CONSTRUCTION BLASTING AND TECHNICAL DRILLING FOR THE WATERVIEW CONNECTION PROJECT

Nick Bastow (BSc Geography and Environmental Science), Blasting Project Manager,
Daniel Leemeyer (BE(Hons) Civil), Blasting Project Engineer, and
Jason Tavioni, Blasting Site Operations for RedBull Powder Company Ltd

1. Introduction

The Waterview Connection Project is the largest civil infrastructural project to be awarded in New Zealand, with an estimated value of $1.4 billion.

The project will complete the Western Ring Route in Auckland city, a collection of projects that make up one of the seven Roads of National Significance projects that have been identified by the Government as key to New Zealand's economy (comment courtesy NZTA).

The Western Ring Route is the section of highway that will provide an alternative route north-south via motorway without having to pass through Auckland on SH1. It begins to the north where SH18 connects with SH1 near Albany, and reconnects with SH1 to the south at Manukau.

The Waterview Connection Project is the largest and final project of those comprising the Western Ring Route, and is represented by the dotted line connecting SH20 with SH16 on Figure 1 below.

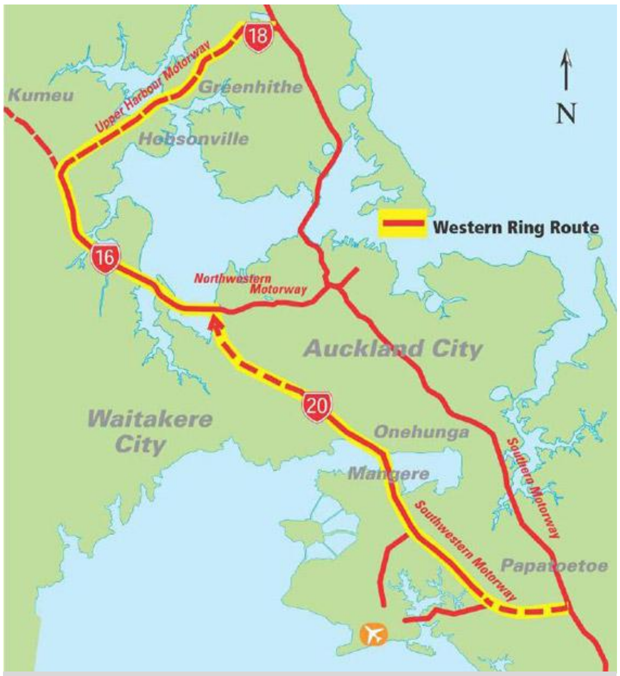


Figure 1 - Western Ring Route (photo courtesy NZTA website)

In addition to relieving congestion on the main SH1 link through Auckland, the Waterview Project will also provide a direct motorway link to the airport from the CBD, significantly reducing travel times between the two.

The project includes 4.5km of six-lane motorway, two 2.5km long dual tunnels passing beneath residential West Auckland, and a large interchange where the Waterview Connection will tee into SH16.

The project is being undertaken by the multi-national consortium, The Well-Connected Alliance (WCA), comprising the New Zealand Transport Agency (NZTA), who are the Client and Principal for this project; Fletcher Construction; McConnell Dowell Constructors; Parsons Brinckerhoff; Beca Infrastructure; Tonkin and Taylor; and Japanese construction company Obayashi Corporation.

Figure 2 - The Waterview Connection Project, connecting SH16 with SH20 (photo courtesy Wikipedia)

At the southern end of the project, where SH20 currently ends at Maioro St, the motorway will begin dropping into the ground in a deepening trench (represented by the purple line on Figure 2 above) until it reaches approximately 30m below the surface, at the southern tunnel portal. In this section of the project (covering the Southern Approach Trench (SAT), and much of the surrounding area) there is a 10-15m deep basalt flow lying north-south across the site.

RedBull Powder Company Ltd was engaged by WCA as the drill and blast contractor to remove this basalt flow where required. The basalt excavation was a significant part of the enabling works for the southern works component of the Waterview Connection Project.

2. Tender Process

There was a long tender process for the blasting operations for the Waterview Connection Project involving a number of competing tenders. RedBull submitted tender documents for the Hendon Sewer Trench Realignment (enabling works for the SAT); the SAT and adjacent wetland areas; and for the Technical Drilling works (Rock Bolting and Bored Drains work packages). In April 2012 RedBull was confirmed as the preferred contractor.

WCA engaged Dr John Heilig, an external Australia-based consultant to peer review RedBull's Blasting Management Plan (BMP). A consultation process began with WCA, Dr John Heilig, and RedBull to review and refine the BMP. Alongside this consultation process, a blasting workshop was conducted where concerns regarding the BMP were raised. Due to the setting of the project in such a confined and visible residential environment it was critical that all of the processes were strictly controlled.

Once all parties were satisfied with the BMP, it was adopted by WCA into their Work Safe packages and Job Safety and Environmental Analysis, and work onsite began.

3. RedBull's Involvement

The intention was for RedBull to start onsite in the early stages of the Hendon Sewer Trench excavation, far from adjacent property. However when blasting commenced the excavation had already progressed to where it was in very close proximity with adjacent property. Small trial blasts were completed, but it became apparent that compliant blasting could not be carried out due to the Charge Masses required to fracture the rock for effective excavation and the close proximity of neighbouring property.

Figure 3 - Aerial view of the southern portal May 2013 (photo courtesy The Well-Connected Alliance)

The SAT blasting began at the same time. 75,000bcm was scheduled and would involve multiple cuts, blasting down to a depth of 15m in places. Additional to the SAT volume 25,000bcm of wetlands and stream diversions was also scheduled for blasting. To date, one of the Ponds has been completed, and it was later found the stream diversions would not require blasting.

Technical drilling began after the first layer of basalt had been excavated back to the design batter lines of the SAT walls, as a part of the rock bolting and shotcrete system used to provide a retaining structure for the basalt face. The technical drilling works followed the basalt excavation layer by layer until completion.

Outside of the main tendered works there was also other miscellaneous drilling work completed, for a variety of work crews to create foundations or determine the depth of the basalt flow, sitting just below the existing ground surface over much of the site.

Blasting operations were conducted daily in the heavily congested SAT. The safe and efficient delivery of the project is a testimony to all personnel on site. Machines, personnel and other equipment were relocated daily during blast windows to reduce the risk of damage from flyrock. Although these precautions were taken for all blasts, no rock left a blasts immediate vicinity.

The BMP stipulated blast guards and a firing procedure that ensured all equipment and personnel were clear of the blast (100m in front, 50m either side) prior to the firing window. Radio contact, warning procedures and diligence from site personnel led to no unidentified issues prior to firing blasts on this project.

4. Southern Approach Trench Volumes

The SAT was divided into five zones by WCA, to create manageable sized work areas in line with changes in the nature of works (due to different ground types for example). The basalt flow sits in various depths along the length of the SAT. With reference to Figure 4 overleaf; zones 4 and 5 represent the basalt flow closest to the southern portal; zone 3 an area in the middle that did not require blasting; and zones 1 and 2 areas with shallower cuts into the basalt as the SAT ramps up out of the ground.

The initial approach to the SAT component of the project was to start in zones 4 and 5. WCA's priority was to excavate the basalt from the southern portal to allow other enabling works associated with the arrival of the tunnel boring machine (TBM) to begin. RedBull started on site in July 2012, and shot approximately 30,000m^3 in zones 4 and 5 from July through to October.

The project had been budgeted on blasting 800m^3 per blast day, and initially this was consistently achievable. However as the excavation began to grow, increasing numbers of other trades and work crews began working in close proximity to RedBull, placing pressure on area availability, affecting production rates. This led to zone 2 being made available, providing an additional 18,000m^3 that offset completing zones 4 and 5. The Alan Wood Pond was also started at this stage, with the 4000m^3 completed in conjunction with Zones 2, 4 and 5.

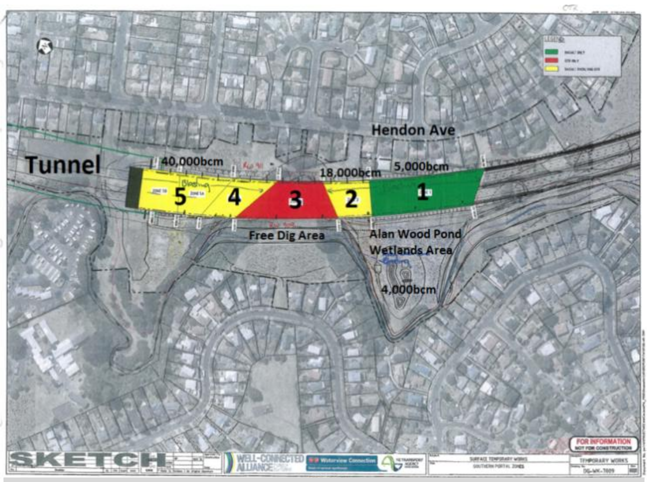


Figure 4 - Southern Approach Trench works zones

Zone 1 was waiting on the connection of the new HS diversion. Once the diversion was complete, Zone 1 opened up another large blasting area, as the completion of zones 4 and 5 and the Alan Wood Pond was beginning to put pressure on blasting production rates.

At the time of presenting this paper (May 2013) RedBull has shot approximately 70,000m^3, which accounts for the SAT, the Alan Wood Pond, and parts of the Hendon Sewer Trench. There are potentially 5,000-10,000m^3 remaining to blast in another wetland area, currently scheduled to start in early 2014.

5. Blasting Process

Drill and Blast operations were undertaken as close as 30m to adjacent properties. Vibration and air over pressure limits were imposed to minimise the effect on people in the surrounding areas, and to reduce the risk of any structural damage that could be attributed to the drill and blast works over the duration of the project.

Prior to work beginning on site, a theoretical vibration model was developed using rock constants (K and n factors) from other similar sites in Auckland. This model was used to estimate the peak particle velocity (PPV) (measured in mm/s) and attenuation of that vibration, to determine what range of PPV could be expected at the residential properties closest to areas drill and blast works were proposed. The model served to demonstrate that RedBull's methodology conveyed in the tender process was viable, and that RedBull was confident compliance could be maintained throughout the project.

To confirm the model would be accurate for this site, small individual charge masses were initially fired. These are known as signature holes.

A series of signature holes were fired, gradually increasing in Maximum Instantaneous Charge (MIC) from 0.75kg to 3.75kg, in line with what would be necessary for production blasting. After demonstrating that this range of charge masses could be used while maintaining compliance, production blasts began.

To begin with, relatively small opening blasts were fired (10-12 holes) to generate a free face, providing relief of some of the blast energy through movement of the rock. This proved to be a key factor in reducing ground vibration throughout the project.

After loading and verifying a blast, heavy-duty wire mesh mats were laid over the top to reduce the risk of fly rock and control any energy escaping upwards from the blast through unknown seams or faults. These were placed on all blasts over the duration of the project.

Once the focus shifted from compliance to production, and blasting on site became a recurring activity, panel blasting was utilised to reduce the effect of blast energy released in any given blast. This technique allows a greater number of holes to be fired in a blast window, as it provides a delay between panels (or a series of holes) allowing the energy to dissipate prior to initiating the next panel. This technique greatly reduced waveform durations and amplitudes, and helped ensure production targets could be met by preventing vibration from dictating maximum blast sizes. The waveform below (Figure 5) gives a visual representation of this.

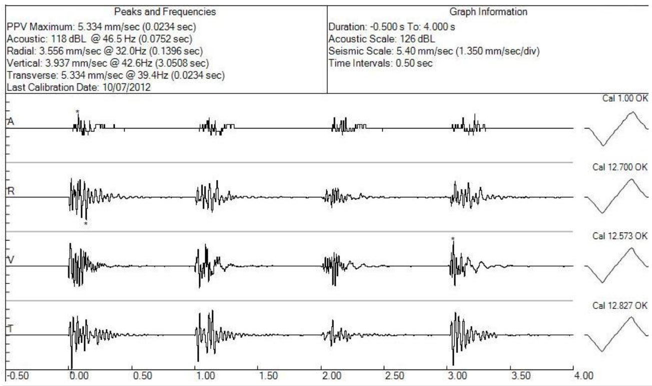


Figure 5 - Typical waveform from a Waterview blast. Note the delay between panels allowing blast energy to dissipate prior to initiating the folowing panel

6. Signature Hole Analysis

RedBull use White Seismology Inc. seismographs and accompanying software to monitor ground vibrations generated from blasting, and assess inter-hole delays to minimise the PPV generated.

The seismographs report vibration and air over pressure as a waveform, which is a graph of ground movement or acceleration with time. An example is shown below for a typical signature hole (see Figure 6).

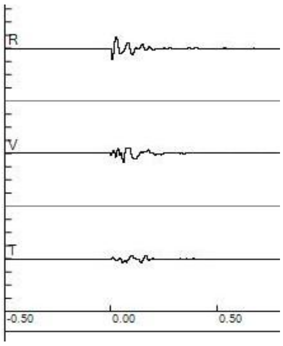
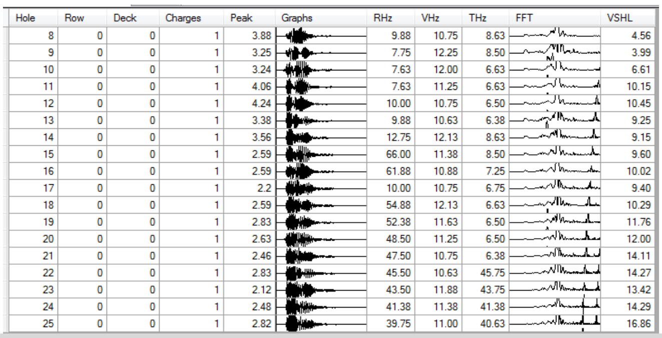


Figure 6 - Typical signature hole waveform. The Radial, Vertical, and Transverse PPV is recorded

Analysing these waveforms allows the inter-hole timing for multiple-hole blasts to be determined. The software simulates the shape of the waveform that could be expected if a given number of holes all producing a similar waveform were fired with a fixed delay (inter-hole timing). The concept is to try and overlap the peaks from one waveform with the troughs of the next, reducing the resultant vibration by overlapping waveforms. The software provides iterations within a range of specified timings, and the user can then review and select the appropriate timing. An example is provided below (see Figure 7).



Hole	Row	Deck	Charges	Peak	Graphs	RHz	VHz	THz	FFT	VSHL
8	0	0	1	3.88		9.88	10.75	8.63		4.56
9	0	0	1	3.25		7.75	12.25	8.50		3.99
10	0	0	1	3.24		7.63	12.00	6.63		6.61
11	0	0	1	4.06		7.63	11.25	6.63		10.15
12	0	0	1	4.24		10.00	10.75	6.50		10.45
13	0	0	1	3.38		9.88	10.63	6.38		9.25
14	0	0	1	3.56		12.75	12.13	8.63		9.15
15	0	0	1	2.59		66.00	11.38	8.50		9.60
16	0	0	1	2.59		61.88	10.88	7.25		10.02
17	0	0	1	2.2		10.00	10.75	6.75		9.40
18	0	0	1	2.59		54.88	12.13	6.63		10.29
19	0	0	1	2.83		52.38	11.63	6.50		11.76
20	0	0	1	2.63		48.50	11.25	6.50		12.00
21	0	0	1	2.46		47.50	10.75	6.38		14.11
22	0	0	1	2.83		45.50	10.63	45.75		14.27
23	0	0	1	2.12		43.50	11.88	43.75		13.42
24	0	0	1	2.48		41.38	11.38	41.38		14.29
25	0	0	1	2.82		39.75	11.00	40.63		16.86

Figure 7 - Waveform iterations for 8-25ms inter-hole delays for a typical signature hole waveform analysis

7. Blast Patterns and Design

The MIC range that was being used on site, required production rates, and nature of other works going on around blasting activities led to a 3m cut depth being used across site. In some areas further from adjacent properties cut depths reached 4.5m, and in areas where final cut depths were required for the bottom of the trench cut depths reduced to as little as 1.5m.

The blast pattern used on site changed regularly. Geology, bench height, and location on site all affected the pattern used for each blast. The properties of the basalt flow changed drastically at varying depths (see Figure 8 below). The columnar basalt in the middle of the flow was far more competent than the more weathered rock at the top of the flow, and a highly fractured section was encountered at the bottom. All of these changes required different blasting techniques for successful excavation of the rock.

Figure 8 - Basalt geology in zones 4 and 5

RedBull elected to use a packaged emulsion cartridge produced at their Kopako Explosives Reserve for the project. RedPak 65mm x 400mm aluminised emulsion cartridges were used on site. These loaded well in the 89mm blast holes and offered good control over MIC, heave and fragmentation. Successful blasting was a balancing act between controlling the vibration and compliance requirements of a construction project, and meeting the production and fragmentation targets of a tight project programme.

The other main factor that led to the use of the emulsion cartridges was their waterproof property. The water table on site was generally fairly high, and the deeper the basalt excavation ran (in areas up to 4 and 5 cuts deep) the more frequently water was encountered. Holes were loaded as soon as practicable after being drilled, but wet holes were not uncommon on site. Cartridges made loading wet holes and controlling MIC achievable. They also removed any potential issues associated with runaways or cavities in the rock mass.

The 89mm diameter blast holes drilled offer good distribution of explosives in the rock mass, while still providing some tolerance for the 65mm cartridges for loading purposes. In areas with clay pockets or where water was causing holes to silt up loading was still possible.

RedBull drilled over 6000 blast holes throughout the duration of the project. These coupled with the 14,000 RedPak 65mm cartridges accounts for the 70,000m^3 of basalt shot on site to date.

Figure 9 - Typical blast on the Waterview project, one panel depicted just after initiationon above

8. Vibration Analysis and Prediction

Maintaining compliance, especially with vibration limits, was one of the key aspects of RedBull's involvement in this project. A felt intensity limit of 5mm/s (PPV) for blasts was imposed for occupied dwellings, with 100% of blasts required to be less than 10mm/s (PPV). The frequency-dependant German DIN4150 Standard was stipulated to protect residential and commercial structures. Notably, 95% compliance was required over the duration of the project.

Early in the project it was identified that in places the felt intensity limit would not be achievable due to the close proximity of proposed blast areas to occupied dwellings. Previous industry experience with close proximity urban blasting has shown that with an increase in PPV comes an increase in frequency, which requires a greater PPV threshold for cosmetic damage as a result of blasting.

Residents in sensitive areas were approached and subsidised for temporarily vacating their premises during blast windows, allowing the DIN4150 frequency dependant curves to govern blasting operations. This allowed production blasting to continue.

RedBull found that the vibration behaviour was very different across the site. Each new area required a repeat of the process; signature holes through to production blasts, with different optimal timings selected for each area as a result of differing K and n factors determined through signature hole analyses. Timings were in the range of 10-20ms per hole.

As the project progressed, and a data set began to build for the fixed monitoring locations, it was apparent that the direction a blast was fired (with relation to an initiation point), and the location and orientation of the blast in relation to the monitoring locations affected the vibration recorded.

Scaled distance relationships were used to predict the PPV at a given distance for a given charge mass. Figure 10 (below) is generated from data from zones 4 and 5 and shows poor correlation. These blasts were fired on all sides, depths and directions of the 15m deep excavation in relation to the monitoring locations.

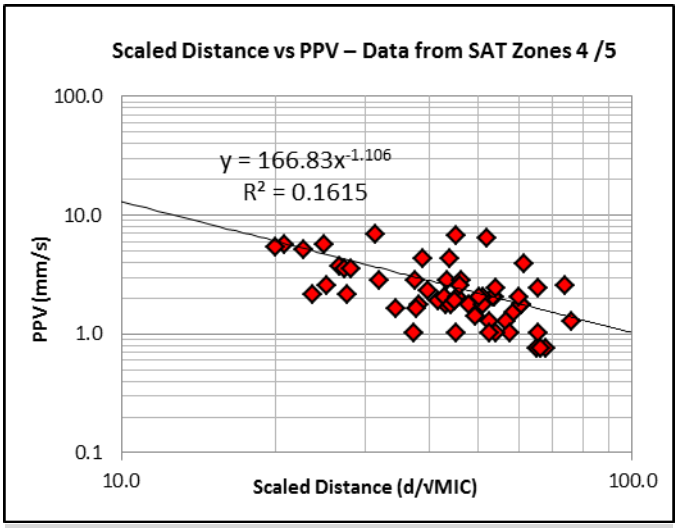


Figure 10 - Scaled distance relationship from the fixed monitoring locations in zones 4 and 5

Around the time zone 2 was made available for blasting, there were questions being asked about blasting a particularly sensitive area of the Hendon Sewer Trench, in very close proximity to dwellings. RedBull took the opportunity to trial the trench blasting situation in zone 2 and investigate the PPV range that could be expected at the distances being proposed.

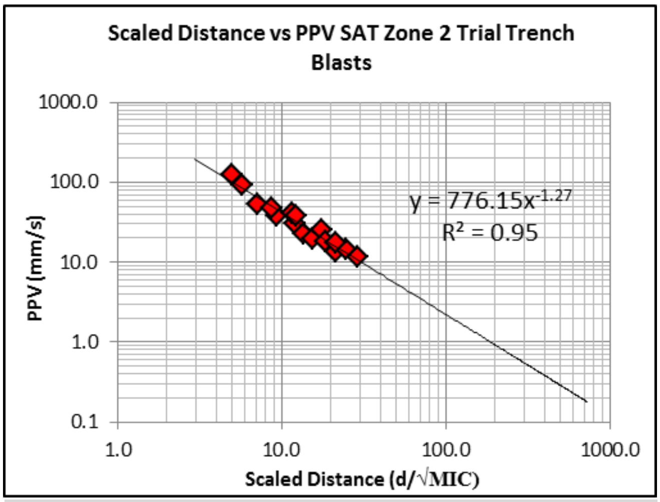


Figure 11 - Scaled distance relationship for blasts initiated in the same direction, working the same free face

Temporary field monitoring locations were set up, and a series of blasts were fired at various depths and with varying

MIC's, but consistently in the same direction. It was found on the scaled distance relationship (see Figure 11 above), that this approach produced a much better correlation. This technique was useful for producing the scaled distance relationships prior to production blasting.

9. E*Star Electronic Initiation System

Austin Powder Company's E*Star Electronic Initiation system was used for the project. The E*Star detonator allows the blasting precision that was required for the technical and challenging vibration control on this project.

The system can fire up to 1600 detonators in a single blast which is ample for this project. It has a firing window of 1-10,000 milliseconds, accurate to 0.1% of the nominal delay. This allows single-hole initiation, which coupled with the signature hole analysis provided the effective vibration control required on this project.

The large time window also enables the panel blasting techniques implemented to help dissipate blast energy. As with all electronic systems, no surface delays are required, significantly reducing the noise of blasting operations.

The E*Star system offers straightforward logging, leakage testing, and blast initiation. On the bench, detonators are individually programmed and leakage tested prior to priming and loading a blast. The verification process starts on the bench, with multiple checks prior to firing time. Faulty detonators can be identified, and detonator leads and harness wire (used for connecting the detonators into a circuit and to the blast box) integrity can be monitored easily

*Figure 12 - Shotfirer connecting E*Star logger to an E*Star electronic detonator clip for programming blast timing at Waterview*

with the logger and leakage tester as required.

The on-bench current testing for blast leakage and detonator verification is a process where all the detonators on the shot can be powered up at a safe non-firing voltage from the logger; checked to ensure all are present and identify any that are unlogged. This ensures the blast has been wired up correctly and flags any issues prior to stemming.

The blast was also tested regularly while placing the blasting mats, ensuring any damage to the detonators or harness wire could be found and mitigated prior to the blasting window minimising disruption to site operations.

When the firing command is sent, all detonators are simultaneously initiated, counting down the programmed timing. The benefit with small pattern construction blasting is any lateral shift damaging down the hole leads will not prevent a hole from firing. Once the fire command is sent, the detonator will fire regardless. This is especially important with large delays between adjacent holes between panels.

Any harness wire or detonator issues present will prevent the system from initiating the blast, allowing troubleshooting and preventing a misfire situation. Remote logging is possible if required.

These abilities meant that any potential misfires could be identified prior to the blast and either rectified or identified reducing the blasting risk to the excavation and processing process.

10. Technical Drilling

Technical drilling was a major component of the project. Production quarry drilling rigs were used for drilling near horizontal rock bolt holes, and beyond horizontal (slightly upwards) bored drains into the basalt face for drainage purposes, as deep as 15m.

WCA's project design team identified that the columnar nature of the basalt coupled with the height of the face above the motorway (approximately 30m at the portal) meant the face would require support for protection from erosion and weathering over time, causing rock-fall onto the motorway. Rock bolting and shotcreting was proposed.

The rock bolts were drilled in diameters ranging from 64-127mm 4-6m into the face, and grouted in, creating anchorage. They were typically drilled at approximately 10-15 degrees above horizontal into the face, perpendicular with the design batter. A reinforcing mesh was applied to the face and connected to the rock bolts, and a shotcrete layer sprayed over the face to form a protective barrier for the reinforcing mesh and a retaining structure for the basalt columns.

Bored drains were later drilled through the shotcrete and into the rock, in diameters ranging from 89-127mm, at depths ranging from 5-15m. These bored drains reduce the water pressure behind the shotcrete layer by providing a drainage path for the water other than the shotcrete basalt interface.

Figure 13 - Columnar basalt and Tamrock drill mast

Figure 13 above shows the nature of the columnar basalt well. This pictures some of the first rock bolt holes being drilled near the southern portal. The blasts bordering the trench walls were kept back at an appropriate standoff

Figure 14 - Tamrock drill rig drilling a bored drain into the completed shotcrete face near the southern portal

distance, with end or back break from the blasts fracturing the rock enough to allow scaling back to the batter lines. WCA scaled the face back to competent rock, and marked out the design pattern, ready for drilling.

Over the duration of the Project, RedBull drilled 1800 rock bolts and 200 bored drains, over 10,000 lineal drill meters.

11. Conclusion

RedBull delivered the blasting operations for the Waterview project in a safe, compliant and efficient manner; strict adherence to the processes put in place during the tender stages facilitated successful blasting. 97% compliance was maintained with the DIN4150 standard, and no significant safety incidents occurred, a credit to all personnel on site given the close proximity of blasting operations with other trades. Figure 15 below is a typical representation of the level of activity encountered daily in the SAT.

RedBull completed the basalt blasting on programme,

Figure 15 - Typical daily works in the Southern Approach Trench

working closely with WCA across the project to meet production targets. RedBull left the site ready for the arrival of the TBM and the vast amount of civil infrastructural work to come.