Drilling and Blasting for Underground Space
R Pesch and A Robertson

ABSTRACT
Australia has been slow in adopting the use of underground space as a part of our urban planning process. Australia has one of the highest levels of tunnel advance per capita per annum in the world, yet the use of underground space in our cities appears difficult for our planners and politicians to comprehend, not withstanding the general availability of good quality rock and contractor expertise in Australia. However, the lack of space in our urban areas is being highlighted as our major cities expand outwards and people and businesses gravitate towards city centres. Typical potential underground space uses include car parking, self-storage and archiving facilities, water storage, underground quarrying, small industrial facilities and another layer of traffic (electric and fuel cell) and services network.

Historically, blasting in high density population areas has resulted in blast vibrations and blast overpressures exceeding the limits, which in some case have been set extremely low in terms of peak particle velocity (PPV). This makes conventional blasting difficult, often requiring low charge weights per delay and associated small blast sizes and slow advance rates. However, the introduction of new technologies, such as computer aided drilling, electronic delays and low-energy explosives has made this task considerably easier. Although more expensive than conventional blasting, excavation by blasting using these products and technologies in relatively good quality ground is believed, in most cases, to be less than the cost of mechanical excavation.

In this paper, the authors look at innovative trends in underground quarrying, underground commercial space and tunnelling and put forward their concept of future excavation demand, future product requirements and technical specifications to the drill and blast community.

INTRODUCTION
With increasing technical sophistication and demand for resources, mining activity has had to expand, resulting in larger, deeper mines with greater densities of blasting in any area. A relevant simple example would be a normal overburden blast in the Hunter Valley where hundreds of tonnes of bulk explosives are blasted in a single pattern in an area that is becoming increasingly urbanised.

Lack of available surface space has forced town planners to literally look under the horizon for solutions to solve traffic flow problems. In Brisbane, a series of tunnelling projects which commenced in 2006 as part of the TransApex Project, will continue the use of drill and blast as a secondary means of rock breakage (to mechanical rock excavation methods), well into the third decade of this century. Whether it is on the surface or hard rock underground, drill and blast activities are going to interact with a sometimes hostile human audience!

BLASTING PARAMETERS
When a certain amount of explosive detonates at a specific depth below the Earth’s surface, approximately 20 - 30 per cent of its energy is utilised in fragmenting the rock or other surrounding materials. As an explosion is an imperfect use of energy, there is a loss of energy transmitted through the Earth in the form of pulsating waves or vibrations. A part of the energy is also dissipated in the air, which produces noise. Two groups of seismic waves are seen to be generated by detonation of explosive charges in drill holes, classified as body and surface waves. Body waves travel within a medium, while surface waves are restricted to travel along free interfaces, such as the ground surface. Body waves comprise of two discrete components – compression or P-wave and shear or S-wave. Two types of surface waves are usually produced from normal mine blasting – Rayleigh (R) and Love (L) waves. Other less perceivable waves are generated also. These waves and their effects on material properties have been widely discussed in papers from explosives suppliers and academics. Generally, a blast initially generates high frequencies which decay into lower frequencies over distance and the resultant amplitude is greatly affected by ground conditions and the interaction of the various waveforms.

Wave propagation phenomena were first investigated by Morris (1950) and his principles have been refined ever since to attempt to determine peak particle velocity (PPV). PPV is the unit of measure used for determining the ground vibration effect of blasting and its formula can be employed to predict vibration levels using empirical constants and determining the maximum permissible charge weight per delay. Modern scientific blast monitoring equipment can measure the actual versus predicted vibration levels.

COMMUNITY PERCEPTION OF BLASTING
One of the more perceptible side effects of rock blasting is ground vibration, which can cause human annoyance and structural damage, although damage only occurs at levels many times higher than those that cause annoyance.

Table 1 shows the typical vibration levels generated by normal day-to-day human activity, measured adjacent to the source of vibration.

<table>
<thead>
<tr>
<th>Household activity</th>
<th>Vibration level (mm/s peak particle velocity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jumping</td>
<td>Up to 250</td>
</tr>
<tr>
<td>Heel drop</td>
<td>Up to 150</td>
</tr>
<tr>
<td>Nail hammering</td>
<td>Up to 100</td>
</tr>
<tr>
<td>Walking</td>
<td>Up to 40</td>
</tr>
<tr>
<td>Shutting door</td>
<td>Up to 30</td>
</tr>
<tr>
<td>Sliding door</td>
<td>Up to 10</td>
</tr>
</tbody>
</table>

Allowable PPV limits within a frequency range stipulated by regulatory bodies vary considerably worldwide. For example, in Japan the permitted vibration amplitude has to be between 0.5 and 1.0 mm/s in residential areas, whereas in New Zealand anything below 5 mm/s is acceptable (Table 2). Generally, higher frequencies generated from blasting have a smaller effect on buildings and people than low frequencies such as those created by earthquakes.

There has been a trend for regulatory authorities, especially those concerned with the environment, to impose low limits on blast vibration levels in response to community pressure, based on human perception and response to vibration. Despite technical advances in blasting which, when used as designed, have
considerably lowered the environmental and human impact, some local authorities have traditionally excluded blasting or provided ridiculously low vibration or air blast limits in excavation contracts in highly urbanised areas.

**Conventional and high technology blasting**

Reinforcement of waveforms from blastholes detonating at different times (thereby increasing the amplitude) can occur and can be potentially more annoying. The choice of initiation timing and quality of the detonator element will greatly determine the vibration level. The advent of electronic detonators has greatly enhanced the choice of sequence timing available for blasting using high energy explosives as they can be programmed to the millisecond. Unfortunately, whilst the demand for this type of delay is likely to increase as environmental management of blasting becomes increasingly important with the sprawl of urbanisation, the high cost remains a major issue for contractors.

In addition to using electronic detonators in tunnelling to reduce environmental impact there is also a demand for good quality explosives that can be used in peripheral holes to reduce overbreak and preconditioning. When deciding to choose between using a roadheader or conventional drill and blast, one of the selection criteria is the ability to control the profile of the heading. In highly jointed rock there is the danger of gases produced by detonation to open up joint systems by ‘gas jacking’. The resultant instability of the tunnel arch accompanied by overbreak, increases use of rock bolting and shotcrete in the primary support phase, thus driving up the overall excavation cost.

**Blasting using ‘low energy explosives’ or ‘non-explosives’**

In Australia, low energy explosives that have been used successfully include:

- Nonex – contains 100 per cent propellants,
- Penetrating cone fracture (PCF) – contains ammonium nitrate (AN), and
- Cardox – rapidly released gas under pressure.

These low energy explosives have an advantage over high energy explosives in terms of their requirements for storage and handling under the relevant State Explosives Acts. In some cases these products can result in significantly lower vibration levels and air blast levels than high energy explosives and associated detonation systems. Lees (2001) describes the successful implementation of PCF in Hong Kong and compares the use of PCF with conventional explosives in the urban environment, particularly in regard to materials handling, safety, vibration and gas emissions.

Sometimes in urban construction and tunnelling, the optimum solution to obtain minimum environmental impact may involve a combination of both low energy explosives and high technology blasting techniques using high energy explosives.

**RECENT PRACTICAL EXAMPLES**

**North-South Bypass Tunnel**

Electronic detonators with an accuracy of 1 ms were used by AVKO Mining for the Brisbane North-South Bypass Tunnel (NSBT) portal works near Shaftston Avenue, Kangaroo Point. Actual works consisted of the access shaft and stub tunnel. Blasting and initiation products consisted of a combination of ammonium nitrate-fuel oil (ANFO), Powergel™, Profiler™, electronic detonators and Devil Dets™. The electronic delays provided the following benefits:

- Accuracy – they ensured single hole per delay, which allowed tighter time windows than the traditional 8 ms rule (eg with ‘non-electric’ detonators), thereby allowing a broader possible range of blast geometries.
- Accuracy also allowed high frequencies to be driven which in turn ‘allowed’ higher PPVs under the ‘new’ frequency based PPV limits in the ‘new’ Australian Standard (criteria as used by other countries for several years already).

**TABLE 2**

Typical blasting limits by country (source: Piyush Pal Roy, 2005).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human perception</td>
<td>0.15 - 1.5 mm/s</td>
<td>Values in excess cause appreciable structural damage</td>
</tr>
<tr>
<td>Visible damage</td>
<td>50 mm/s</td>
<td>British Standard BS 64722.1992</td>
</tr>
<tr>
<td>British Standard BS 64722.1992</td>
<td>8.5 - 12.7 mm/s</td>
<td>90 per cent confidence limit – permissible impulsive vibration at residential property</td>
</tr>
<tr>
<td>Leicestershire County Council (UK)</td>
<td>6 mm/s</td>
<td>95 per cent confidence level – part of conditions covering blasting within modern planning permissions</td>
</tr>
<tr>
<td>Australian Standard Explosives Code AS2187-1993</td>
<td>5 mm/s</td>
<td>Common environmental limit (EPA) – depends on administering authority</td>
</tr>
<tr>
<td>(AS2187.2-2006)</td>
<td>0.2 mm/s</td>
<td>Historical buildings and monuments – displacement for frequencies less than 15 Hz</td>
</tr>
<tr>
<td></td>
<td>19 mm/s</td>
<td>Houses and low rise residential buildings – resultant PPV for frequencies greater than 15 Hz</td>
</tr>
<tr>
<td></td>
<td>25 mm/s</td>
<td>Commercial limit AS 2187.3</td>
</tr>
<tr>
<td>India</td>
<td>5 mm/s</td>
<td>Domestic houses/structures – frequencies less than 8 Hz</td>
</tr>
<tr>
<td>German Standard DIN 4150 (GIS, 1986)</td>
<td>5 mm/s</td>
<td>Domestic houses/structures – frequencies less than 10 Hz</td>
</tr>
<tr>
<td></td>
<td>5 - 15 mm/s</td>
<td>Domestic houses/structures – frequencies 20 to 40 Hz</td>
</tr>
<tr>
<td></td>
<td>15 - 20 mm/s</td>
<td>Domestic houses/structures – frequencies 50 to 100 Hz</td>
</tr>
<tr>
<td>Hungarian Standard</td>
<td>5 mm/s</td>
<td>Panel houses</td>
</tr>
<tr>
<td>Swiss Standard</td>
<td>8 - 12 mm/s</td>
<td>Objects of historic interest or other sensitive structure – frequency bandwidth: 60 - 90 Hz</td>
</tr>
<tr>
<td>Swedish Standard National Museums</td>
<td>25 mm/s</td>
<td>Building structure</td>
</tr>
<tr>
<td></td>
<td>5 mm/s</td>
<td>Sensitive exhibits</td>
</tr>
</tbody>
</table>
Flexibility – electronics allowed usage of a ‘wedge’ cut to create relief using relatively long delays between holes, then using shorter delays for the bulk of the blast firing into the wedge. With pyrotechnic methods, this type of timing is almost impossible, or at least extremely difficult.

Security – for sleeping shots overnight in the inner city, electronics are integral to reducing the risk of inadvertent initiation or malicious action. No explosives are left on the surface.

Two-way communications – when burying shots under false burden and mats, electronics communicate back allowing the shotfirer to confirm the circuit is still intact thus reducing the chance of a misfire.

Figures 1 and 2 show photographs of the area where blasting was carried out.

Fig 1 - Shaft site where blasting was carried out (photo supplied by AVKO Mining).

Fig 2 - Development of the stub tunnel (photo supplied by AVKO Mining).

Southport Central car park

This excavation involved the removal of 50 000 bcm of rock in two car parks, one five levels deep and the other seven levels deep, within the Gold Coast central business district (CBD). The nearest neighbours were:

- an office tower and café precinct (12 m distant),
- a Red Cross building and church office (25 m distant),
- a public library (25 m distant), and
- residential dwellings (40 m distant).

The blasts used packaged emulsion with electronic initiation. A total of 30 blasts were required, averaging 1600 bcm per blast with multiple deck blasting of benches varying from 6 - 13 m high. Flyrock control methods involved the use of blast mats, importing false burden or drilling through rippable material left in situ. The innovative excavation method involved loading blast holes with up to five individual explosive decks (between 0.75 kg and 4 kg) with each charge firing individually to effectively control vibration levels. Electronic detonators increased the safety of sleeping blasts, allowing large blasts to be loaded over three to four days, with approximately one blast per week. The excavation is shown in Figures 3 and 4.

Fig 3 - Southport site showing proximity to residences (photo supplied by Orica Mining Services).

Fig 4 - Southport site showing proximity to library (photo supplied by Orica Mining Services).

Blasting ‘The Summit’, Coffs Harbour

This project involves the removal of part of ‘The Summit’, adjacent to Coffs Harbour township, for a housing development involving the establishment of foundations for multi-level buildings. The rock varies from a highly fractured, weathered metamorphosed siltstone to very hard, fresh siliceous siltstone with a compressive strength in the order of 240 Mpa. PCF RocKracker™ is used as the primary means of rock breakage for a blast of around 250 t in size, providing a product suitable for ‘free digging’ with a 25 t excavator which fed the material to a crusher to produce a quarry product for road base and gabion material. The blasting, carried out by Alterrain Civil and Geotech Mining Contractors (2007), is less than 200 m from the nearest house, located on an adjacent hill. The PCF charges are decked in the holes, the number of PCF cartridges depending on the...
depth of the hole and the rock quality. The holes are drilled on a staggered pattern, resulting in an average powder factor of 0.12 kg/bcm. To date, very low heave, flyrock and vibration levels have been experienced, supporting the use of the PCF explosives. Blast sizes could be increased with an initiation system that allows surface or in the hole delays.

UNDERGROUND SPACE – UNTAPPED APPLICATIONS

The authors believe that underground space in Australia is a major untapped market for the tunnelling and construction industry and the associated suppliers of technology, design, equipment, consumables and human resources. Applications include:

- underground quarrying – underground extraction of rock material for use as extractive industry material,
- underground tunnelling, and
- underground space.

Underground space can be developed using two major methodologies:

- by conventional tunnelling from a portal or from an existing underground excavation, and
- by excavating and ‘open cut’ void and covering the excavation using ‘cut and cover’ methods.

UNDERGROUND SPACE IN SOUTH-EAST QUEENSLAND

At Queensland’s Third Underground Space Workshop, held in Brisbane in November 2006, a number of important conclusions were made in regard to the future potential for underground space in Brisbane.

Some potential underground commercial and industrial sites for Brisbane include:

- Mt Coot-tha Quarry (water storage, industrial);
- Roma Street Parklands and Albert Street (self storage, archiving);
- Park Road Milton (self storage, shopping, parking);
- Hale Street Bridge – cut and cover past the State High School (shopping, commercial);
- quarry housing developments – the Gap;
- Paddington, Red Hill;
- Bowen Bridge to Kedron (Airport Link); and
- University of Queensland, St Lucia (archives, office, shopping).

Underground self storage and archiving

The authors have been advised that inner city residents are prepared to pay up to $3000 annually (based on 20 m² of storage) for each dwelling for self-storage facilities because:

- storage is required for furniture and other items (particularly heirlooms, recreational gear) that do not ‘fit in’ to the new residence; and
- savings in yard maintenance, water usage, rates and other costs associated with inner city living can be allocated towards self-storage.

The requirements for a self storage facility include:

- Good ground conditions allowing adequate free spans and minimum ground reinforcement costs. Shotcrete is an acceptable final finish.

- Vehicle access for removal type vehicles (up to 4 m high) to the main loading/unloading level.
- A dry cool environment that can not be flooded.
- Multi-levels with lift and small forklift access.
- A means of egress and appropriate fire fighting, security and ventilation facilities.
- Self draining facility.

Water storage

The drought which has plagued the east coast of Australia for more than a decade has highlighted the need for underground water storage in the CBDs of the major cities. The Mt Coot-tha Quarry, 5 km from Brisbane’s CBD, has been identified as a potential long-term water storage and/or water treatment facility for the City of Brisbane. The current quarry will cease extraction due to urban boundary constraints in approximately 20 years. It is believed that there is still over 200 Mt of rock in the underground resource which, after excavation, could be used for water storage, subject to geotechnical suitability of the rock mass for underground excavation.

Ellefmo (2006) describes the successful 400 000 tpa underground quarry at Bergen in Norway where they produce quality aggregates from the competent gabbro rock mass. Crushers and storage silos are located in caverns underground and stopes voids are 250 m long, 50 m high and 25 m wide. When the stopes are emptied the voids are used for ‘dry’ landfill material. Advantages of this ‘co-use’ include:

- a low production cost for aggregates of around A$12/t, which is only slightly higher than the conventional quarrying costs for a similar sized quarry in Australia;
- often the same equipment that is used to haul aggregates out of the mine hauls waste back into the mine; and
- fewer complaints compared to a surface landfill in regard to dust, noise, odour and air and water emissions.

Marshall, Ohsberg and Robertson (2000) described the massive potential for underground quarrying adjacent to urban areas.

Car parking

While the authors do not promote car parking in the city, there is a major shortage in Brisbane according to the Courier Mail (2006). This can cause a disincentive for people to use cars to commute to the city but it does cause problems for those who might genuinely need to use motor vehicles. The authors believe that there is a need to provide more parking for commuters who need to use a combination of private and public transport. Underground parking stations offer a number of advantages because:

- they can be located under existing facilities, eg suburban railway stations;
- they offer security and protection of vehicles from the weather; and
- the parking facility can include shopping facilities and commercial uses.

Tunnel spoil – a source of extractive industry material

Planned tunnel projects for Brisbane under TransApex will create approximately 20 km of tunnels over the next decade in the Brisbane area. The amount of material created is of the order of 10 Mt and this will vary from poor quality shales to quality aggregates and potentially dimension stone. A by-product of underground space in areas of good rock quality is good quality
extractive material. If the material is blasted, it is of considerably more value than material produced by a roadheader or tunnel boring machine (TBM). The authors suggest that the concept of Key Resource Areas used in Queensland, as applied under the State Planning Policy for Extractive Industry, should equally apply to areas suitable for underground space.

The future of underground space in Brisbane

Underground Space development, in parallel with infrastructure development, is a vital part of the combination to ensure that Brisbane is well planned for the future. It is important that Brisbane planners take the following action with regard to Brisbane's future:

- identify areas where underground space could be developed,
- identify the market needs for underground space projects and the commercial aspects of underground space projects including the full cost of construction and operation,
- identify areas that can be excavated by drill and blast methods, and
- incorporate underground space projects with the current TransApex Tunnel system.

Brisbane's first underground space commercial project

Over the past two decades, Alan Robertson has been enthusiastic to commission an underground space commercial project for Brisbane. He believes that the initial project should be kept simple and should be a 'test case' in terms of the relatively new concept of underground space which poses the following challenges:

- obtaining planning approval from the Brisbane City Council;
- drainage is a major issue – a self draining site is preferred;
- application of the Queensland Volumetric Titling Act, 1994, in regard to below ground strata in title; and
- ensuring excavation ground support, fitting out and fire and life safety installations are competitive with above ground construction in terms of risk management and cost.

Discussions are in progress with AVKO Mining and owners of potential sites in order to determine the best option for an initial construction project which may include a mix of commercial and office use in the CBD area.

CONCLUSIONS

The marketing of advances in open cut and underground blasting in the urban environment has not matched the technical improvements in recent years, mainly due to historical perceptions as to the effect of blasting in urban areas. The mindset, held by the public and authorities has meant that drill and blast is often not considered for underground tunnelling and underground space projects. This can affect the project price as generally drill and blast excavation is cheaper than mechanical excavation. Technical advances in blasting design and products, combined with a professional attitude by contractors will see a reintroduction of blasting in the urban environment, particularly in the development of underground space projects.

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REFERENCES