The Use of Electronic Detonators in Vibration Control for Blasting

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Abstract

This paper presents an overview on the use of pyrotechnical and electronic detonation system in tunnel blasting works, and explores the optimization in the productivity of blasting works while minimizing the ground vibration through the use of an electronic detonation system. Vibration monitoring data obtained from the project are examined and compared with predicted values obtained from empirical solutions. This paper also compares the use of pyrotechnic and electronic detonation system and assesses how the electronic detonation system can improve the reliability of blasting works.

Introduction

Harbour Area Treatment Scheme (HATS) Stage 2A Sewage Conveyance System **(see figure 1)**, commenced in July of 2009, is to collect screened sewage from existing Preliminary Treatment Works, which are located at Northern and Northern-western shoreline of Hong Kong Island, to Stonecutter Island Sewage Treatment Works for further treatment. To overcome the many different constraints and technical difficulties, deep-seated tunnel is chosen as the design solution, and the tunnels will be constructed using the drill and blast method.

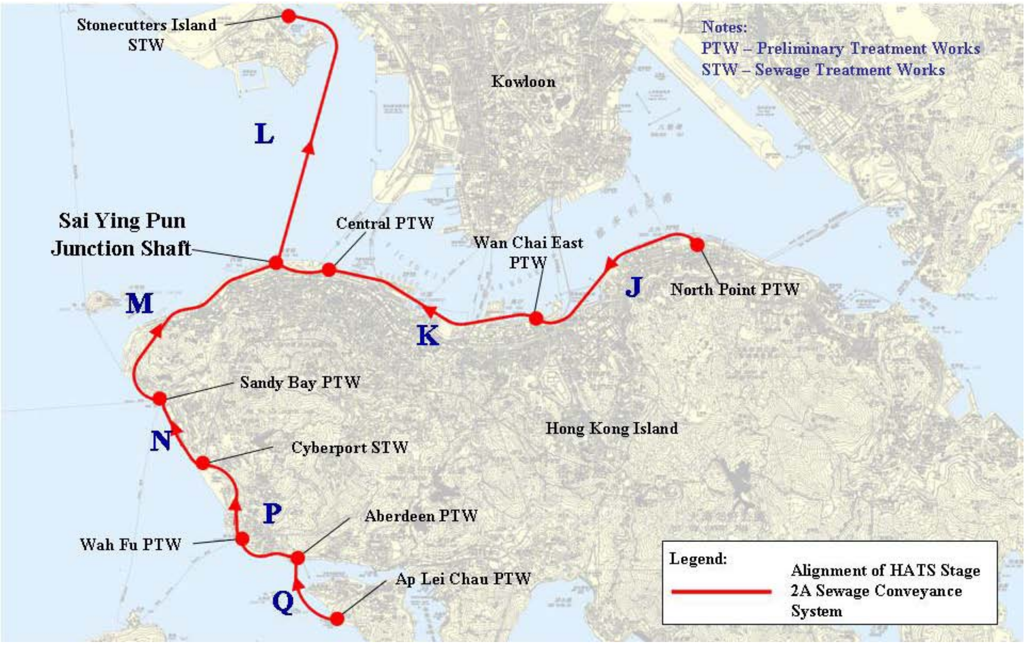


Figure 1 Alignment of HATS 2A Sewage Conveyance System

Excessive ground vibration generated during blasting is always a concern of shotfirers and blasting engineers. In consideration of increasing awareness of general public and decreasing tolerance for disturbance and safety, attempt to control and minimize the ground vibration associated with blasting works has been made. Electronic initiation system, which facilitates self assigned delay timing and communication between the detonators and blasting box, has been introduced to the project by the Contractor, Leighton-Leonhard Nilsen & Sonner Joint Venture.

Blasting Vibration Control in Hong Kong

Blast vibration is conceived as ground shaking caused by elastic wave emanating from a blast. It is in fact the residual seismic wave generated by an expanding gas in confined blast holes during detonation of a charge. The pressure in a magnitude of 30GPa crushes and fractures surrounding rocks. The intensity of the seismic wave deteriorates with distance and propagates in the form of elastic waves beyond the fracture zone.

Excessive vibration may cause damage to structures. In Hong Kong, blasting engineers predict blast vibration levels using the empirical propagation formula proposed by United States Bureau of Mines with the attenuation constants proposed by Li and Ng (1992). The constants were obtained by linear regression analysis at 84% confidence level using data collected in local blasting sites:-

$$PPV = 644 \times (D / W^{0.5})^{-1.22}$$

Where PPV is the predicted maximum vibration in mm/s;

D is the distance from the nearest point of the blast to the sensitive receiver, in metres;

W is the charge mass per delay, in kilograms.

Regulatory control by authorities imposes charge weight per delay limits with respect to vibration sensitive receivers and alert monitoring action plan. Vibration limits adopted in Hong Kong are generally 25mm/s for building and structures which are designed up to current design standard, 13mm/s for water retaining structures and 5mm/s for significant monument structures. Vibration limits for geotechnical features are obtained by pseudo-static analysis as per coding requirements. Charge weight per delay for a particular blast is limited by these limits for which the predicted vibration levels are controlled below the alert levels of the affected sensitive receivers.

From engineering point of view, proper design gives rise to better control of blast vibration. Parameters in consideration for a proper design include proper design of burden, firing pattern, delay interval between adjacent charges. Understanding the dominating factors is crucial in vibration control.

In practice, blasting round is fired in sequential charges within which delay time interval are given. This is to achieve proper development of free face in the course sequential detonation and lower charge weight per delay. Proper blast design facilitates best optimization of use of explosive energy. It reduces blast vibration in a significant manner.

Given the same geology and other blasting parameter like spacing and burden, shorter delay interval results in better fragmentation but higher vibration. Blasting engineers alter various blasting parameters in designing tunnel blasts in order to obtain the best optimization of blasting results like blast vibration, fragmentation, over-break and costs.

Vibrations recorded in the field are complex waveform formations which are appear to be in collective results of many variables. In simple terms, the waveform blasting vibration could be considered as a combination of series of single charge detonations that are separated by the designed time intervals between charges. The relation of this time interval and the site specific geology has the most effect on the amplitude and frequency compositions of the ground vibration wave (Bartley & McClure, 2003).

Sufficient time separation between sequential charges avoids superposition of single waveforms generated by individual charges. In practice, blasting engineers separate individual charges by a delay of 8 milliseconds in designing a blast. This rule of thumb has been followed in the past decade.

Overview of Pyrotechnic Delay Detonators

Pyrotechnic delay detonators are utilized pyrotechnic energy as a means of delay and initiation. Systems currently used in Hong Kong are shock tube initiated detonators in which pyrotechnic delay element is fitted between the igniter and base charge. They are commonly known as non-electric detonators. Previously, pyrotechnic delay detonators are initiated by electrical energy which called electric detonators. **Figure 2** shows the typical configuration of shock tube and electric pyrotechnic delay detonators.

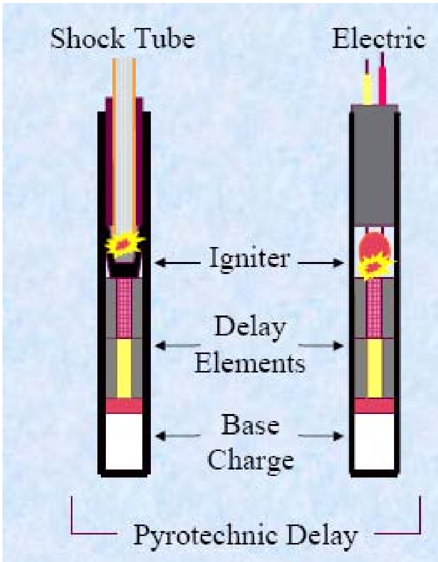


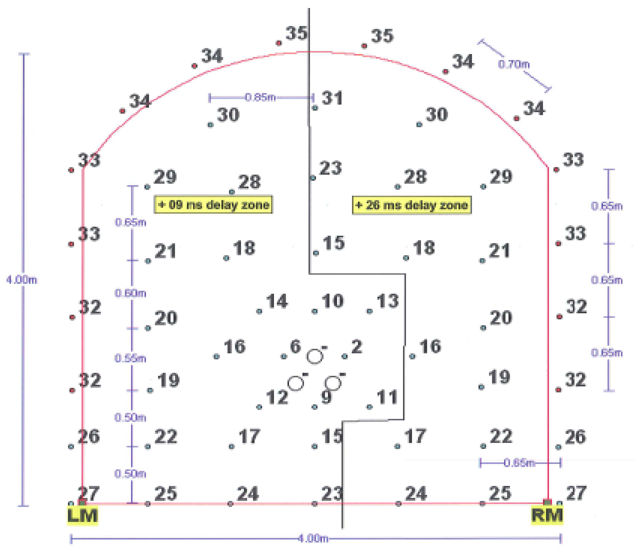
Figure 2 Pyrotechnic delay detonators

The delay timing is achieved by igniting the delay element which is initiated at a pre-set rate before initiating the base charge. The delay element is commonly made of low explosives which have relatively lower velocity of detonation than those of signal tube and base charge. The velocities of detonation for shock tubes, base charges and other blasting accessories including detonating cord is higher than 2000m/s which are considered virtually instantaneous when compared with the delay element.

Delay timing is governed either by various composition of delay charge or by various length of the same composition. Cunningham (2003) suggested that precision in timing of delay highly relies on the capability of the manufacturer. Factors affecting the precision of delay timing also include length of time since manufacture, temperature and precondition stress pulse from surrounding holes. In general, it is commonly known by the industry that the fuse error of pyrotechnic detonators is 2% of the delay time preset by the manufacturer. The higher the delay number, the wider is the fuse error in millisecond time.

There are two types of delay detonators readily available in Hong Kong, namely Long Period (LP) and Millisecond (MS) delay detonators. Delays are available in a range of 5 to 30 for LP and 18 to 36 delays for MS detonators amongst various suppliers. Delay periods arranged from 0.2 second to 9 seconds for LP and 25 milliseconds to 1 second for MS detonators.

For tunnel blast, separation of delays between individual charges is commonly achieved by in-hole detonators with different pre-set timings. Common tunnel blast designs arrange small delay number in cut holes and radiate out with large delay numbers in production holes and perimeter holes. In large tunnel section for which available delays are insufficient, charging face would be divided into different delay sectors which delay timing are differentiated with surface delay detonators. **Figure 3** illustrates a typical blast design pattern.



Non-electric Detonator					
MS Delay No.		Quantity	MS Delay No.		Quantity
1	25		19	1025	2
2	50	1	20	1125	2
3	75		21	1225	2
4	100		22	1400	2
5	125		23	1675	2
6	150	1	24	1950	2
7	175		25	2275	2
8	200		26	2650	2
9	250	1	27	3050	2
10	300	1	28	3450	2
11	350	1	29	3900	2
12	400	1	30	4350	2
13	450	1	31	4850	1
14	500	1	32	5350	4
15	600	2	33	5900	4
16	700	2	34	6550	4
17	800	2	35	7250	2
18	900	2	36	8050	
Bunchdet	9 ms	1	Bunchdet	25 ms	
Bunchdet	17 ms	1			

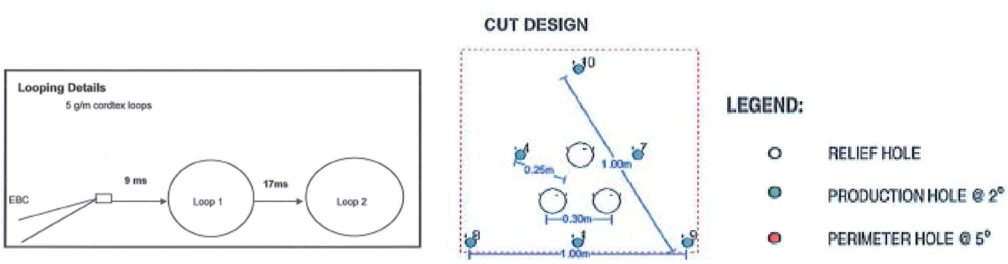


Figure 3 illustrates a typical blast design pattern

All in-hole detonators are bunched or connected to loop of detonating cords at the charge face. A conventional electric detonators is connect to the detonating cord of the initial delay sector for firing after the blast area clearance is fully implemented and permission to fire the blast is given.

Overview of Electronic Delay Detonators

Electronic delay detonators have a several different types and design. They all utilize stored electrical energy inside the detonators as a means of timing delay and initiating energy. The system adopted for the project is a field programmable two line system electronic detonator system. The delay element is a capacitor controlled by application-specific integrated circuit (ASIC) fitted before the igniter and the base charge. **Figure 4** shows the configuration of a electronic detonator.

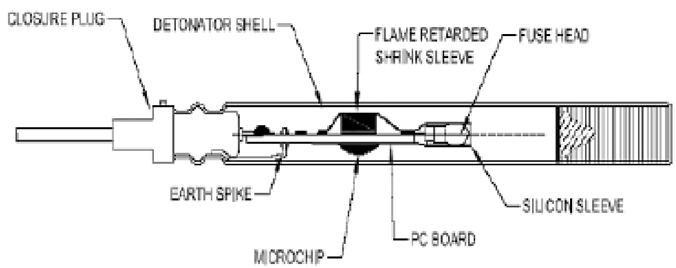


Figure 4 configuration of the electronic detonator.

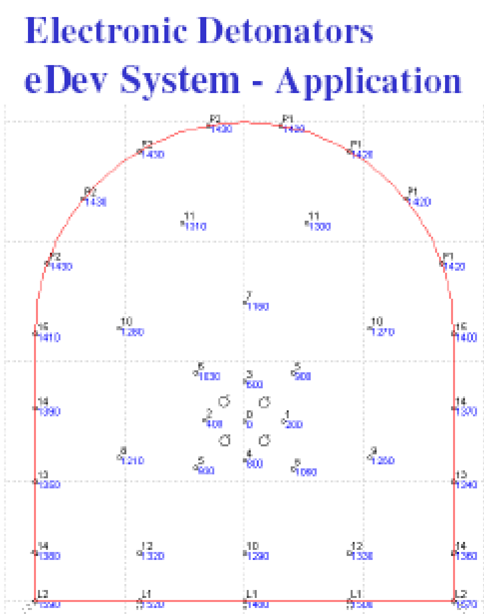
There is no preset delay time to detonators. The delay time are programmed in the field by the blasting machines. Programmable delays range from 0-10 seconds in 1 millisecond increments. Despite all detonators appear identical, each detonator has a unique factory ID in the ASIC and printed on the barcode tag at the top end of the lead-in wire.

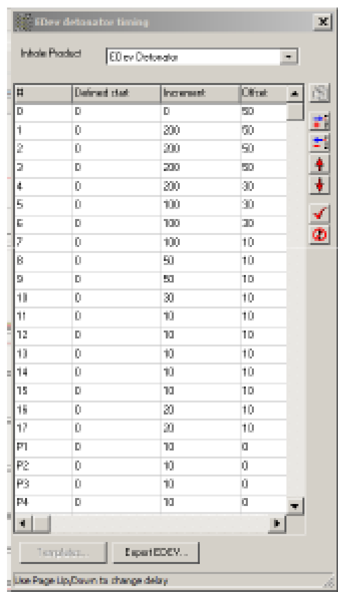
The proclaimed accuracy is better than +/-0.1% of the programmed delay. This is due to the intrinsic property of a capacitor discharging its stored energy in the course delay firing.

During the hook up after charging, a scanner is brought to the charging face to store all detonators IDs and delay numbers in table as assigned in the design. After all detonators have been connected to blasting machine through loop of harness wire, data stored in the scanner are transferred to the blasting machine for delay assignments after tunnel evacuation.

Functions of the blasting machine include powering up all detonators connected at specific voltage and current, test the network with respect to integrity and completeness, programme the assigned delay for each detonators and finally fire the shot.

To assign delay times, delay sequence pattern is translated to a delay table and preset to the scanner before charging at the face. The table contains a list of delay numbers with respective to delay time increment and offset. IDs of detonator installed are stored against the delay numbers in the table during scanning. Delay timing for each detonator is determined in the blasting machine by adding all the time increments and offset with respect to delay numbers assigned. **Figure 5** illustrates a typical blast design pattern and delay table for electronic detonator.





#	Defined start	Increment	Offset
0	0	0	50
1	0	200	50
2	0	200	50
3	0	200	50
4	0	200	30
5	0	100	30
6	0	100	30
7	0	100	10
8	0	50	10
9	0	50	10
10	0	30	10
11	0	10	10
12	0	10	10
13	0	10	10
14	0	10	10
15	0	10	10
16	0	20	10
17	0	20	10
P1	0	10	0
P2	0	10	0
P3	0	10	0
P4	0	10	0

Figure 5 Typical blast design pattern and delay table for electronic detonator

Comparison of Field Data

The contractor has adopted different initiation systems for tunnel blasts to form construction adits in Cyberport and Sandy Bay sites. Conventional non-electric initiation system was adopted in Sandy Bay while electronic initiation system was used in Cyberport. Tunnel size and the proximity to residents are essential considerations in determining which initiation system to be adopted.

Blasting vibration recording is a requirement of blasting permit. The data are collected by seismograph model Nomis Mini Supergraph. Set up of seismograph has been carried out in accordance with Guidance Notes of Vibration monitoring. 240 observations for Cyberport adits and 512 observations for Sandy Bay adits taken in December 2011 are chosen for the discussion. Vibration data in PPV for both these adits are plotted in Figure 6. Linear regression line using square root scale distance making reference to Li & Ng (1992) and regression outputs are shown as follows:

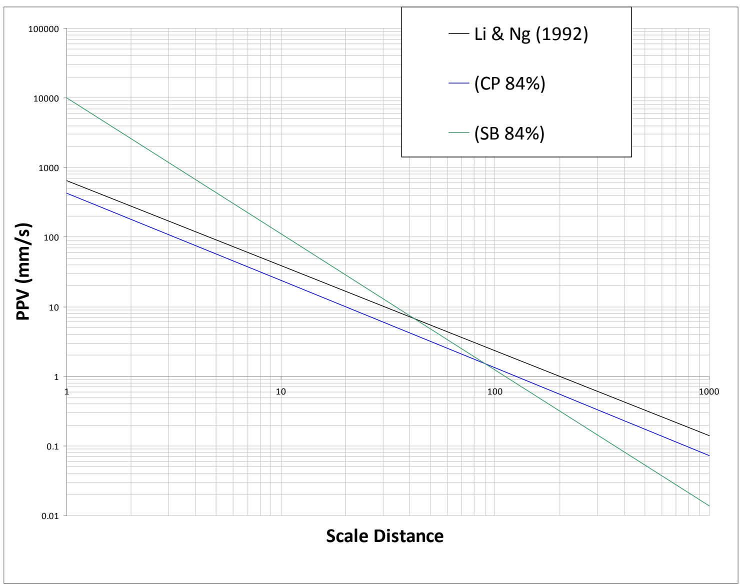


Figure 6 Regression lines for Cyberport and Sandy Bay vibration monitoring data.

Regression line for Cyberport Adits 84% line PPV = 429(SD)^-1.26

Regression Statistics	
Multiple R	0.529801112
R Square	0.280689218
Standard Error	0.266710742
Observations	240

Regression line for Sandy Bay Adits 84% line PPV = 9994(SD)^-1.95

Regression Statistics	
Multiple R	0.624834644
R Square	0.390418333
Standard Error	0.342770613

Observations 512

In general, delay interval ranges from 100 to 150 milliseconds for cut holes and 20 to 80 milliseconds for production and perimeter holes. The contractor had successfully applied for an increment for the charge weight for Cyberport Adits with the support of their regression analysis. The increase was at most 20% compared to Li and Ng (1992) 84% regression line.

Noting the coefficients of determination were found relatively low. It may be attributed to the bias distribution of data. The tunnel is running at approximate 80m below existing ground level. Data collected in close proximity are not possible. Data at far distance tend to be affected by nearby vibration events other than blasting.

Geology of the blasting sites are similar. The Lithology of them is predominant volcanic slightly recrystallised coarse ash tuff. Volcanic rocks are highly variable with regard to joint intensity and orientations in nature. Such factor adds uncertainties to blast vibration propagation.

Comparing the two regression lines, it is noted that electronic initiation system adopted in Cyberport adit tunnel blasts has better vibration performance. It is also observed that data collected for electronic systems are less scattered. The frequency of exceeding Li & Ng (1992) prediction is lower than conventional pyrotechnic system.

The author opines that such observations are attributed to scatter delay time of individual charges and hence overlapping of delays for non-electric detonators. Electronic system has delay accuracy up to 0.1% of the assigned timing in the light of intrinsic properties of electronics. Delay time increment and offsetting from precedence charge, which is the core feature for the system in regard of blast design, has effectively prevents delays overlapping due to imprudent design. The opportunity of having delays overlap and hence superposition of blast vibration waveforms due to scatter delay timing is low.

For 2% accuracy of pyrotechnic delay detonators, the possible error is ±170 millisecond for delay no 36. This possible scattered delay time is already longer than the time delay of the separating surface delay amongst various delay sectors. Under the circumstance, the chance of delay overlap is very high.

Comparison of the Use of Pyrotechnic and Electronic Detonators

In comparison with electric detonator, pyrotechnic detonator is safer to use in view of the design configuration which enables immunity of stray current and current leakage hazards. Signal Tube is relatively more robust than firing cables. Delay paradigm enables delay separation of 8 milliseconds readily achievable.

The Intrinsic properties of the electronics detonators enable the design and development of special features with regard to system safety. General features are summarized below:-

1. Bleed resistor discharging electricity in the circuit within the detonators continuously. This feature safeguards against accidental detonation stemmed from stray current or premature arming.
2. ASIC accepts specific digital code only from specific blasting machines before giving any digital signals or electrical energy to igniter. This is one of the core feature in controlling premature firing.
3. Scanner has no communication with detonators during scanning. It prevents pre-mature arming of detonators.
4. The microchip and the blasting machines enable checking on the integrity of the firing circuit. Connection problems can be addressed before firing. This feature eliminates the opportunity of misfire significantly.

Handling signal tubes and associated accessories especially in their connections requires throughout understandings of explosives properties. Integrity of the connections relies on experiences of the shotfirer. Electronic systems which involve simple connection of electric wires, are relatively easier to be handled by shotfirers. Integrity of the connections within circuits can be checked by the blasting machine before firing. This feature allows participation of other supervisory staff like the blasting engineers in checking the integrity of the circuits and correctness of delay sequence and timing before firing.

For controlling blast vibration, accuracy of firing time for each charge plays a significant role given a fixed charge weight. The precision of delay times for electronic systems is definitely an edge over conventional pyrotechnic systems. The accuracy of delay timing eliminates simultaneous firing of charges in a blast.

With the aid of computer programs, electronic systems offer features convenient to the design of delay times of charges in the sequence of detonation. Delay times are readily changeable in during desktop design or charging at the face. This feature allows blasting engineers to design optimum frequency and amplitude content of ground vibration which induces least vibration impact to surrounding sensitive receivers without compromising blasting productivity (Bartley & McClure, 2003).

Conclusion

Overview of electronic and pyrotechnic delay detonation system in regard of vibration control, safety and use are presented. Data collected on field for the two systems given in similar geology are examined and assessed. It is concluded that electronic systems enable blasting engineers to design proper delay time intervals between charges in a blast with a good vibration control.

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