Electronic detonators and the Gautrain rapid rail project

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Abstract

The Gautrain rapid rail link project is currently Africa's largest infrastructure project connecting South Africa's major airport (or Tambo), Johannesburg and Pretoria. Phase 1 is planned for completion in time for the 2010 FIFA Soccer World Cup and involves 80 km of track and 15 km of underground tunnels. The key blasting issues revolve around maximising advance and improving blasting cycles to meet the tight deadlines as well as environmental control in tunnel blasting which, in some cases takes place only 15 m below the city infrastructure.

To achieve success, DetNet South Africa supplied a range of electronic detonator systems to cater for the different blasting applications involved (tunnels, portals, shafts and viaduct foundations). One such product, QuickShot, was used for the first time in a major civil engineering project and has been used for every tunnel blast to date since.

The QuickShot system combines pre-programmed electronic detonators with special on-face components that enable the user to quickly and easily design the firing sequence solely by using the order of connections. This precludes the user from having to deal in absolute delay times. The connecting system enables faces to be hooked-up speedily by multiple users who have differing levels of experience.

This paper provides details of how, after 26 months, the system has been embraced by the project by aiding in maximised advances, improved cycle times and meeting the required environmental constraints.

1 Introduction

The Gautrain rapid rail link project started in September 2006. The Bombela Concession Company is a consortia of companies tasked to carry out the work. African Explosives Limited (AEL) was awarded the contract to supply the explosives. The strict requirements in terms of this project were that an initiation system that was safe, reliable, user friendly, able to minimise air blast and vibrations should be used. After a lengthy analysis process where all the various factors were taken into account, it was decided that this project would make use of electronic detonator initiating systems supplied by DetNet South Africa, a joint venture between AEL and Dyno Nobel.

Based on the construction schedule for the project, the consumption of the electronic detonators is between 15,000 to 20,000 detonators per month. Depending on the size of the tunnel a typical end takes anything between 100 and 150 detonators in one blast whether it's a 3.5 m or 5.8 m advance. One particular tunnel has regularly achieved a clean advance of 5.8 m per round over a 2 km section with dimensions of 11 m wide and 7 m high.

Tunnelling is taking place through complex deformed geology. This geology is made up of granite, with all degrees of weathering from soft to sound rock containing some intrusions of diabase (diorite) and heterogeneous ground composed alternatively of quartzite, siltstone and shales in various degrees of weathering, with water circulation.

The planned 15 kms of underground tunnels are making use of drill and blast techniques, except for a 2.8 km stretch of tunnel which is using a tunnel boring machine (TBM) to excavate soil in an area where there is a very shallow water table requiring work to be done in extremely wet conditions most of the time. There are a total of seven emergency shafts with diameters varying from 10–12 m and depths between 35–60 m deep. These are being constructed by means of drill and blast shaft sinking techniques. Two train stations, namely Sandton North and South, are also being constructed using drill and blast shaft sinking techniques with dimensions; 60 x 20 x 45 m deep and 20 x 18 x 48 m deep respectively.

Figure 1 illustrates the tunnelling lengths and in which direction they are being constructed using drill and blast methods, as well as the section where the TBM is being used. There are a total of seven emergency shafts (E1–E7) which are being sunk. The entire section of tunnels as seen above from Park Station to Sandton Station will accommodate a single for the passage of one train at a time. Single track tunnel dimensions are 7 x 8m.

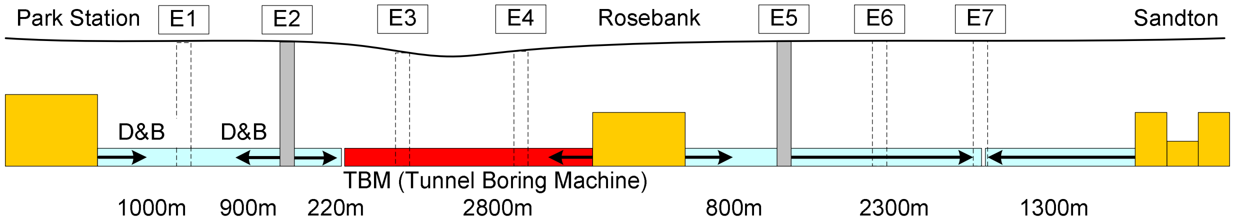


Figure 1 Single track tunnelling lengths

Figure 2 illustrates the tunnelling lengths and in which direction the double track tunnels are being constructed. The double track tunnels will accommodate two trains at the same time. This is being constructed from Sandton Station through to a portal called Marlboro where the train will surface. A shaft called Mushroom Shaft (dimensions 11 x 22 m and 32 m deep) was sunk to lower equipment and personnel to allow for drill and blast operations in the direction of the Sandton Station and Marlboro Portal. Double track tunnel dimensions are 11 x 7m.

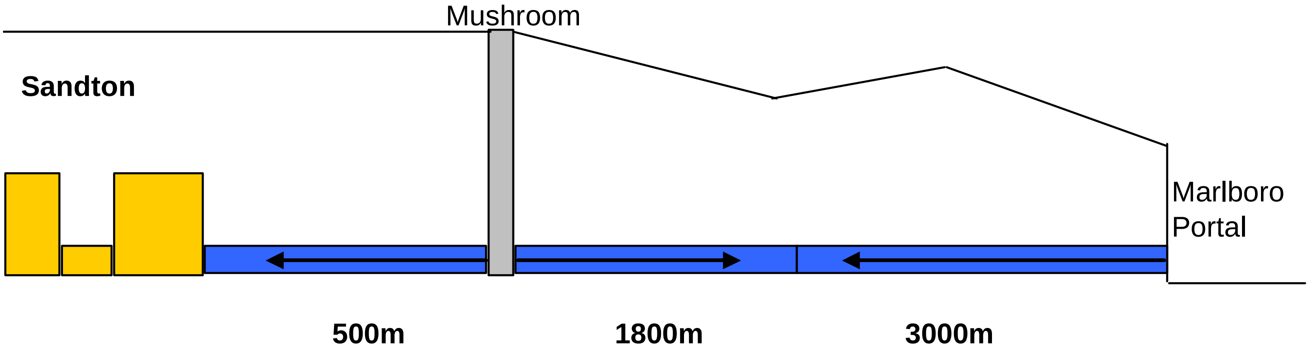


Figure 2 Double track tunnelling lengths

2 Tunnelling

The products used in the tunnelling application include an AEL pumpable underground bulk explosive, R100G, cartridge emulsion explosives and the QuickShot electronic detonator initiating system.

2.1.1 QuickShot electronic detonator initiating system

The QuickShot system is a pre-programmed electronic initiation plug and shoot system with centralised blasting capability. The system offers a daisy chain type of hook up. Each detonator has two plugs on it, a male and female plug where the male plug mates with the next detonators female plug. In its simplest form, users merely connect QuickShot detonators in the order in which they want the round to fire. A fly lead provides the means to connect the detonators to the control equipment. The first detonator connected to the fly lead will be the first to initiate. QuickShot can be used as a stand-alone system or as part of a centralised blasting network. The system allows for continuous testing of the installation using inherently safe control equipment.

Figure 3 The QuickShot detonator

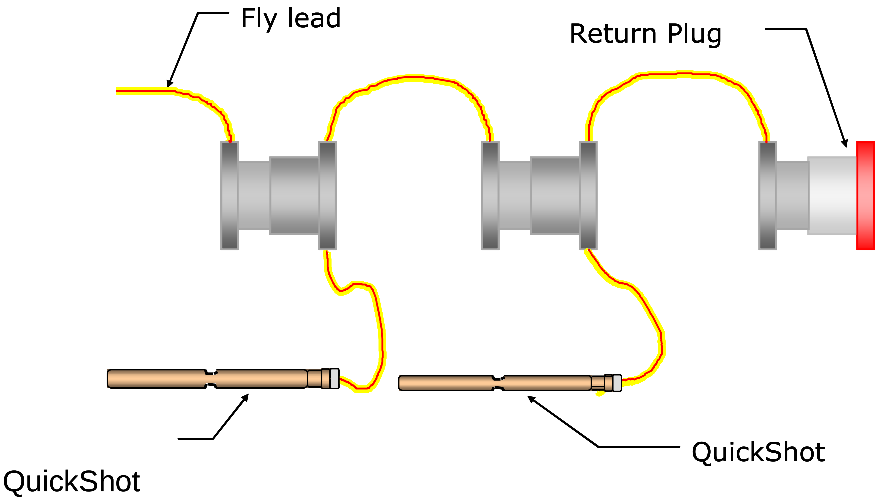


Figure 4 The QuickShot detonator daisy chain connection with a return plug connected which informs the system that it is the last detonator in the chain

Figure 5 The QuickShot accessories from left to right: QuickShot splitter; QuickShot pause marker; and QuickShot delay marker

The QuickShot detonators are all pre-programmed with a factory default delay of 125 ms. The system contains a number of accessories that allow for some inter-hole delay flexibility when required. These accessories are known as splitters, pause and delay markers. The QuickShot splitter is a hardware device which allows the signal to be split from one into two. The QuickShot pause marker is a non explosive hardware device. When placed in series with a QuickShot detonator it delays the signal from the previous detonator to the next in line by a delay which the user can define using a handheld device. The QuickShot delay marker is also a non explosive hardware device. When placed in series with a QuickShot detonator, it will change the factory default timing of 125 ms to the defined timing delay as determined by the user.

2.1.2 Tunnel designs

Major factors influencing the tunnel design are: the required wall finish; type of roof support; type of lining material; rock types encountered; drilling; charging; loading equipment; ventilation; skills and experience of labour; and other local constraints such as proximity of structures or the presence of excessive ground water.

The equations found in this section of the paper are based on Tose (2003) AEL's tunnel blasting handbook which are used as a reference for the Gautrain project. The grid size is initially estimated from the diameter of the blastholes, explosives type and rock hardness. The amount of emulsion varies between 300–1000 kg per blast. Normally equal hole spacing in both vertical and horizontal directions is assumed, and the following equation is used as a rough guide:

$$G = \sqrt{\frac{Mc}{k}} \tag{1}$$

where:

G = grid spacing (m).

Mc = mass per metre run of explosives (kg/m).

K = nominal grid powder factor.

K varies from 3.0 kg/m^3 for hard rock to 1.2 kg/m^3 for weak rock.

One of the most important blast design parameters for the project is to control vibration and airblast generated by blasting activities due to the proximity of homes, offices and other crucial city infrastructure.

This is done by adopting the following guidelines based on the recommendations published by the office of surface mining (formerly the US Bureau of Mines (USBM)), to determine the potential risk to structures (equation for vibration control in absence of monitoring equipment):

$$\frac{D}{\sqrt{E}} \geq 31 \tag{2}$$

where:

D = distance from blast (m).

E = mass of explosives per delay (kg).

Table 1 **Vibration limits**

Blasting Situation	Recommended Maximum Level (mm/s)
Heavily reinforced concrete structures	120
Property owned by the concern performing blasting operations where minor plaster cracks are acceptable	84
Private property in reasonable repair where public concern is not an important consideration	50
Private property if public concern is to be taken into account or if blasting is conducted on a regular and frequent basis	10

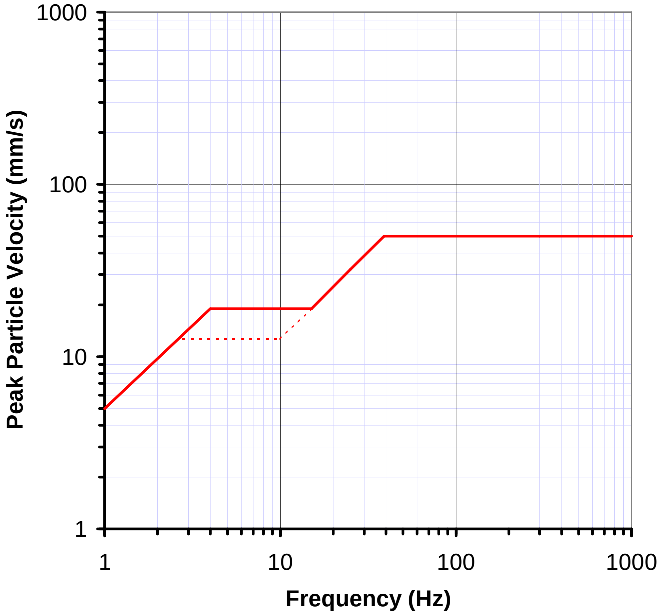


Figure 6 **USBM damage criteria, based on frequency. Peak particle velocity (PPV) (mm/s) limits = frequency (f) (Hz); logarithmic scale**

Tose (2007) states that for frequencies higher than 50 Hz recommendations are made which are based on the USBM limits as shown in Table 1. For lower frequencies these limits are reduced as shown in the graph in Figure 6. In order to determine the mass of explosives per delay at this limit, for the initial blast design, Equation 2 is used. The control that is required is determined by the mass of explosives detonating in a measured time interval. This is called a delay.

The magnitude of the ground vibration motion depends on the following:

- The maximum mass of explosives detonated within a particular time interval (E).
- The distance between the blast and the monitoring location (D).
- The direction of direct energy propagation.
- The geological structure of the rock mass.
- The blasthole pattern, timing and sequence.

The maximum upper vibration limit tolerated for the project is 25 mm/s but an average of 12 mm/s has been achieved for the past 26 months.

The tunnels for this project use the smooth blasting technique, where decoupled perimeter holes are drilled on a closer pattern than the fully charged holes. These are initiated last to maximise relief of burden and thereby reduce over break. The perimeter holes are also timed to not initiate instantaneously and a 26 ms delay is commonly used between holes in the perimeter. In conditions where there is weak or fractured geology, the charge is reduced in the perimeter easer holes. At the start of the project AEL Energex barrel charges were used in the perimeter holes. After initial trials using R100G emulsion and decoupling the explosives with the aid of plastic sleeving, which showed excellent results, it was decided to only use emulsion in the entire tunnel round.

The optimal burden and spacing for the perimeter holes is determined from trials using the equations:

$$B \times S = \frac{Mh}{k} \tag{3}$$

and

$$Dc = L \times \frac{Mc}{Mh} \tag{4}$$

where:

B, S = burden and spacing of holes (m).

Mc = mass of explosive per metre charge length (kg/m).

Mh = effective mass of explosive per metre length of hole (kg/m).

Dc = centre to centre distance between cartridges (m).

L = cartridge length (m).

K = powder factor (kg/m^3) 0.50–0.75 kg/m^3 for tunnelling.

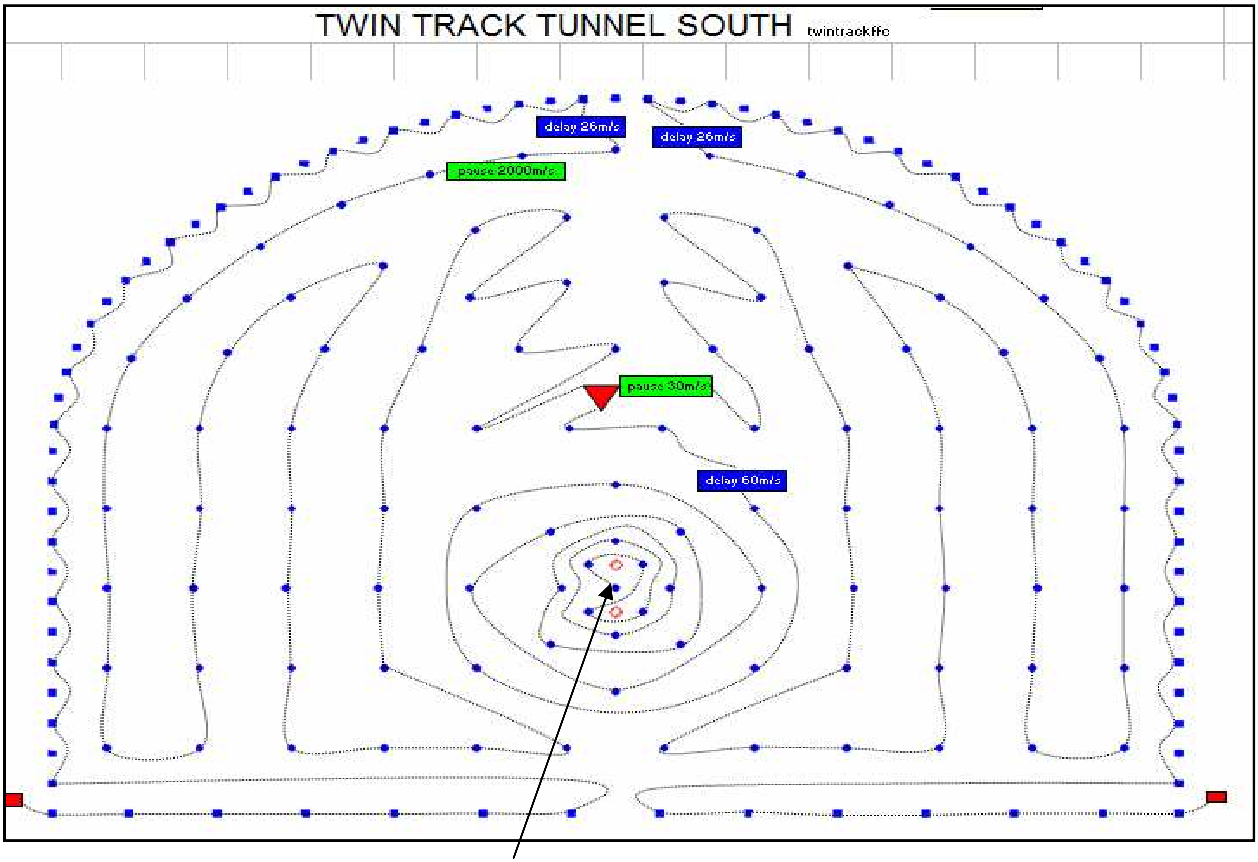
The holes are mechanically drilled with extreme accuracy and the hole diameters used are either 45 or 48 mm in size. The ream holes are drilled to 127 mm in diameter. Drilling is closely monitored and has been identified as one of the critical factors to determine whether a blast has been successful in achieving the required results. In the initial phases of the project, conservative drilling rounds were used but were later optimised through trial and error to allow for fewer holes to be drilled without compromising the rock breaking performance; this was largely due to the flexibility and accuracy which the electronic detonators allowed in timing the rounds.

Blasting cycles would vary depending on the geology of the rock, equipment breakdowns and other unforseen problems, but an average cycle of 15 hours is currently being achieved. The breakdown of the cycle time is as follows:

- Five hours for mucking the face.
- One hour for scaling.
- One hour to profile and map the round.
- Five hours to drill the round and all tunnel support.
- One and a half hours to charge the round.
- One hour to connect and time the round.
- A half an hour waiting period after the blast.

Progress is steady and an average advance of 35 m per six day week is being achieved.

A typical twin track tunnel design is shown in Figure 7. Starting at the initiating point, a 125 ms inter-hole delay increment is used until the sequence reaches the first delay marker where the inter-hole delay is changed to 60 ms. At the splitter (red triangle) the firing signal is split. On the right hand side of the blast a 30 ms pause marker is placed to ensure single hole firing between detonators, firing continues until another delay marker is reached at the perimeter holes where the inter-hole delay is changed to 26 ms to ensure that the perimeter holes are fired faster than the production holes whilst the easers are fired last. There is a 2000 ms pause marker on the left hand side of the blast to allow the right hand side perimeter and easer holes to fire first to minimise vibration and airblast levels.



Initiating point

Figure 7 A twin track tunnel design and connection method using the QuickShot system

Conclusions

The project was completed in 26 months and the QuickShot initiation system was proven to be successful with features such as inter-hole flexibility; pre-blast testing of all detonators; immunity to electromagnetic radiation and stray currents; and improved blast cycles due to better advance, fragmentation and cleaning cycles. Civil engineering tunnels are of no value until they are completed, so a rapid rate of advance was a major goal. The success of the project is due to a combination of knowledge, application and the use of a product that was robust for the conditions. Electronic timing delivers control and hence predictability of blasting results.

Acknowledgements

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