SHAFT SINKING WITH ELECTRONIC DETONATORS AT THE GAUTRAIN RAPID RAIL PROJECT

C G Goncalves
DetNet South Africa (Pty) Ltd, South Africa

S J Tose
African Explosives Limited, South Africa

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 one 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 shaft sinking blasting issues revolve around maximising advance and improving blasting cycles to meet the tight deadlines as well as environmental control which, in some cases takes place only 15m from 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 in most of the shaft sinking blasts to date.

The QuickShot system combines pre-programmed electronic detonators with special on-bench 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 benches to be hooked-up speedily by multiple users who have differing levels of experience.

This paper provides details of how, after 33 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 consortium of companies who were 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, was an initiation system that was safe, reliable, user friendly and able to minimise air blast and vibrations. 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.

There are a total of seven emergency shafts with diameters varying from 10–12 m and depths between 17–72 m deep. The traditional top-down (blind sink) shaft sinking method involves making a hole in the ground which is progressively deepened and lined until the required shaft depth is reached. This technique has been employed on six of the seven emergency access shafts in the underground section of the Gautrain Project.

Shaft E6 is the only shaft being constructed using the raise boring method due to underground access already being available to the position at the bottom of the proposed shaft. A small-diameter "pilot" hole has been drilled to intersect with the Gautrain tunnel which had already advanced beyond this point underground. Once the pilot hole has broken through into the tunnel below, the drill bit is removed and a reamer head is attached to the drill string which is then rotated under pressure against the rockface thereby slowly enlarging the pilot hole to the required shaft diameter (in this case 6.1m) as the reamer is drawn toward the surface.

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 positions of the emergency shafts and the required depths of these shafts relative to the surface. There are a total of seven emergency shafts (E1–E7) which are being sunk.

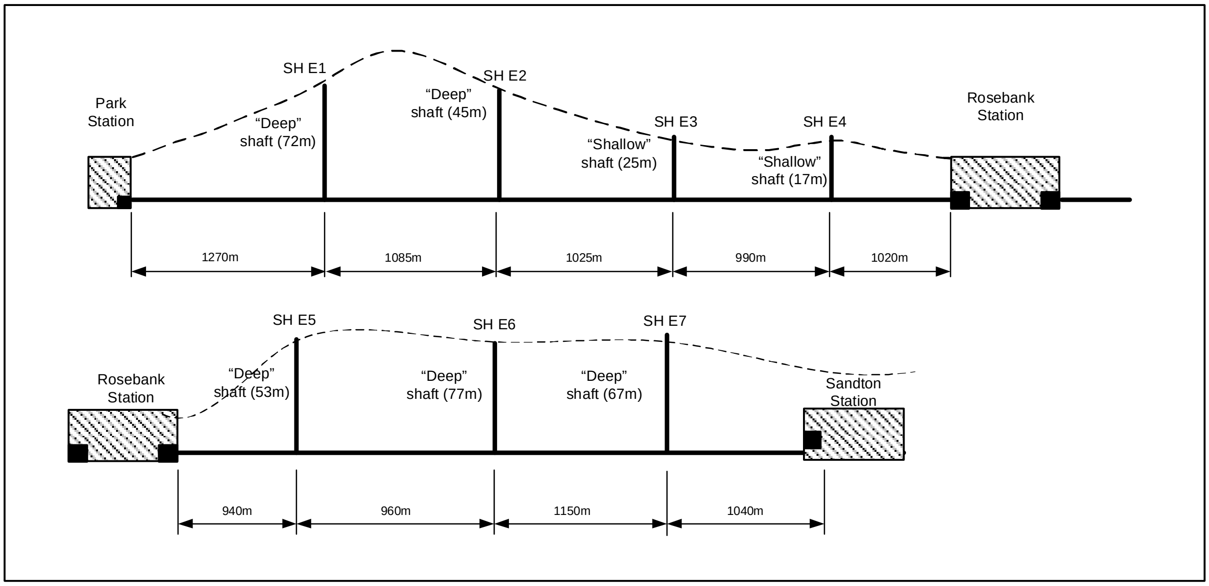

Figure 1 Emergency shafts (E1 – E7)

Figure 2 illustrates the proximity of emergency shaft E5 to nearby residential property thus requiring absolute control over blasting conditions to minimize airblast and vibration.

Figure 2 Emergency shaft E5, proximity to nearby residential property

2 Shaft Sinking

The products used in the shaft sinking 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

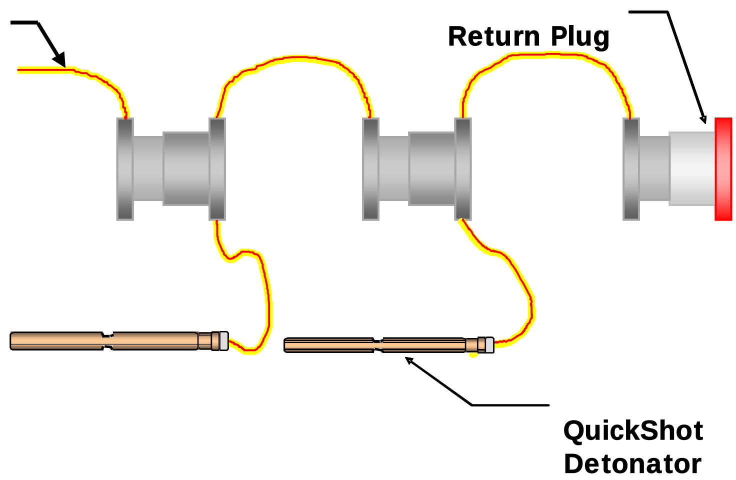

Figure 4 The QuickShot detonator daisy chain connection with a return plug connected which informs the system that it is the last detonator in the chain

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 Shaft sinking designs

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

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):

$$\frac{D}{\sqrt{E}} \geq 31 \qquad (1)$$

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

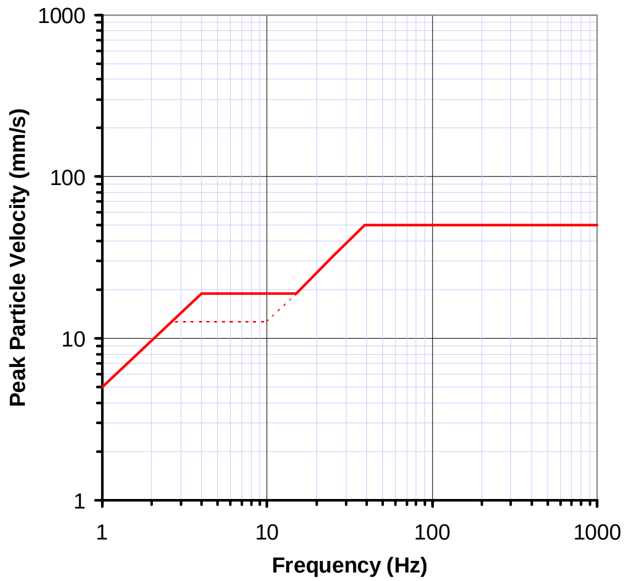

Figure 5 USBM damage criteria, based on frequency. Peak particle velocity (PPV) (mm/s) limits = frequency (f) (Hz); logarithmic scale

- 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 5. In order to determine the mass of explosives per delay at this limit, for the initial blast design, Equation 1 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 28 months.

To minimize airblast all the current literature was reviewed and based on regression data from similar field work and guidelines a 95% confidence could be given that adoption of the recommended measures, in the absence of unforeseen events, e.g. failure along a geological feature, would result in the required control of the airblast i.e. < 134 db.

The recommended measures to minimize airblast are the following:

- Assure that all holes have adequate stemming (A minimum stemming height of twenty borehole diameters is usually sufficient to prevent "blowouts" and resultant airblast).
- Ensure proper timing sequence.
- Limit the kilograms of explosives per delay.
- Single hole firing (Accuracy of electronic detonators, ensured single hole firing).
- When possible, delay the blast to direct movement away from critical areas.
- Avoid adverse environmental conditions such as blasting when wind is blowing toward residential areas, or under an atmospheric temperature inversion
- Do not blast more often than necessary and time blasts to coincide with peak ambient noise levels.
- Use a blast cover. e.g. sand and/or blasting mats
- Minimize the number of blasts and how often (electronic detonators allowed the blasting crews to blast larger and more controlled blasts due to the accurate predictability of timing delays).
- Do not allow any exposed explosives including detonating cord or surface connectors.

Table 1 AEL Guide for Airblast criteria

Level	Description
100 dB (2.0 Pa)	Barely noticeable
110 dB (6.3 Pa)	Readily acceptable
128 dB (50.2 Pa)	Currently accepted by South African authorities as being a reasonable level for public concern (No more than 10% of measurements should exceed this value)
134 dB (100.2 Pa)	Currently accepted by South African authorities that damage will not occur below this level (No measurements should exceed this value outside of the mining boundaries.)

The emergency shafts of the Gautrain project are designed to be circular. Gaining the maximum advance is critical and fine fragmentation is essential as dealing with oversize rocks in the bottom of the shaft are time consuming and dangerous. The circular shaft holes are drilled in rings and are blasted in a sweep pattern motion from the cut which has an altered position for every blast as seen in Figure 6.

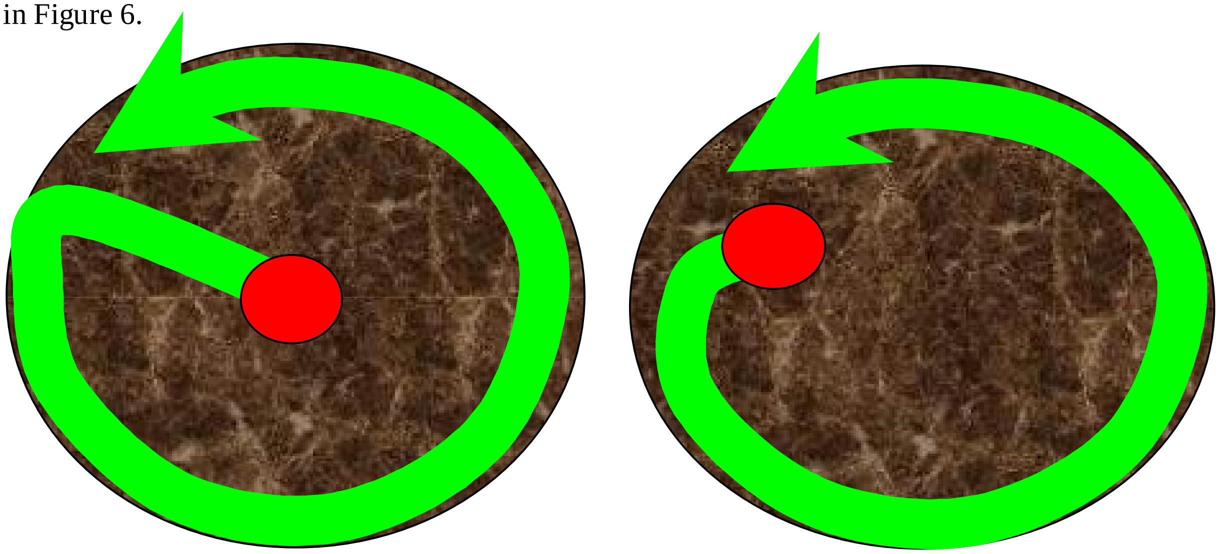

Figure 6 Alternating of cut between blasts and sweep pattern blasting motion

Firing and tie up sequence of circular shaft blast using the QuickShot system is shown in Figure 7. A fly lead is used to connect the first detonator to the control box on surface. 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 26 ms. This allows the blast to be fired quicker and ensure that the total blast duration is kept to a minimum whilst ensuring the required fragmentation is obtained. Single hole firing is of great importance and is achieved as the daisy chain connection of detonators does not allow two detonators to be connected to each other and the accuracy of the electronic detonators ensure this.

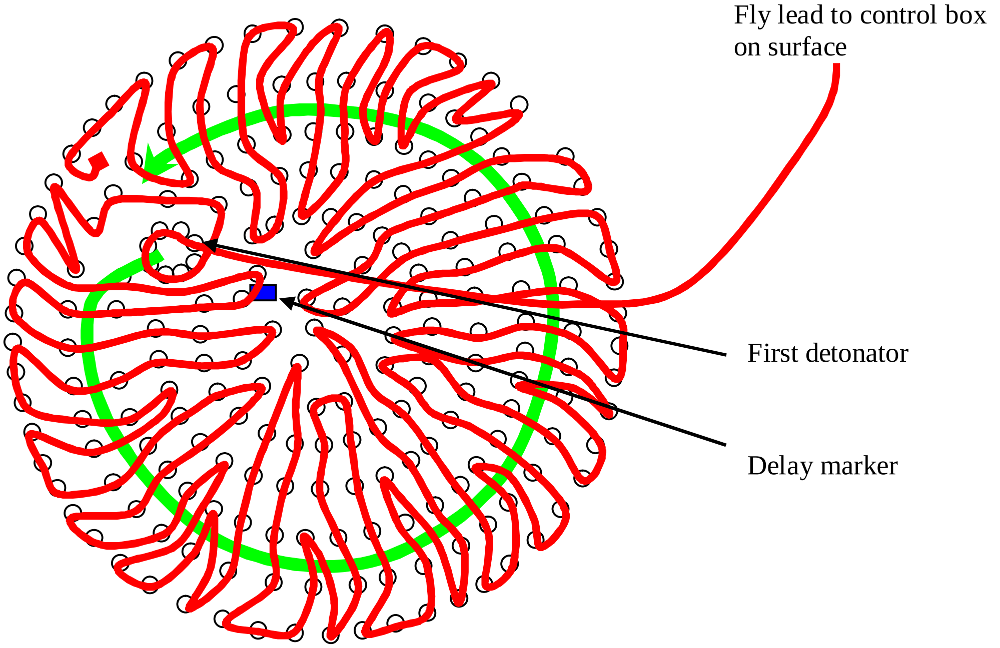

Figure 7 Firing and tie-up sequence of circular shaft

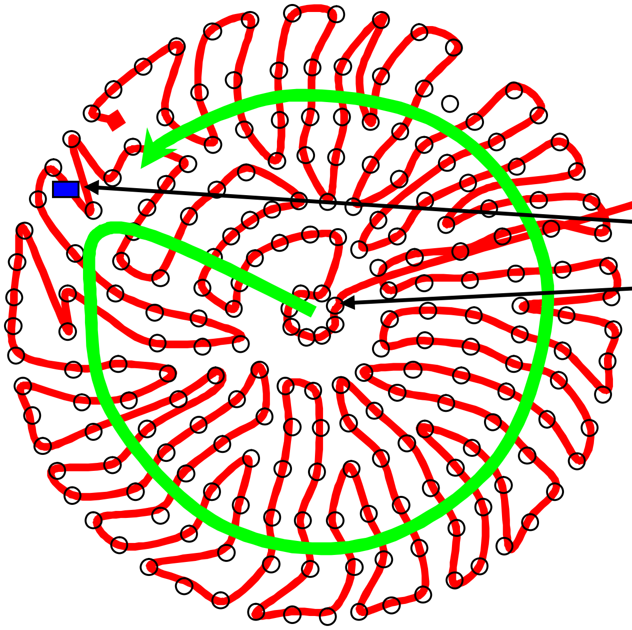

Figure 8 Firing and tie-up sequence of circular shaft with cut in center

Firing and tie up sequence of Sandton north shaft blast using the QuickShot system is shown in Figure 9. The Sandton shafts are rectangular in shape and at the start of the project were blasted in a benching method but the timing flexibility and precision of electronic initiating systems have allowed the entire shaft to be fired in a single blast thus ensuring minimal disturbance to nearby residential and commercial residents with fewer blasts and reduced levels of airblast and vibration. Fly lead's are used to connect the first detonator to the control box on surface. Due to the size of the rectangular shaft blasts, the blast is divided into three sections.

The first section of the blast is connected to fly lead one which is connected to a delay marker (delay of the inter hole is changed from 125ms factory preset delay to 28ms inter hole). The delay marker is then connected to a splitter which splits the signal into two. At the one output of the splitter a pause marker is inserted and set to a delay of 14ms, this offsets the firing time between the detonators on opposite sides of the splitter and ensures single hole firing. The same process is followed for the third section of the blast which is connected to fly lead three.

The second section of the blast is connected to fly lead two which is connected directly to the first detonator at the cut. The cut is fired slower than the rest of the round with the factory preset of 125ms between holes to ensure enough time for the round to break into the void created by the previous hole. A blasting mat or sand is used to cover the cut as most flyrock is generated from the cut. After the cut a delay marker is inserted to change the inter hole delay from 125ms to 28ms thus speeding up the firing time between holes. A splitter is inserted after the delay marker to split the section into two and then a pause marker of 14ms is inserted on the one output of the splitter to offset the time between the detonators on opposite sides of the splitter and ensures single hole firing.

The inter hole delays can be change at anytime using delays between 1 – 20000ms but the 125ms and 28ms inter hole delays have proved to be the most favourable for this project.

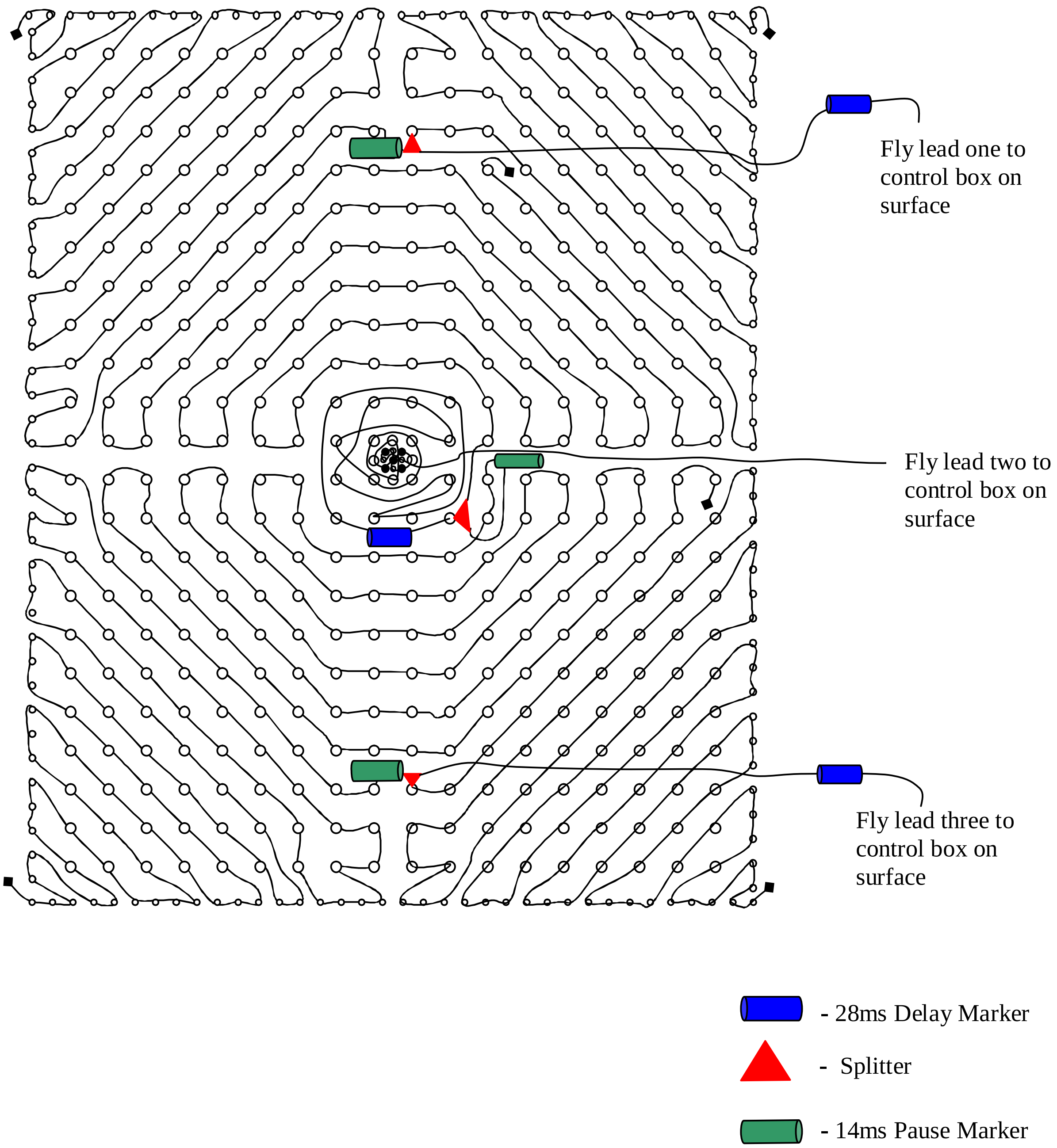

Figure 9 Firing and tie-up sequence of rectangular shaft with cut in center

Conclusions

The project is progressing well after 33 months and the QuickShot initiation system has 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. The tight deadlines and environmental constraints for this project are proving to be very challenging but being achieved due to a combination of knowledge, application and the use of a product that is robust for the conditions. Electronic timing delivers control and hence predictability of blasting results.

Acknowledgements

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