drilling pattern spacing was in the range of 1.2-1.4m.

Electric detonators were preferred as the blast area had to be backfilled with overburden which consisted of soil and blasted material. The electric system allowed the team to consistently monitor the circuit readings whilst the backfilling works were undertaken and preventing wire cuts while covering the area and eventually minimizing the possibility of misfires. The maximum charge per delay was kept below 2.0 kg per blast and in some occasions it was as low as 1.0 kg. The explosive column was consisted of packaged emulsion primers and mainly ANFO to use the gaseous energy created by the bulk explosives. So, in addition with the small number of blastholes used per round the vibration readings were expected to be low. The drilling depth was optimized for every blast operation depending on the location of the blast. The depth would range from 2.7m to 1.5m. The powder factor would be in the range of 0.4 to 0.5 kg/m^3. Last but not least, line drilling was carried out around king posts and close to the ERSS structure to absorb the energy generated by the blast.

Table 1. Blasting design details used in C919 project site

Blast design information	Location		
	Outside RPZ	Within RPZ 3rd reserve	Within RPZ 2nd reserve
No blastholes	25-30	18-25	15-20
Diameter	64mm	64mm	64mm
Spacing	1.3-1.4m	1.3-1.4m	1.2-1.4m
Depth	2.7m	2.7m	1.5-2.0m
Max Charge/delay	2.0kg	2.0kg	1.0-1.4kg
Blast Volume	100-140m^3	80-100m^3	30-35m^3
Powder factor	0.45	0.45	0.45-0.5

Table 2. Details of the blast operations within the Railway Safety Zone and PPV readings within the existing station

Blast No	Location Grid Lines	Number of blastholes	Max charge per delay (kg)	PPV readings (mm/sec)	
				VMB001	VMB002
1	3-4 / B-C	12	2.0	BTV	BTV
2	4-5 / A-B	28	2.0	BTV	BTV
3	4-5 / B-C	15	2.0	BTV	BTV
4	3-4 / C-D	20	2.0	BTV	BTV
11	4-5 / C-D	20	2.0	BTV	BTV

13	4-5 / A-B	25	2.0	BTV	BTV
14	4-5 / C-D	15	2.0	BTV	BTV
15	3-4 / B-C	25	1.65	BTV	BTV
16	4-5 / B-C	20	1.85	BTV	BTV
17	3-4 / C-D	25	1.3	BTV	BTV

*BTV stands for "Below Trigger Value" which was 5mm/sec

Table 3. Details of the blast operations between the 2nd and 3rd reserve lines in the RPZ and PPV readings within the existing station

Blast No	Location Grid Lines	Number of blastholes	Max charge per delay (kg)	PPV readings (mm/sec)	
				VMB001	VMB002
5	2-3 / A-B	13	2.0	BTV	BTV
6	3-4 / A-B	27	2.0	BTV	BTV
7	2-3 / C-D	17	2.0	BTV	BTV
8	3-4 / A-B	26	2.0	BTV	BTV
9	3-4 / A-B	23	2.0	BTV	BTV
10	2-3 / B-C	24	2.0	BTV	7.52
12	3-4 / A-B	30	1.85	BTV	BTV
18	1-2 / B-C	25	2.0	BTV	5.33
21	3-4 / B-C	13	1.0	BTV	BTV
24	2-3 / B-C	28	1.0	BTV	BTV
27	2-3 / A-B	30	1.0	BTV	BTV
28	2-3 / B-C	30	1.0	BTV	BTV

* BTV stands for "Below Trigger Value" which was 5mm/sec

Table 4. Details of the blast operations between the 1st and 2nd reserve lines in the RPZ and PPV readings within the existing station

Blast No	Location Grid Lines	Number of blastholes	Max charge per delay (kg)	PPV readings (mm/sec)	
				VMB001	VMB002
19	1-2 / A-B	14	1.0	BTV	BTV
20	2-3 / B-C	12	0.3	BTV	BTV
22	1-2 / A-B	20	2.0	BTV	BTV
23	1-2 / B-C	12	0.3	BTV	BTV
25	1-2 / C-D	22	1.4	BTV	BTV
26	1-2 / C-D	10	1.4	BTV	BTV
23	1-2 / A-B	14	1.0	BTV	BTV

* BTV stands for "Below Trigger Value" which was 5mm/sec

5.4 Line drilling – relief holes

The logic behind the line drilling – relief holes is to create a strip of a "non-effected by the blast" zone. The drill holes will remain empty to act as a vacuum of the energy created by the blast and minimize the impact of blast on the structures behind them. This technique has been carried out successfully in other blasting projects and was adopted to help maintain the vibrations levels to a strict minimum. To achieve the desirable results drill holes (Ø64mm) were drilled approximately 800mm away from the structures (Kingposts, diaphragm wall, etc.) and the depth of the holes were 10-15% deeper than the blast holes.

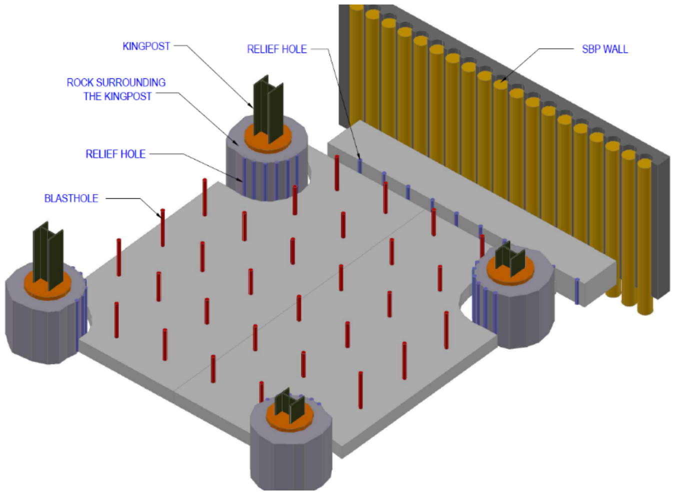

Fig. 7 3D view of blast area

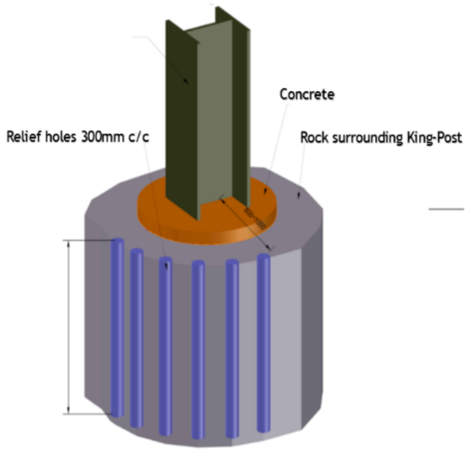

Fig.8 Line drilling next to structures

5.5 Fly rock prevention

One of the proven method in fly-rock prevention is by covering the blast area with an overburden of soil/excavated material. This is a common practice in Singapore and has been extensively practiced in most construction blasting projects. The overburden (1.5m – 1.8m) buries the blast area and holds the blasted rock at its original position. As an additional measure, the overburden is further covered with rubber mats and geo-textile material to ensure that even smaller particles/fragments will not be scattered out from the blast area. As safety precaution measures demand, the blasting area is thoroughly evacuated ensuring that nobody is close to the blasting area at firing time. Monitoring of fly-rock is usually done by recording the blast with a video camera.

6. Ground vibration monitoring

To collect and analyze the blast vibration data, three blasting seismographs and analysis software were acquired to monitor the vibrations within the station box proximity and two seismographs were mounted in the existing station to monitor any vibrations caused by the blasting operation. The trigger level was 2.5mm/sec for the seismographs within the station box and 5mm/sec for the seismographs mounted on the existing station walls.

7. Expectations and results

The blasting operations within the under-construction station box had started from the opposite end of the rail protection zone and gradually came closer to the rail safety zone limit. Based on the blast vibration data gathered whilst working outside the influence zone, the blasting engineers were

Fig.9. Overburden backfilling at blasting area

confident to work within the RPZ. The seismographs mounted within the station under construction recorded readings within the acceptable limits which were 150mm/sec for the ERSS and the monitors installed within the existing station did not trigger throughout all the blasting operations outside the RPZ.

Once the permit was granted to blast in the 3rd reserved area a more conservative approach was adopted which resulted in completing the works successfully. Though the blast area was limited to not more than 30 blast holes, it did not hamper the progress too much, as two to three blast areas were fired in a working day.Finally, to tackle the critical area of the 2nd reserved area (14-18m proximity to the adjacent station) the charge weight per delay was further reduced to 1.0-1.4kg. The drill spacing and burden was also reduced. This mitigation measures were carried out to ensure the authorities that the rock blasting works can encroach even closer provided the adequate counter measures in place. Two rows of relief hole drilling were carried out close to the diaphragm wall as one of the mitigation measures. Throughout the duration of the blasting works within the RPZ only two recordings were registered at the adjacent station (5.33mm/sec and 7.52mm/sec) after blasting 15 times within the 2nd and 3rd reserve limit. The excavation of the station box was completed within schedule and fly rock incidents were minimized to zero.

8. Conclusions/Discussion

Blasting in sensitive areas such as a rail protective zone is a difficult and very demanding task which hides risks and requires good preparation and planning. The factors that affect/influence/determine the outcome of the blasting works in terms of vibrations are highly related with the geological environment and the site conditions of each project.However, blasting in such areas is possible, given that data and information of blasting activities in the same areas are available and based on them the design and approach is detailed, well-studied and organized. Controlling the weight per delay and ensuring the drilling pattern is followed as best as possible is part of an approach which could be improved by using a more safe and precise detonating system. A great asset was the possibility of blasting close to the RPZ and receiving data next to the sensitive area. Improvements in blast efficiency and ground movement minimization was achieved by strict monitoring and active collaboration of all parties involved on site. Proper planning and stringent safety control measures ensured that the controlled blasting works were completed without imposing any danger damage to the nearby rail protective zone.

Following the successful completion of this Drill & Blast works mentioned in the case study for the DTL C919 project, some of the lessons or conclusions may be summarized as follows:

- The data received from previous projects with similar rock conditions close to the proposed site were crucial to evaluate the rock response from the blasts and the vibration generated and played a key role in the blast designing.
- Blasting operations in RPZ can be undertaken, provided a well prepared blast design and blast safety system is adopted. Data and information from prevailing blasting projects in similar rock conditions were beneficial to understand the ground vibration characteristics.
- The possibility of blasting just outside the RPZ area, which was critical to understand the ground vibration effects, resulted in preparing a well suited blast design for the actual ground conditions encountered within the RPZ.
- The ground vibration monitoring plan was instrumental in providing the blast engineers with information on each blast design.
- In order for the blast design to be successful, the blasting crew had exercise due diligence and professionalism in ensuring the blast design process is followed in relation to the maximum allowable charge weight and drilling pattern.
- Though extensive relief hole drilling works were undertaken along the perimeter of the kingposts and diaphragm wall, it played a key factor in ensuring minimal stress was induced on the structures.
- Trials are imperative to determine the K values (site constant), which is always a subject of great discussion. Avoiding trials can result in lost time and longer cycles for blasting.
- Free face blasting or blasting towards an un-mucked blasted zone has a great influence on the vibration as well.
- With experience dealing in such ground conditions and with the availability of a more precise electronic initiating system, future projects of similar nature can be handled with even more safe and efficient blasts with improved productivity and better assurance on ground vibration control.

Acknowledgements

C919 LTA team

Sembawang Engineers and ConstructorsPte Ltd

References

Egan, J., Kermode, J., Skyrman, M. & Turner, L. “Ground vibration monitoring for construction blasting in urban areas”, CALTRANS, Apr. 2001.

Harries, C. and Gribble, D.P. (1993) The development of low shock energy explosive ANRUB, Proc. 4th Int. Symp. Rock Fragmentation By Blasting, Vienna. pp. 379-386.

Hossaini, S.M.F. and Sen, G.C. (2004) Effect of explosive type on particle velocity criteria in ground vibration, The Journal of Explosive Engineering, July/August, pp. 34-39.

Hossaini, S.M.F. and Sen, G.C. (2006) Ground vibrations arising from using two different types of explosives – Acomparative study, Coal Operators’ Conference.

Hunter, C., Fedak, K. and Todoeschuck, J.P. (1993) Development of low density explosives with wall control applications, Proc.19th Annual Conf. Explosives and Blasting Techniques, Jan, 31-Feb. 4, San Diego, California, USA, ISEE, pp. 549-555.

Land Transport Authority of Singapore. Code of Practice for Railway Protection. October 2004 edition

Land Transport Authority of Singapore. Guide to Carrying Out Restricted Activities within Railway Protection and Safety Zones. May 2009 edition.

Lopez Jimeno, E., Lopez Jimino, C., Ayala Carcedo. Land vibrations, air blast and their control. Drilling and blasting of rocks, Geomining Technological Institute of Spain.

Manolas, F.I. &Arusu, T. Blasting works in Urban Areas – A Singapore Case Study. November 5, 2012, Fragblast12.

Rapid Transit Systems Act (Chapter 263A, Section 42) “Rapid Transit Systems (development and Building Works in Railway Corridor and Railway Protection Zone) Regulations”. Original Enactment: Act 29 of 1995, Revised Edition 2004.

Rehak, T.R., Bajpayee, T. S.,Mowrey,G. L. and Ingram, D. K.,Flyrock issues in blasting. Article in The National Institute for Occupational Safety and Health

http://www.lta.gov.sg.