4. Management covering blast design

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A study on vibration isolation effect of damping holes in excavation blasting

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ABSTRACT: Based on subway station excavation blasting, the isolation principle and effect of damping holes are studied through numerical simulation and statistical analysis. Damping holes in the transmission path have changed the physical properties of propagation medium, the medium interface of damping holes is seen as a displacement of the interface of elastic half space. The transmission coefficient is less than 1, which shows the blasting seismic wave energy is reduced by damping holes.

The Midas / GTS numerical simulation results show, in the case of 2m distance between a single row of damping holes and explosion source, the vibration isolation rate of damping holes is 5% ~ 13%. With the increase of the distance between the vibration measuring point and the single row of damping holes, its isolation effect decreases gradually.

In excavation blasting, the blasting vibration is tested and vibration data with or without damping holes are collected. Regression analysis for the blasting monitoring data shows the peak particle velocity of vibration with damping holes is less than those without damping holes, which will reduce the vibration intensity and damage to the surrounding structures (such as the underground continuous wall). With the increase of the distance from the blasting area, the blasting vibration isolation effect of the damping holes is not obvious more and more, which is similar for both simulation results and monitoring results.

1 PROJECT OVERVIEW

Changsha automobile north station, the starting point of Changsha metro system, is located in Kaifu District of Changsha City. It is an underground two island station, surrounded by dense buildings and vehicles/pedestrian traffics. The station has a total length of 495.5m, an effective platform width of 11m. The excavation site of the standard segment pit has a width 19.7m, depth 16 ~ 23m, and weak rock structure with a overburden of 10m thick. Underground continuous wall is used as the retaining structure of the pit.

Bench blasting (milliseconds delay) is used in the pit excavation—blasting hole diameter 90mm, hole depth 5-6m, hole distance 2-3m, the maximum charge for the single delay round is 3.2~6.4kg. NONEL detonation system is adopted with a delay interval of 110ms.

Therefore, how to reduce the influence of blasting vibration on the surrounding structures, particularly in the blasting operation of foundation pit, is the focus of the construction .The damping holes are used and their isolation effect is studied.

2 MODEL AND PARAMETER SELECTION

Midas / GTS finite element analysis software is used to simulate the excavation conditions, three cases are considered in the building of simulation models: 1st case-- one row of holes pitch damping (with 0.3m hole distance and 2m distance between the load and the row), 2nd case-- one row of holes pitch damping (with 0.5m hole distance and 2m distance between the load and the row), 3rd case-- no damping holes at all.

For the simplification of simulation, the model used has a pit length of 200 m and a width of 20 meters in Midas / GTS. In order to eliminate the boundary effect on the results of the calculation, the simulation size has a length of 400 m, a width of 20 meters and a height of 100 meters - 2 to 3 times the size of the pit concerned. The whole model has nearly 100,000 units in the division unit in order to make computing faster, and to make the calculation more accurate, the regional division of the blast loads more dense grid near some of the grid length is about 1m, with blasting loads farther distance, unit length increases from 1m to 5m arithmetically. In this model, two layers of rock and soil are considered, of which the upper layer is 10 m of coarse sand and the rest are weathered slate. Model diagram is shown in Figure 1.

2.1 The choice of parameters

Table 2. Ground reaction force coefficient.

Ax (m^2)	Ay (m^2)	Az (m^2)
5000	20000	10000
Kx (Pa)	Ky (Pa)	Kz (Pa)
1.84×10^9	1.09×10^9	1.42×10^9

The Mohr coulomb model is used, with unit area damping $C_p=1.41\times10^7 Ns/m^3$ and $C_s=9.978\times10^6 Ns/m^3$.

2.2 The determination of blasting load

The explosive charge is calculated by volume, then fine-tuned according to the actual situations of the blasting and the blasting engineer's experience to ensure the blasting efficiency and reduce the blasting vibration effect on the surrounding environment.

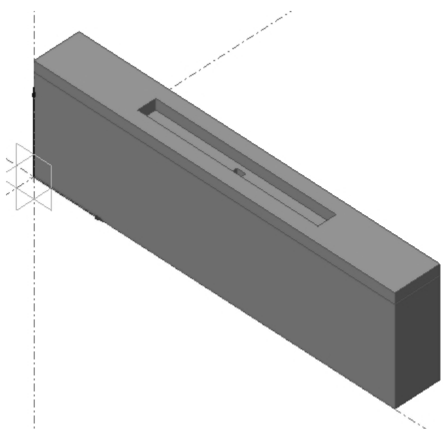

Figure 1. Model of pit excavation.

Table 1. The basic parameters of the material.

Material	Modulus of elasticity E(GPa)	Poisson's ratio	Density (kN/m^3)	Cohesive strength (KPa)	Angle of internal friction (degree)
Coarse sand	40	0.24	20	0	30
Slate	50	0.16	22	30	32
concrete diaphragm wall	45	0.16	25	250	50

The charge per blast hole is finalized as 4.9 kg, blasting holes as Φ = 90 mm, hole depth L = 5.0 m, hole pitch of 2 m, row spacing of 1.8 m. In cut blasting the detonation is done with the same period for holes 1, 2, 3 and 4, after the formation of free surface, and then holes 5, 6, 7 and 8 are initiated at 50ms delay interval. Schematic diagram is shown in Figure 2.

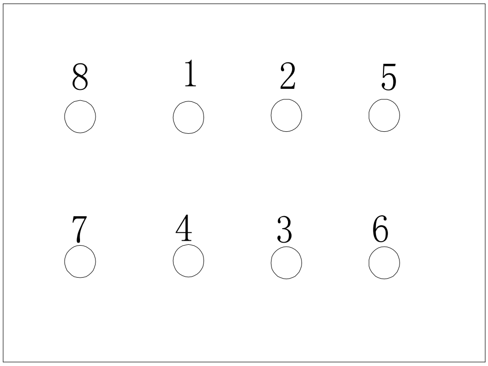

Figure 2. Schematic diagram cut blasting hole layout.

In this paper, the blasting load curve is triangle. In the cut blasting, we can calculate the peak load 7000 KPa, load rise time of 10 ms, unloading time of 90 ms according to the empirical formula. Using the same formula, the peak load of 5, 6, 7, 8 hole can be calculated. After cut blasting holes are initiated, a new free surface is formed, which can reduce the blast resistance of subsequent holes, and reduce the blasting vibration effect on the walls of the foundation pit. Except the cut hole, a peak load reduction factor is adopted when calculating the peak load of the subsequent holes. For subsequent holes, the peak load is of 3500 KPa, the load rise time of 10 ms, the unloading time of 90 ms.

According to the relevant experience, the two segment of initiation delay time is generally 50ms. The above two bands of blasting load curve are superposed, getting the synthetic load curve shown in Figure 3.

3 THE ANALYSIS OF NUMERICAL SIMULATION RESULTS

3.1 PPV analysis with and without damping holes

1.PPV in vertical direction

Peak particle velocity of blasting vibration (PPV), in vertical direction, without damping holes and with a row of damping holes (with 0.3m hole spacing and 2m distance between the load and the row) are shown in Table 3. The observation points arrangement diagram is shown in Figure 4:

From Table 4: when the blast center distance of 10.12 m, the PPV in the vertical direction without damping hole is 1.8386 cm/s, and the PPV with a row of damping holes is 1.6071 cm/s. The vibration velocity is reduced 0.2315 cm/s. It can be concluded that vibration velocity with damping holes is less than that without damping holes. The damping rate of the damping holes is defined as follows:

$$\rho = \frac{V_0 - V_1}{V_0} \times 100\% \tag{1}$$

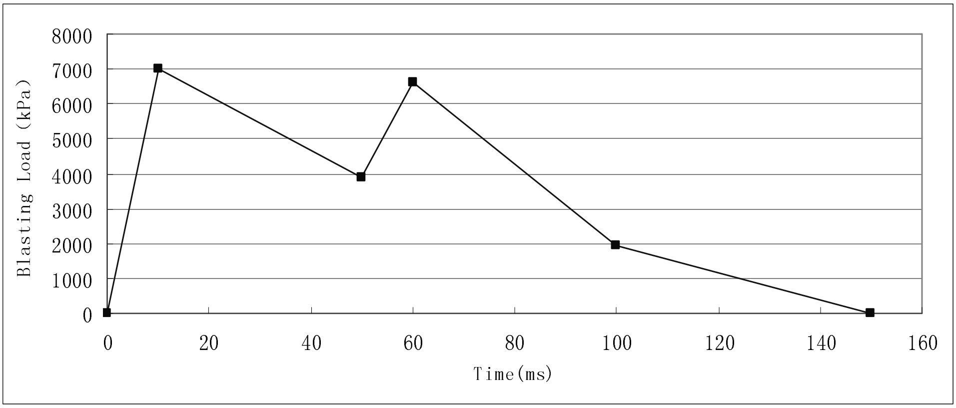

Figure 3. The synthetic blasting load curve.

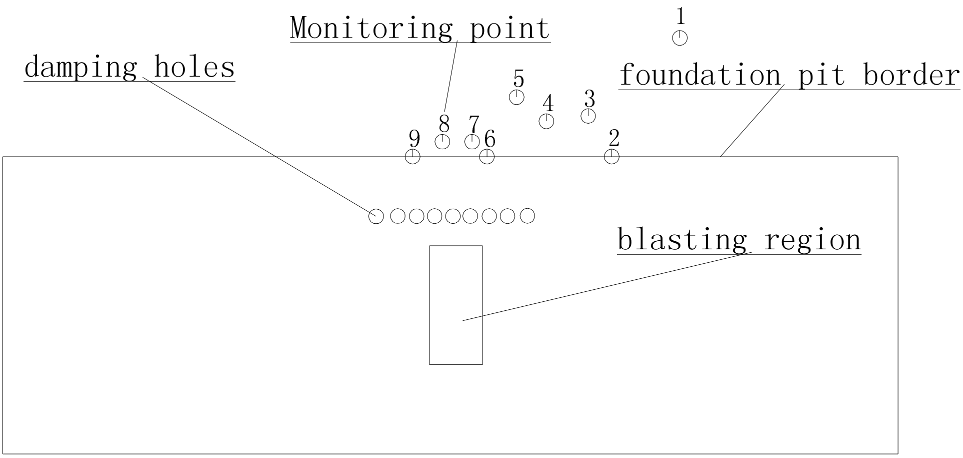

Figure 4. Monitoring point arrangement diagram (hole pitch of 0.3 m).

Table 3. PPV without damping holes and with a row of damping holes.

Observing point	Distance to blast center (m)	Observation point coordinate			PPV without damping hole (cm/s)	PPV with damping hole (cm/s)	Damping ratio
		x (m)	y (m)	z (m)			
1	25.59	214.99	44.98	100.00	0.4577	0.4243	7.30%
2	15.16	210.40	35.00	100.00	1.3255	1.2122	8.55%
3	16.08	208.82	37.73	100.00	0.7727	0.716	7.34%
4	14.23	206.03	37.38	100.00	0.9981	0.8995	9.88%
5	15.10	204.39	39.11	100.00	0.7989	0.726	9.13%
6	10.61	202.56	35.00	100.00	1.8259	1.6039	12.16%
7	11.72	201.81	36.38	100.00	1.3258	1.1867	10.49%
8	11.23	199.38	36.23	100.00	1.3444	1.1946	11.14%
9	10.12	197.45	35.00	100.00	1.8386	1.6071	12.59%

Where ρ is damping rate in %; V_0 is Vertical vibration velocity without damping hole in cm/s; V_1 is Vertical vibration velocity with damping hole in cm/s.

As shown in Figure 4 and Table 3, observation points 2, 6 and 9 are in a straight line parallel to the long edge of the foundation pit (x axis), with the increase of blast center distance, blasting vibration velocity is reduced and the damping rate is also dropped (at observation points 2, 6 and 9 it is 8.55%, 12.16%, 12.59% respectively). Figure 5 shows that the damping rate decreases with the increase of blast center distance, when blasting center distance is greater than 15 m, damping rate remains the same and less than 7%.

2. PPV in the horizontal longitudinal direction

Based on peak particle velocity of blasting vibration (PPV), in the horizontal longitudinal direction, without damping holes and with a row of damping holes (with 0.3m hole spacing and 2m distance between the load and the row), the relationship of blast center distance and shock absorption rate is shown in Figure 6. From comparison of Figures 5 and 6, it can be seen that the vibration attenuation range in the horizontal longitudinal direction is larger than in the vertical direction, the vibration isolation effect is obvious in the distance from the blasting center for the 10.0m to 21.8m range, and the damping hole near

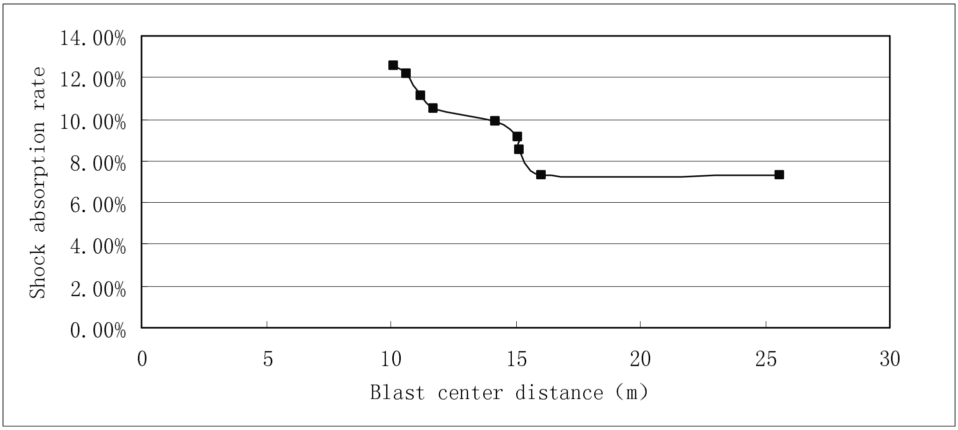

Figure 5. Relationship of blast center distance and damping rate in vertical direction.

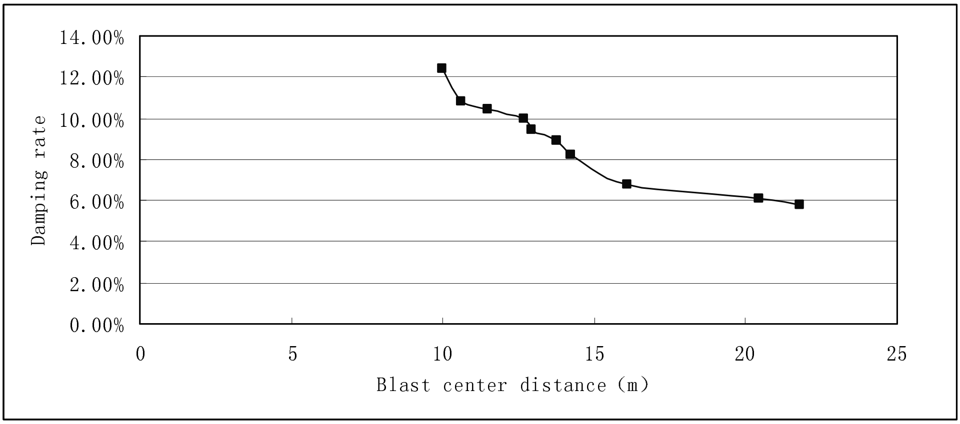

Figure 6. Relationship between blast center distance and damping rate in horizontal direction.

zone has a better effect of isolation. This is good for foundation pit enclosure structure. Therefore, the damping hole in the actual construction can play an important role to reduce the vibration effect.

3.2 PPV with spacing of 0.3 m and 0.5 m

The simulated horizontal longitudinal PPV data of damping holes with 0.3 m spacing and 0.5 m spacing are shown in Table 4.

As shown in Table 4, the PPV of damping holes with 0.3m spacing is less than 0.5m spacing of 0.0036 ~ 0.2867cm/s, which shows that the damping hole more intensive, the better isolation effect. But the damping rate of most observation points is lower than 1%, which also means 0.3m spacing holes compared with 0.5m spacing holes, the damping effect is not very obvious. From the perspective of economic benefit, the damping holes with 0.5m spacing are suitable.

4 ACTUAL MONITORING DATA ANALYSIS

The 6 times of blasting vibration test with comparative significance are conducted in the construction site, among them, 3 times have damping holes, and 3 times have not. The 6 damping holes, with diameter 90mm, spacing 0.5m, are arranged in a row, and the depth of damping hole is more than that of blast hole 0.5m.

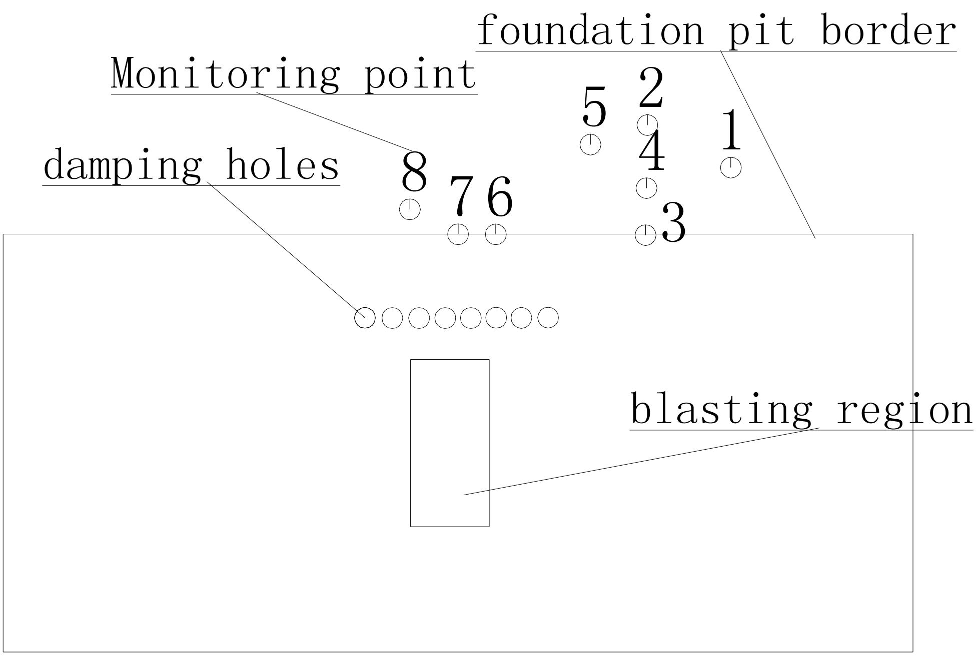

Figure 7. Monitoring point arrangement diagram (hole pitch of 0.5 m).

Table 4. PPV in horizontal of damping holes with spacing of 0.3 m and 0.5 m.

Serial number	Blast center distance (m)	Observation point coordinate			PPV (pitch of 0.3m) (cm/s)	PPV (pitch of 0.5m) (cm/s)
		x(m)	y(m)	z(m)		
1	22.07	216.26	38.76	100.00	1.5962	1.5998
2	21.74	210.71	43.31	100.00	1.8005	1.8144
3	15.16	210.40	35.00	100.00	2.1227	2.2092
4	19.31	210.21	40.72	100.00	1.9719	2.0029
5	20.49	208.28	43.27	100.00	2.0027	2.2894
6	11.48	204.63	35.00	100.00	2.4214	2.4321
7	10.61	202.56	35.00	100.00	2.4736	2.4924
8	11.33	200.59	36.21	100.00	2.4809	2.5002

The connecting line of single row damping holes and the connecting line of single row blast holes are ‘T’ shaped arrangement. The site monitoring data is shown in Table 5.

The fitting curves of relationship between PPV in vertical and scaled charge are shown in Figure 8, which have damping holes and have not, respectively.

The mathematical relationship between PPV with damping holes and scaled charge is in formula (2) and (3):

in Vertical direction
$$V_V = 9.024\left(\frac{Q^{1/3}}{R}\right)^{1.109} \tag{2}$$

in Horizontal direction
$$V_H = 7.893\left(\frac{Q^{1/3}}{R}\right)^{1.072} \tag{3}$$

Table 5. The site monitoring data.

With damping hole.						Without damping hole.					
Test No	Charge per delay (kg)	Measure point	Distance (m)	PPV(cm/s)		Test No	Charge per delay (kg)	Measure point	Distance (m)	PPV(cm/s)	
				Vertical	Horizontal					Vertical	Horizontal
1	6.4	1	16	1.56	1.43	4	4	1	4	2.76	3.31
		2	25	1.47	1.13			2	15	1.02	1.08
		3	50	0.29	0.20			3	22	0.35	0.29
		4	93	0.06	0.04			4	46	0.08	0.13
		5						5	98	0.05	0.03
2	4	1	5	2.08	2.19	5	6.4	1	10	1.75	2.61
		2	22	0.55	0.46			2	23	1.41	1.13
		3	21	0.63	0.59			3	50	0.62	0.53
		4	23	0.46	0.32			4	60	0.43	0.36
		5	49	0.02	0.09			5	80	0.05	0.13
3	5.6	1	70	0.23	0.11	6	5.6	1	6	3.07	2.42
		2	9	1.45	1.15			2	10	1.49	1.46
		3	60	0.59	0.61			3	55	0.59	0.91
		4	4	1.48	1.47			4	65	0.68	0.46
		5	110	0.02	0.09			5	105	0.25	0.24

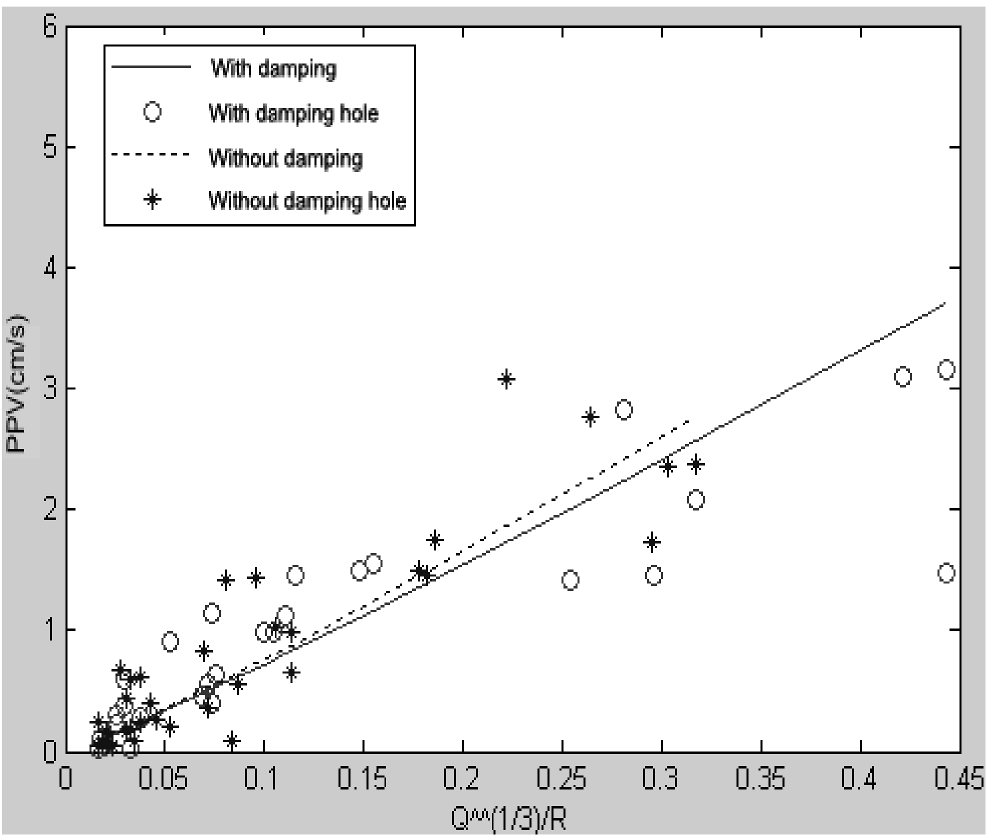

Figure 8. Fitting curves of vertical PPV with or without damping holes.

The mathematical relationship between PPV without damping holes and scaled charge is in formula (4) and (5):

in Vertical direction
$$V_V = 11.877(\frac{Q^{1/3}}{R})^{1.211} \quad (4)$$

in Horizontal direction
$$V_H = 11.740(\frac{Q^{1/3}}{R})^{1.214} \quad (5)$$

where V_V and V_H are PPV in Vertical direction and Horizontal direction respectively, in cm/s; Q is weight of the maximum charge per delay, in kg; R is distance between the detonation point and survey point, in m.

The Figure 8 shows that the fitting curve (solid line) with damping holes is lower than the one (dotted line) without damping holes in most segments, the greater the scaled charge (i.e., the same amount of explosive, the distance from the blasting centre ever smaller), the solid line compared to the dotted line is more and more low, the damping effect of the damping holes is obvious. With the increase of the distance from the blasting center, the two curves slowly close, almost overlapped, where almost no damping effect of the damping holes. As the above indicates, if the damping holes are far away from explosion source, the damping effect is not obvious. This is consistent with the simulation results which show that the distance from the blasting center is outside of 15m, damping effect of the damping holes is not good. This is mainly due to the damping hole is only 90mm in aperture with 0.5 m hole spacing, hole depth is insufficient, when the blasting seismic wave encounter the row of damping hole, diffraction will occurs, or the wave will pass through directly from the rock and soil under the holes or between the spacing of the holes. Therefore, the attenuation of blasting seismic wave has little to do with the damping holes, if they are far away from the blasting area.

In excavation practice, 0.5m damping hole distance has been adopted in blasting operation. The monitoring results and numerical simulation results are very close. Its damping effect is significant, which can fully meet the demands of the pit retaining structure.

5 CONCLUSIONS

(1) Simulation results show that both longitudinal and vertical blasting vibration velocities with damping are less than those without damping holes, their damping rate is about 10%. When the blast center distance is greater than 15m, the isolation effect of the damping hole is poor.

(2) Although the smaller the damping hole distance, the better the vibration isolation effect, the comparison results of damping rate for the single row of damping holes with 0.3m hole distance and with 0.5m hole distance show that the difference of their damping rate is not significant. So the 0.5m damping hole distance is recommended for its better economic efficiency.

(3) In excavation practice, 0.5m damping hole distance has been adopted in blasting operation. The monitoring results and numerical simulation results are very close. Its damping effect is significant, which can fully meet the demands of actual excavation concerned.

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Control blasting technology for a bridge with prestressed continuous concrete beams

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ABSTRACT: In consideration of the structural property of Maotai Bridge and the characteristics and requirements of its environment, a combination of mechanical and blasting techniques were used to demolish it. Windows were opened on the deck, steel pipe frame ladders were erected to connect arch ribs, steel pipe frame corridors and handrails were set up on arch ribs, and baskets were hung above piers, to overcome issues with high altitude construction and safety. Because of the technically exacting environment around the piers, different blasting parameters and protective designs were adopted to reduce the blasting damage. Flexible collapse of the bridge was achieved by controlling the delay time of the blasting network, which effectively reduced the shock load to the ground. Given the importance of the discharge pipes of Maotai Winery under the bridge, active combined with passive, and solid combined with flexible, protective schemes were used based on the theoretical analysis and model tests, which dramatically cut down the shock load damage of large fall to the ground.

1 INTRODUCTION

To develop the landscape on both sides of Chishui River, the Maotai Town in Renhuai City of Guizhou Province decided to demolish the Maotai Bridge. The bridge is a major thoroughfare in the centre of Maotai Town. It was opened in 1993 and has been in use for 19 years. Its deck was maintained in 2009.

1.1 Surrounding environment

The distance from the east side of the bridge end on the Maotai bank to civilian residences is about 50 m, and that from the west side is about 5 m. Crossing Chishui for Four Times Memorial Scenic Spot is about 25 m away from the east side of the bridge end on the Gulin bank, and there are houses 50m away from its west side. Directly below the bridge along the river are the Maotai Distillery's sewer pipe and the Maotai Town's waste water ditch. The surrounding environment is shown in Figure 1.

1.2 Bridge structure

The bridge is 281.923 m in total, of which the abutment of the Maotai bank is 24.6 m and that of

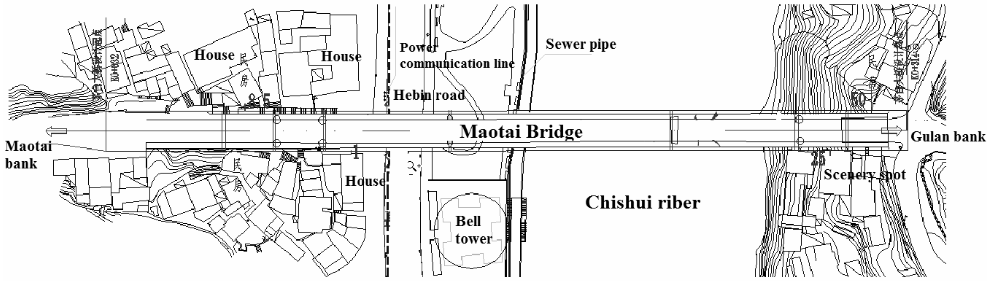

Figure 1. Surrounding Environment of the Maotai Bridge (Unit: m).

the Gulin bank is 17.68 m. The spans between the two banks are 12.158 m, 20 m, 50 m, 88m, 50m and 19.485 m. They are recorded as Span 1, Span 2, Span 3, Span 4, Span 5 and Span 6 for convenience. The main part of the bridge, Span 3, Span 4 and Span 5 (50 m, 88 m and 50 m) is the prestressed concrete continuous girder rigid frame and its vector height is 9.61 m. There are 4 main trusses across the bridge and the string axis of the main span is a quadratic parabola. The upper part of the approach are the simply supported reinforced concrete T beams, whose spans are 12.158 m, 20 m, 19.485 m separately (from the Maotai bank to the Gulin bank). Across the bridge there are 8 beams. The bridge is 13.0 m wide, including a 9 m driveway and two 2 m pavements. Pier No. 3 and Pier No. 4 supporting the main bridge are wall-shaped steel reinforced concrete pier structure. The lower part of the abutment cap is 2.4 m wide and 12 m long, and its upper part is 1.6 m wide and 12 m long. The upper part of Pier 3#'s abutment cap is 8.2 m high and its lower part is 7 m high. The upper part of Pier 4#'s abutment cap is 18.5 m high. The distance from the deck to the ground is 20 m, and to the water is 30 m.

1.3 Operational difficulties

The surrounding environment is complicated. The closest object requiring protection is just 5m away from the west side of the bridge end on the Maotai bank. Extremely strict control of the blasting damage and the vibration while the bridge falls to the ground will be required.

The time is limited. The divides from the deck to the ground and from the deck to the water are big, and the drilling, exploding and protection of the standing pole on the arch, the diagonal pole, the lower chord pole and Pier 4# above the water are difficult.

The distance from the deck to the sewer pipe and the waste water ditch is 26.5 m, which would lead to a huge shock. The protection work would be a big challenge.

2 OVERALL PLAN

Based on the bridge's structural characteristics, its surrounding environment and the owner's requirement, the plan of blasting demolition combined with mechanical demolition is decided.

Spans 3, 4, and 5 of the main bridge and Piers 3# and 4# will be demolished by blasting.

Spans 1, 2, and 6, Piers 1#, 2# and 5#, and the abutments on both sides will be demolished first by blasting and then by machine.

While the main bridge is exploding, spare Pier 4# 1m above the water. After the explosion above the water finishes, the underwater part will be

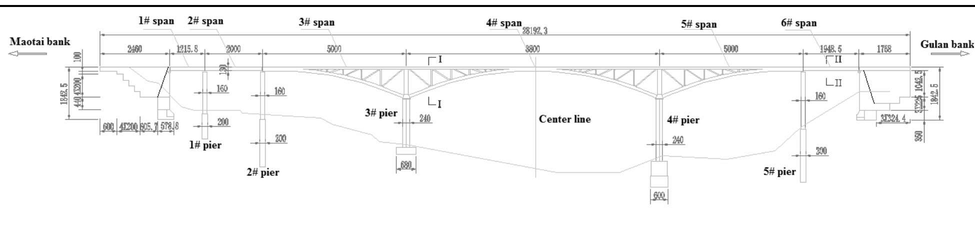

Figure 2. Maotai Bridge's structure (Unit: cm).

demolished by blasting.

Break the blocks into fragments by machine to meet the size requirement.

2.1 Construction plan

Because the arch of the Maotai Bridge is 20 m above the water (the ground), it is very inconvenient for workers or machines and dangerous. In order to finish the project safely and on time, before the demolition the position of the wall-sniped piers and the upright poles on the arches are marked on the deck. Dig holes on the deck, and build steel pipe scaffold ladders along the upright poles, corridors between ladders and arch ribs, and corridors and handrails on the arch ribs. The arrangement of the trestle are shown in Figure 3.

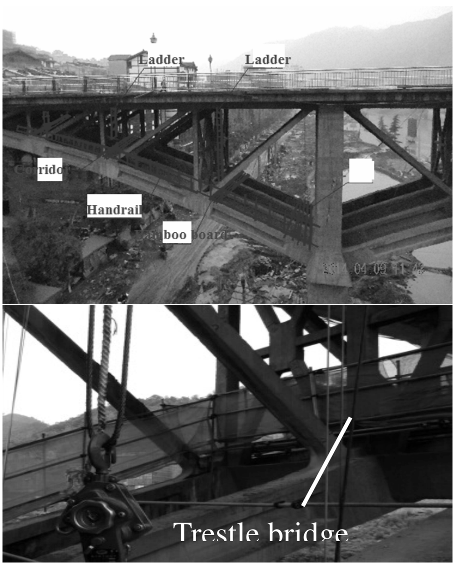

Figure 3. Schematic diagram and on-site picture of the trestle.

Set up two rows of scaffolds next to Pier 3#, and build a construction platform every 2 m. Set up a basket at Pier 4# to build the construction platform and safe passage. The construction schematic diagrams of the two piers are shown in Figure 4.

2.2 Blasting parameters

2.2.1 Blasting cut design on piers

The blasting cut of Pier 3# is 0.5 m above the ground. The part of the pier under the arch is from +0.5 m to +7 m. Holes were drilled on the pier from +0.5 m to +2.5 m. The hole distance is 80 cm, the row distance 50 cm, the hole depth 1.8 m, the dammed length 1 m and the charge amount of a hole Q is 800 g. The part of the pier above the arch is from +7 m to +15.2 m. Two rows of holes every 3 meters were drilled in this part. The hole distance is 60 cm, the row distance 50 cm, the hole depth 1m, the dammed length l is 0.5 m and the charge amount of single hole Q is 500 g.

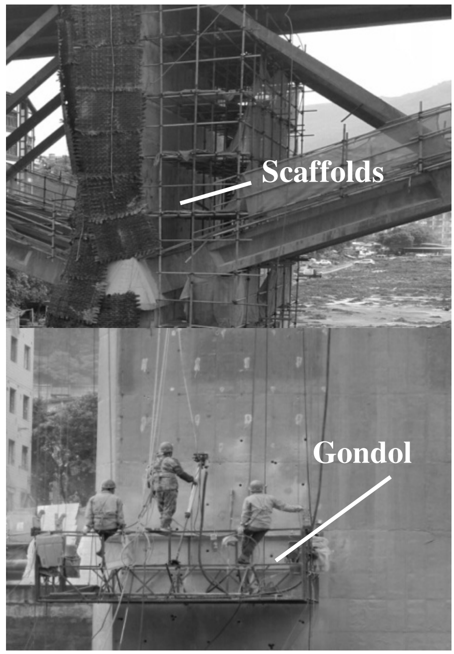

Figure 4. Construction schematic diagram of wall-shipped piers.

The blasting cut of Pier 4# is 1.0 m above the water. The part of the pier under the arch is from +1.0 m to +18.5 m. Holes were drilled in this area. The hole distance is 80 cm, the row distance 50 cm, the hole depth 1.8 m, the dammed length l is 0.5 m, and the single hole charge amount Q is 1300 g. The part of the pier above the arch is from +18.5 m to +26.7 m. Two rows of holes every 3 meters were drilled in this part. The hole distance is 60 cm, the row distance 50 cm, the hole depth 1 m, the dammed length l is 0.5 m, and the single hole charge amount Q is 500 g.

2.2.2 Blasting parameters of upper and lower chords, diaphragm plate and uprights on arch

The lower chord is 1.07 m high and 60 cm wide.

Table 2. Blasting design parameters of the lower chord.

Position	Hole Direction	Hole Distance /m	Hole Distance /m	Row Distance /m	Hole Depth /m	Number of Holes	Single Hole Charge Amount /g	Total Charge amount /kg
Upper Part	Vertical	0.25	0.25	0.15	0.15	640	35	22.4
	Vertical	0.3	0.3	0.3	0.8	192	70	13.44
Lower Part	Inclined	0.25	0.25	/	0.15	640	35	22.4

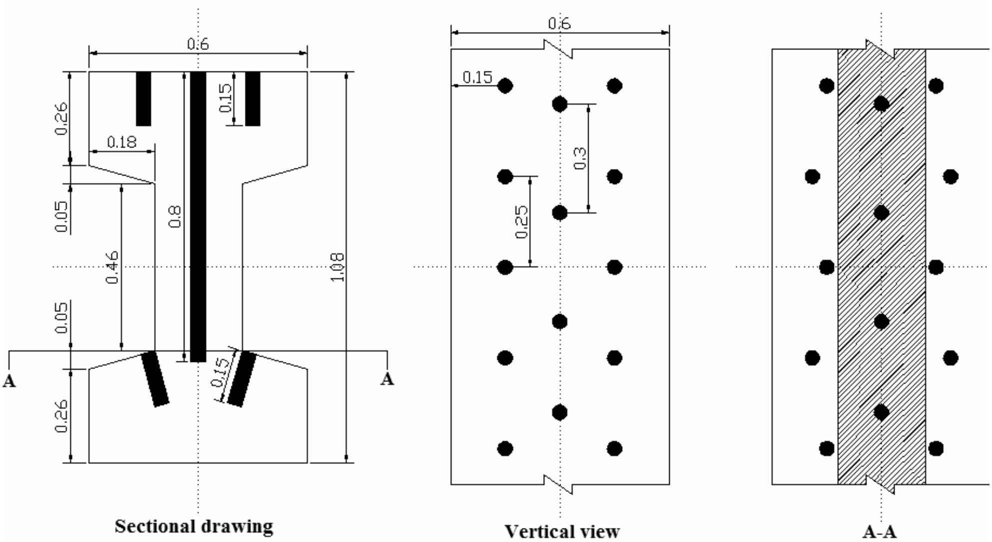

Figure 5. Hole arrangement of the lower chord.

Three rows of vertical holes were drilled on its top surface. The first and the third rows are 0.15 m away from the sideline. Its hole distance is 0.25 m and its hole depth 0.15 m. The second row is on the midline. Its hole distance is 0.3 m and its hole depth 0.8 m. Two rows of inclined holes were drilled on the lower wing of the lower chord. Its hole distance is 0.25 m, and its hole depth is 0.15 m. The drilling points of the lower chord are shown in Figure 5.

The upper chord is 0.7 m high and 60 cm wide. Vertical holes were drilled on it. The hole depth is 50 cm, the hole distance a is 50 cm, the dammed length l is 0.23 m and the single hole charge amount Q is 270 g.

The diaphragm plate is 0.8m high and 0.32 m thick. The diameter of holes drilled φ is 40 mm, its hole depth is 21 cm, its hole distance a is 30 cm, its dammed length l is 0.15m, its minimum burden w is 0.11 m, and its single hole charge amount Q is 60 g.

2.2.3 Blasting parameters of the bridge deck

The centre of the deck is thicker and its sides are thiner. There are chamfers at their connecting points with the upper chord. The thickness are 0.40 m, 0.35 m and 0.45 m. In order to reduce the vibration by falling, two rows of holes were drilled every 5 meters on the deck above the bank. Two rows of holes every 10 meters were drilled on the deck above the water, but the range of 10 m above the sewage pipe and the waste water ditch is fully drilled to decrease the size of the falling objects for reducing the damage of the falling shock at the largest extent. The hole diameter is 40 mm, its hole distance is 30 cm and its row distance is 30cm. The hold depth is 0.7 times of the thickness of the deck and the single hole charge amount is 30 g.

3 INITIATING NETWORK DESIGN

3.1 Division of blasting areas

In order to control blasting vibration and falling vibration, 4 segments of detonations were used in blasting the deck and the cross duel detonating network of the parallel-series-parallel-series circuit was applied. That is, from the Maotai bank, from the south to the north and from holes under the bridge to those on the bridge on a elevation, take 20 nonel tubes from two near holes in this order, use 2 Segment 1 detonators to propagate, 2 double Segment 5 detonators crossly to propagate, and then merge into the double main relay detonating network. The upmost explosive weight of every independent blast area on the piers is not more than 80 kg, and those on other places are not more than 40 kg.

3.2 Design of delay time

Use 1 Segment 15 nonel detonator at every hole to connect nonel tube bunches of every pier or beam into one cluster. The number of nonel tubes in each cluster is not more than 20. Millisecond delay detonation network is used in the main network. See Figure 6. Connect neighbouring big blasting areas in series by using MS-9 detonators to achieve the long period delay in the propagation, and in every big blasting area MS-5 detonators were used to make the short period delay. 2 double detonators were connected crossly at all propagation points to make sure the blast propagation from the Maotai bank to the Gulin bank.

4 PROTECTION DESIGN

4.1 Protection from blasting flyrock

To reduce the damage of flyrock by blasting, double rubber nets were tied by iron wires on holes under the deck and double rubber nets were weighed down by sandbags on holes on the deck. As the houses to the west on the Maotai bank are just 5 m away from the bridge, palm mattresses were hung on the part of bridge near the buildings. Because of the huge amount of explosives used in Pier 3#, a sandbag segregation barrier of 3 m high and 2 m wide was built 0.5 m away from the pier.

4.2 Falling vibration control

To control the damage from falling vibration, 9 sandbag damping dykes, which were 3 m wide and 2 m longer than the width of the deck, were built from the bridgehead on the Maotai bank to that near the Chishui River. The damping dykes have different heights so as to distract the weight falling to the ground at the same time, which could reduce the vibration by falling rocks. The heights of the damping dykes and the distances from each other are shown in Figure 7.

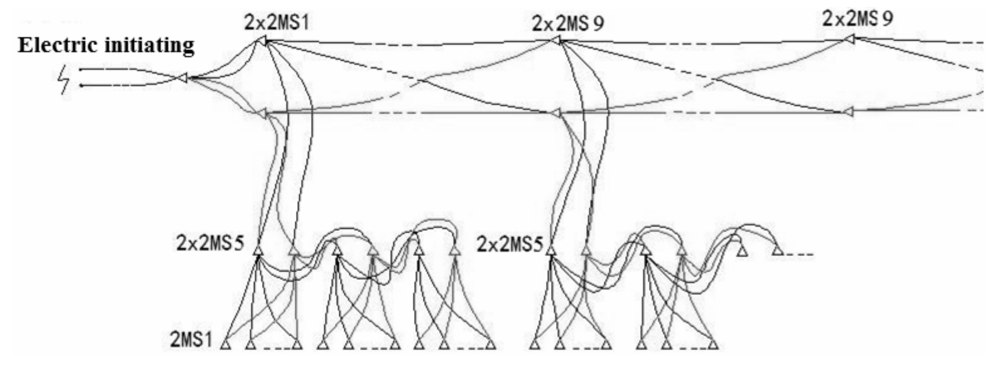

Figure 6. Diagram of initiation network.

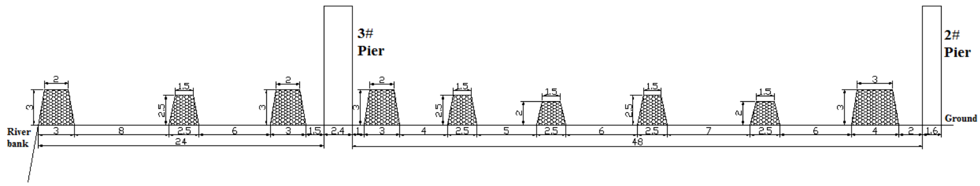

Figure 7. Arrangement of damping dykes under the bridge.

The sewage pipes of Maotai Winery and the waste water ditch of Maotai Town require the most protection. To reduce the distraction of the high falling shock to them, a comprehensive protection plan was applied. Since the beams and the cover plates of the sewage pipes cannot bear too much weight, the cover plates were opened in advance. The ditch bottom was flattened by sandbags, and double pipe culverts (φ 1.8 m) were set on the sandbags. The steel pipe culvert is 10 mm thick. Cross supports were welded in it to strengthen its stability. Steel plates were welded between the two pipes to fix them. The protecting wall of the dyke was covered by steel plates to prevent the pipe culverts destroying the wall when they are deformed by shock load. The double pipe culverts were covered by sandbags, and the pipe culverts of φ 2.8 m were set on them (steel pipe culverts, 10 mm thick, welded with cross supports). To make sure the sewage pipes stressed equally while the bridge is falling and avoid the destruction by stress concentration, fine sand and sawdust were filled between pipe chases and steel supports. The top of the ditch was filled with sawdust to increase buffering, then covered with steel plates of 3 m width, and finally set 2 to 3-layer sandbags. The protection range is 24 m, 5 m longer than each side of the bridge. The sandbag damping dyke on the ground and outside of the river dyke, with the steel pipes and the steel plates formed a closed protection system (see Figure 8).

5 BLASTING RESULT

The bridge was exploded at 1:03 p.m. on June 6, 2014. The main bridge was destroyed steadily from the Maotai bank to the Gulin bank. The blasting was successful, achieving the predicted results and producing good social benefits.

- The blasting fly rock was constrained in a controlled area, and did no damage to the surrounding environment.
- The measured vibration data of the nearest building to the Maotai Bank is only 1.23 cm/s. Neither the blasting vibration nor the falling vibration brought any damage to the surround houses.
- Piecewise initiation was applied and the bridge was destroyed steadily. The size of broken pieces was rather equal. See Figure 9.
- The sewage pipes and the waste water ditch were not damaged by the blasting. See Figure 10.

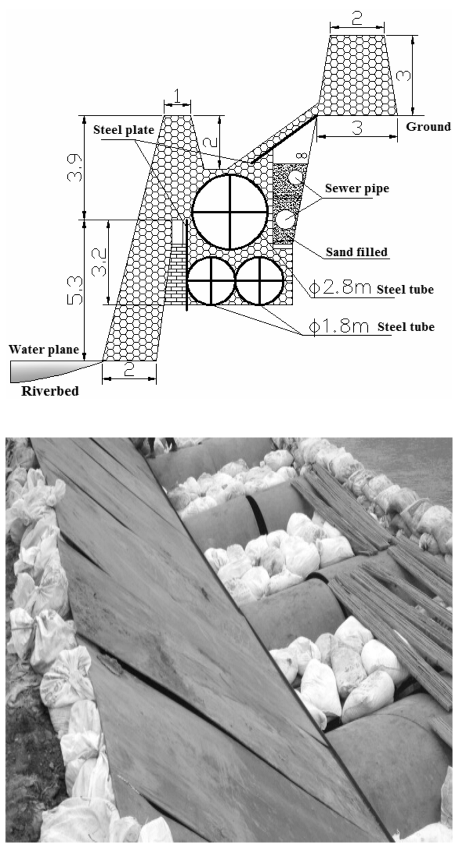

Figure 8. Protection of the sewage pipes.

Figure 9. Blasting result of the bridge.

Figure 10. The pipes and the ditch were not damaged.

6 CONCLUSIONS

When demolishing a bridge by blasting in a complicated urban environment, the bridge's structural characteristics, its surrounding environment and its owner's requirements should be considered carefully, and a combined blasting plan and different blasting parameters should be applied. What's more, the underground infrastructure should be checked, and specific protection schemes should be implemented to ensure the safety of the blasting program.

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Structure from Motion for blast planning

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ABSTRACT: Structure from Motion enables the automatic computation of 3D images from a set of unorganised photographs. 3D images are useful for surveying blast sites and planning blasts. Data acquisition reduces to free-hand photo taking at very high flexibility either for terrestrial or aerial imagery. Compared to classical photogrammetry the technique shows several advantages: firstly, it is much more flexible to use in the field, i.e. image taking; secondly, processing can be much more automatic; and thirdly, the results are more complete without (data) gaps. Compared with laser scanning the approach stands out by its cost-effectiveness and data quality.

1 INTRODUCTION

Incomplete knowledge of the geometry of a blast site and especially the face leads to unexpected blasting results. The consequences are not always severe but include safety-related and economic issues:

– Fly rock incidents
– Uneven walls and floors
– Boulders
– Excessive vibrations
– Too much fines
– Immoderate consumption of explosives
– Higher efforts for loading, hauling, and processing

The simple key to overcome these issues is comprehensively surveying bench face(s) and blast site and using this information accordingly. Comprehensive surveying means firstly, three-dimensional data over the entire face area plus secondly, visual information that captures the structure of the rock mass. Both entities are nicely combined with so-called 3D images. They provide a clear, understandable representation of a rock mass, which makes their use for face profiling straightforward.

2 BACKGROUND

Photogrammetric reconstruction of surfaces recovers 3D information using at least two photos from different angles, where the photos show the same part of a ‘scene’, e.g. a rock surface. The technology behind this is called photogrammetry and dates back to 1850 (Slama 1980).

In the 1990s upcoming digital imaging and availability of computing power brought new algorithms and new applications to image based stereoscopic measurement and led to the introduction of the term Computer Vision (Faugeras 1993). This technique has been used mainly in robotics but also for geometric rock mass characterisation (Gaich *et al.* 2003).

A more recent approach handles multiple photographs simultaneously in order to perform a fully automatic 3D reconstruction. This technique is known as Structure from Motion (Snavely *et al.* 2008). Structure from Motion has reached maturity in the computer vision domain but the number of applications using structure from motion remained rather low. Although the geometrical principles were developed in the 1990s it took until the 2010s where an application to high resolution unordered input photos have been realised mainly for the reconstruction of objects from unordered image collections obtained from internet user photo galleries (Snavely *et al.* 2008). Photogrammetry and structure from motion have merged then which brought structure from motion also to measuring and surveying tasks (Pollefeys *et al.* 2001, Hoppe *et al.* 2012)

3 STRUCTURE FROM MOTION – PROCESSING CHAIN

Photogrammetry as well as computer vision tries to recover a previously unknown 3D scene structure from a set of redundant 2D photographs. Structure from motion is a more recent approach that processes unordered images to a consistent 3D model. It uses an incremental reconstruction pipeline consisting of several steps that are conducted sequentially:

– Extraction of visual features
– Feature matching
– Verification of matched features
– Estimation of geometric camera arrangement
– Optimisation of geometric camera arrangement (see **Error! Reference source not found.**) Optional: determination of internal camera parameters (camera calibration)
– Densification and fusion of results

Step 1 extracts distinct visual features while Step 2 tries to find corresponding image points that are re-used later in Step 4 for finding the camera arrangement. If the input images are unordered and no other a priori information over common parts of the scene is available, the algorithm needs to match all possible image pairs. Since this might be computationally intensive and therefore a time-consuming task, the matching is split into a coarse and a fine matching step. After the coarse matching the number of potentially suitable images is reduced.

Once corresponding points between single pairs are available, Step 3 verifies the results by calculating an estimate for the arrangement of the two cameras that led to this pair using the fundamental matrix or in the case of calibrated cameras using the essential matrix (Hartley & Zisserman 2004). This step eliminates false feature matches and it inter-connects the images with each other (relative orientation) providing valuable information for the latter computation of the overall camera arrangement.

Step 4 unites all relative orientations and brings all into a common co-ordinate system. The basis is the knowledge of how single pairs are inter-linked. Here it becomes obvious why high redundancy is important, i.e. several images showing the same part of a surface: without that feature, the single pairs are not automatically connectible and the arrangement decomposes into parts.

Step 5 performs a global optimisation of the estimated camera arrangement from Step 4 - also known as ‘bundle adjustment. Bundle adjustment was originally defined in the photogrammetry world but later re-defined in the computer vision domain (Hartley & Zisserman 2004, Triggs *et al.* 2000). The basic idea behind it is to align a set of 3D points and their corresponding 2D positions in the images (described by projection matrices) and jointly optimise the projection matrices in a way that a definable cost function, e.g. the re-projection error, is minimised.

An option in Step 5 includes the determination of the internal camera parameters. The internal parameters include the focal length, the optical centre, and lens distortion. If determined, the camera is called calibrated.

This processing chain, from Step 1 – 5, may run with already defined internal camera parameters or they can be determined during the Step 5, which is then called auto-calibration. Practical applications showed that auto-calibration requires high redundancy and proper image quality for getting the internal camera parameters robustly. Vice versa, pre-calibrated cameras are advantageous when the image set not highly redundant which results in less photos being used in the processing chain and means less computing power is required.

Finally, Step 6 uses the results so far and provides a dense set of surface points. In this step, additional matching points are identified, but now under defined boundary conditions from the already determined camera arrangement. One possibility performing Step 6 is to densify the surface in pieces (see Figure 2) and then connect the single patches to a large 3D image. The advantage of this approach is that the images can be used in their original quality for the final representation (see Figure 3).

Figure 1. Automatically computed arrangement of 11 imaging locations using some thousand identified tie points, i.e. points seen on several photos for inter-linking them. All photos are processed simultaneously to one consistent camera arrangement.

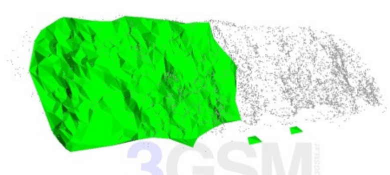

Figure 2. Densified part of the 3D image as seen by a single camera pair.

Figure 3. Resulting dense 3D image.

4 PRACTICAL APPLICATION

Structure from motion allows for a high flexibility in photo taking. The camera can be used free-hand (see Figure 4), from different imaging distances, and even with different focal lengths. However, for practical application one issue is of prime importance: having sufficient overlap information between neighbouring images. Structure from motion relies on high redundancy. Image overlaps from 60% up to 90% exploit the possibilities at best.

Furthermore it showed to be beneficial when keeping the camera settings fixed for a set of photographs especially if the camera is auto-calibrated, i.e. calibrated on the project data (see also previous section).

Although structure from motion delivers qualitative correct 3D models, scale information is still missing in order to enable measurements. Mainly two possibilities apply in practical application: firstly, the use of elements with known geometry (scaling elements) or secondly, the use of (externally) surveyed control points. For both approaches it holds, that they need to be visible in at least two images. Once any scaling elements or control points are in place, data acquisition is a matter of some minutes.

The technique is feasible whenever free sight to the surface of interest and several viewpoints are available. Foggy weather, light rain, or snowfall do not hinder the system from working.

Figure 4. Free-hand image taking.

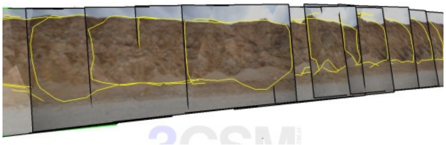

Figure 5. Overlapping image series of a bench face; 11 photos acquire the overall length of 50 m leading to a geometric resolution of 15 mm and an averaged overlap of 85%.

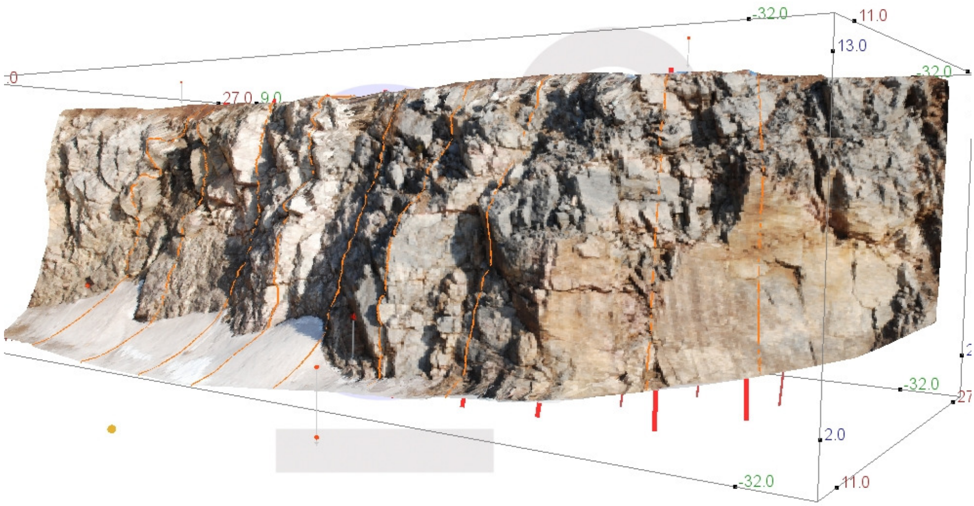

Figure 6. 3D image of a single bench with boreholes and according profiles. Note that image quality enables geological assessments during the blast planning.

5 BLAST PLANNING

3D images are useful for blast planning in two ways: firstly, before drilling (proactive blast design) and secondly, when the holes already exist (reactive blast design). Both use the ability to determine burden information from the borehole while the first in addition allows for adapting borehole locations according to geometric peculiarities of the bench face.

The key information for the optimisation of a drill pattern is minimum burden, which is defined as the minimum distance from the borehole to the free face (Moser *et al*. 2007). Minimum burden information is available in two ways: firstly, in a diagram analogue to a profile or secondly, as colour-coded information over the entire face. Both representations enable the planner of a blast to optimise a drill pattern either by relocating boreholes or by changing azimuth or inclination. All changes are visualised instantly. Figure 7 shows an example of a drill pattern together with the minimum burden diagram of a selected borehole. Any change in location, inclination, or azimuth updates immediately the burden diagram.

Figure 8 depicts another example. The special case of a corner blast usually requires special attention. Minimum burden is determined by a full 360° spherical search around a borehole hence dealing with two free faces makes no difference to a linear blast site. Special attention is paid to the corner holes that are adapted to the geometry of the bench. Using pure profiling might bear the risk to miss locations of low burden which consequently might lead to a flyrock incidence.

Once the blast is designed, a reasonable estimate of the volume to blast is calculated. The algorithm behind this uses a geometric criterion that describes the influence area around each borehole. By summing up all influence areas, the overall volume to blast is approximated. A nice property of this pure geometric approach is that it handles irregular drill patterns without problems. It works also if the boreholes are surveyed with a down-the-hole probe.

6 AERIAL IMAGERY

The structure from motion approach can handle a large set of photos simultaneously and deliver a consistent 3D model taking into account all contributing images. Unmanned aerial vehicles (UAVs) such as multi-copters are used to carry a camera and shooting a series of images of the region of interest. Major applications include:

– the determination of stockpile volumes

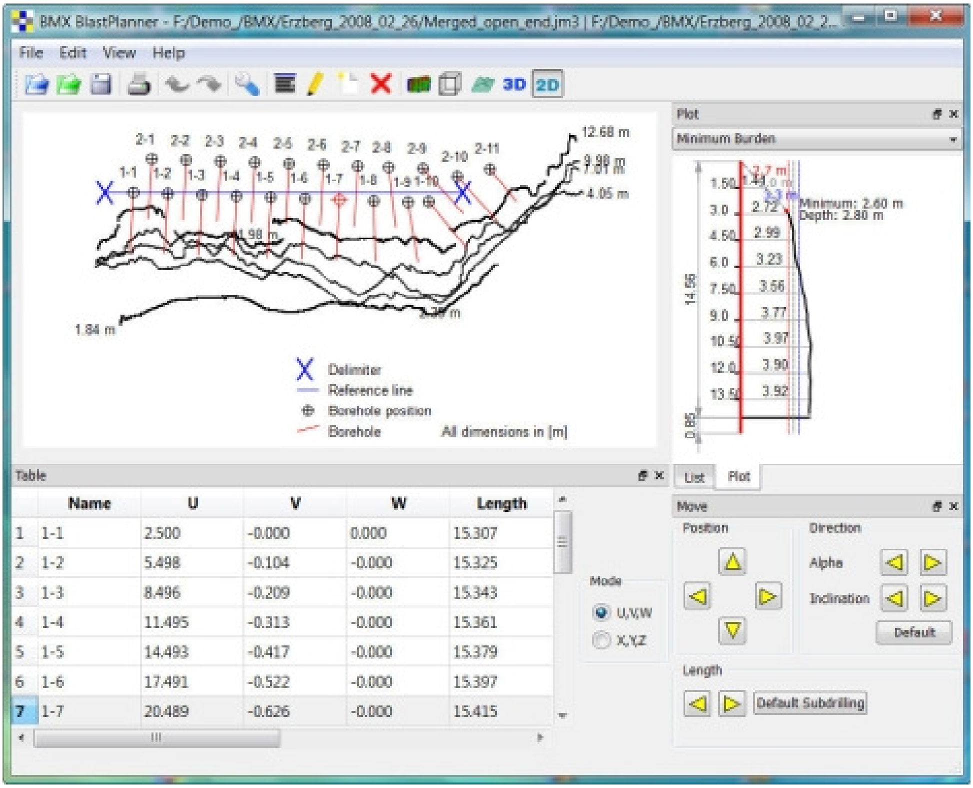

Figure 7. Plan view of blast site and burden diagram of one borehole. Using this representation individual boreholes are adapted to the bench face geometry by relocation and/or changing inclination while instantly updating burden information.

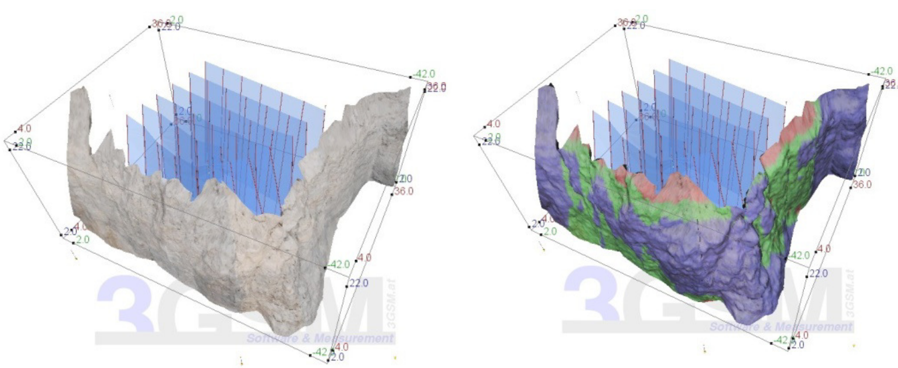

Figure 8. 3D image of a corner blast with two free faces. Proactive planning led to six rows with the corner holes adapted to the actual geometry. The left picture shows the actual rock mass situation of the bench face while on the right side the burden information is provided as colour-coded overlay.

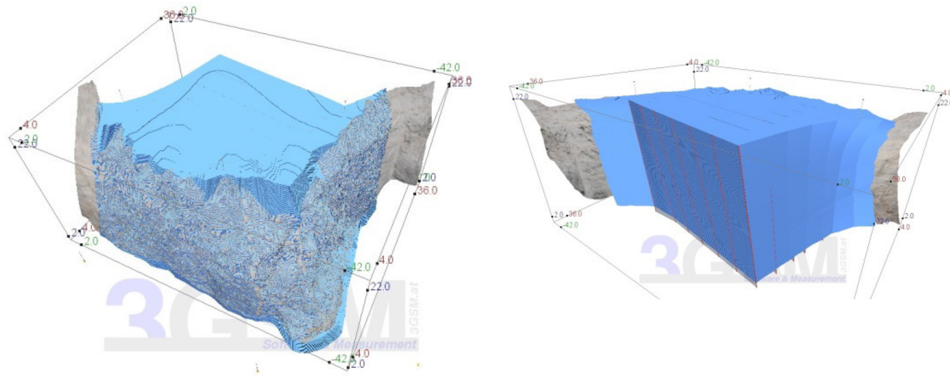

Figure 9. Analytical determination of the expected blast volume. Calculation considers the actual drill pattern and bench face geometry as well as irregular borehole inclinations that might result from drill pattern optimisation or borehole survey using a down-the-hole probe.

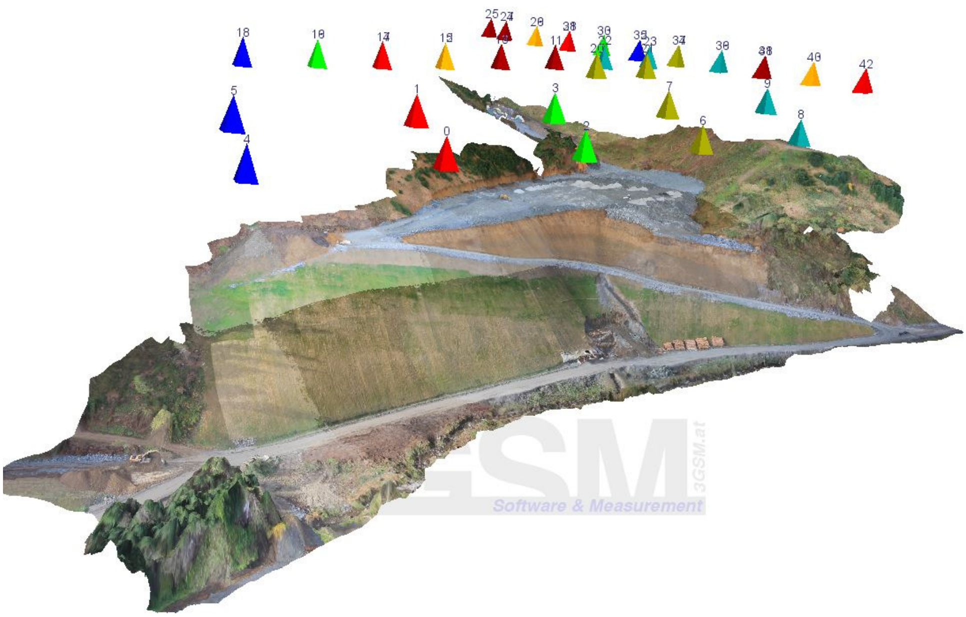

Figure 10. 3D image of a material heap near a tunnel construction site. The covered area is about 7 hectares at a resolution of 3 cm. The 3D model has been generated from a set of overlapping images taken with an UAV using the structure from motion technique. Small pyramids outline the determined camera locations. The subsequent application allowed the determination of volume changes in the heap and documented its evolution.

- the documentation and quantification of landscape modelling
- the survey and documentation of large blast sites

Figure 10 shows an example of a heap where tunnel excavation material is dumped. The area embraces about 7 hectares; the 3D image shows a resolution of about 3 cm/pixel. With the Structure from Motion technique the entire set of images is processed simultaneously leading to a consistent and accurate 3D model of the surface. The heap has been surveyed this way regularly which on the one hand delivered an objective and reproducible documentation of its evolution and on the other hand allowed for a precise determination of volume changes over time.

7 CONCLUSIONS

3D images combine visual and geometric data making them a valuable source for blast planning. With the structure from motion technique multiple photos from different locations are processed simultaneously to a consistent and accurate 3D image.

They allow proactive blast optimisation reducing the risk of flyrock and the use of explosives while leading to better blasting results in terms of wall geometry and expected fragmentation.

The quality of the 3D images aids taking account of geological features during the blast planning and for a more thorough geological and geotechnical analysis (3GSM 2014) to be used for stability analyses or excavation planning.

Structure from motion makes the field procedure very quick and easy especially for complex regions of interest. However, the technique also applies advantageously for aerial imagery where large blast sites are surveyed as well as stockpiles or dumps.

Another feature of structure from motion is that cameras can be calibrated while processing the project (auto-calibration) provided sufficient images at proper quality are taken.

Structure from motion provides a possibility to survey large and complex regions by a set of unordered photographs making it a highly cost-effective and accurate tool for blast profiling and other surveying tasks in mining and construction.

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Safe blasting - proper vibration prognosis

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ABSTRACT: The proven sonic effect of the dynamic phase when an explosive charge is detonated opens up new methods for the safe fragmentation of rock both on the surface and underground. A direct correlation exists between the fragmentation effect and the resulting vibrations: increasing the sonicity (i.e. increasing the detonation velocity) leaves the input unchanged but produces more intense fragmentation while lowering the vibration immissions. In this way, drilling and blasting equipment can be safely optimised for all types of conditions and the vibrations controlled.

Understanding these processes enables the vibrations to be correctly predicted by means of physically verifiable factors such as explosive density, detonation velocity, filling ratio and charge weight in a blast hole as well as on the basis of extensive measurements. The realistic guideline values which can be verified by means of the mechanics of rock breakage and which are permissible near structures without damaging them were worked out by determining the ultimate tensile strength of rock and building materials as well as by closely analysing an earthquake causing low to medium damage to buildings. These objective guideline values apply to all structures, buildings, roads, pipelines and sensitive equipment, and are recommended for use as uniform parameters for both short-term blasting (≤ 2 s) and long-term vibrations (> 2 s).

1 PRELIMINARY REMARKS

Whenever blasting arrays are designed, empirical approaches still prevail. The use of systematic scientific techniques and other innovative methods in blasting practice is discouraged by market pressures and cost-cutting among explosives manufacturers, with blasting contracts simply being awarded to the lowest bidder.

Vibration problems are dealt with worldwide by simply referring to a set of ostensibly objective correlations based on the charge weight per round introduced many years ago. The problem is that this accepted practice ignores the explosives' vibration characteristics and has no physically or statistically proven basis. The permissible guideline values for peak particle velocities and their associated frequencies contained in DIN

4150, Part 3 were taken from empirical findings based on certain experience. However, there is a lack of objective guideline values based on scientific observations or calculated from the mechanics of rock breakage which quantify the effect of blasting on built structures. The aim of this paper is to highlight new, reliable ways of overcoming the above-mentioned drawbacks of drilling and blasting systems.

2 PHYSICAL PRINCIPLES

Detonating an explosive charge initially causes a dynamic phase in which a shock wave travelling at the velocity of detonation tears through the rock. This is followed shortly afterwards by the quasi-static gas pressure phase, in which the resulting plumes penetrate cavities and cracks and are almost completely responsible for the ejection of rock mass (Figure 1). The shock wave reacts with the P- and S-wave velocities of the rock, creating the sonic effect. This powerful physical process shown in Figure 2 was first discovered by E. Mach, who described the sonic effect in the air caused by a projectile (Young & Freedmann 2004). H.P. Rossmanith subsequently proved that the shock wave initiated by a detonating explosive also causes wave interaction in solids (Figure 3) (Rossmanith 1998). His experiments carried out in Plexiglas® bodies at Vienna University of Technology made the resulting Mach fronts of P- and S-waves visible. The Mach numbers triggered and the test parameters are shown in the images generated during his experiments (Figure 3).

If the explosive's detonation velocity is greater than the P- and S-wave velocities of the rock, a supersonic effect arises. This resulting double Mach cone causes very good or even optimum shattering, yet is associated with relatively low vibration immissions. If the detonation velocity is slower than the P-wave velocity but faster than the S-wave velocity of the rock, only one Mach cone arises with the velocity of the S-wave. This transonic effect results in medium fragmentation and moderate vibration immissions. In subsonic cases, the detonation velocity is too low and a Mach cone does not arise. Subsonic detonation is unfavourable since it results in not only low fragmentation but also very high vibrations (Müller, Lange & Pippig 2011a).

If this physical principle is to be harnessed, the rock's P- and S-wave velocities need to be known. The P- and S-wave velocities of a wide variety of rock types measured in our laboratory are shown in Figure 4. Since the shaded areas roughly correspond to the explosives specified, the diagram enables the most suitable charge mixture to be selected. Whenever possible, the aim should

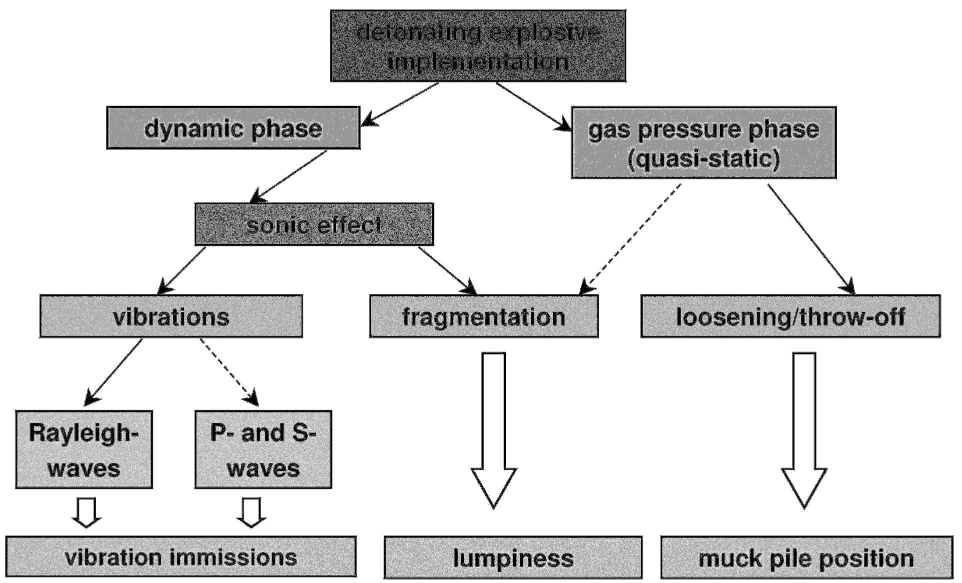
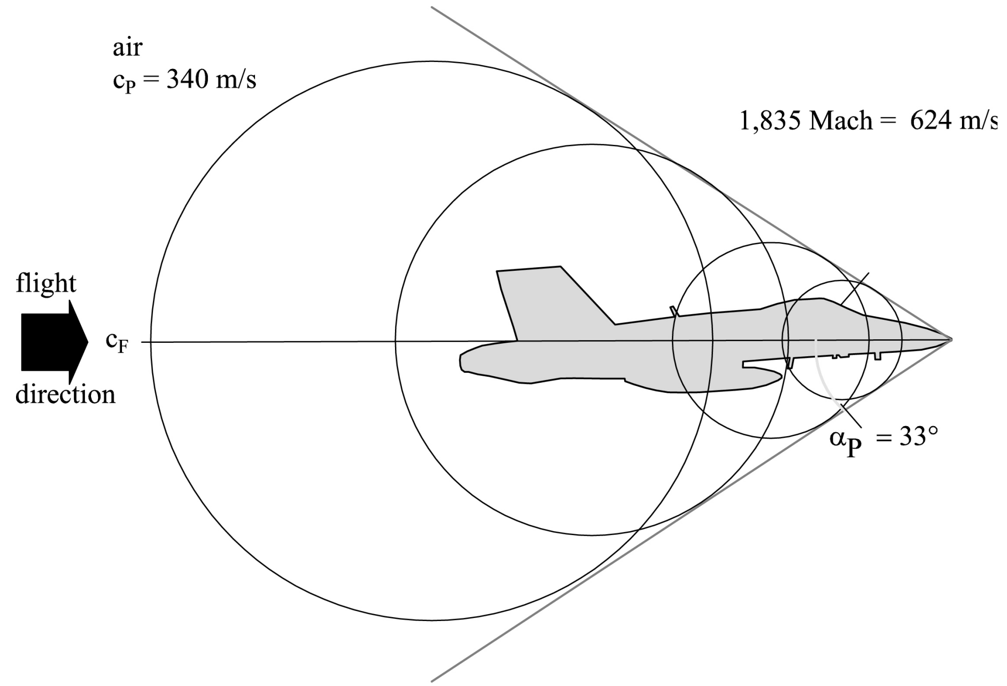


Figure 1. Action phases of a detonating explosive charge.



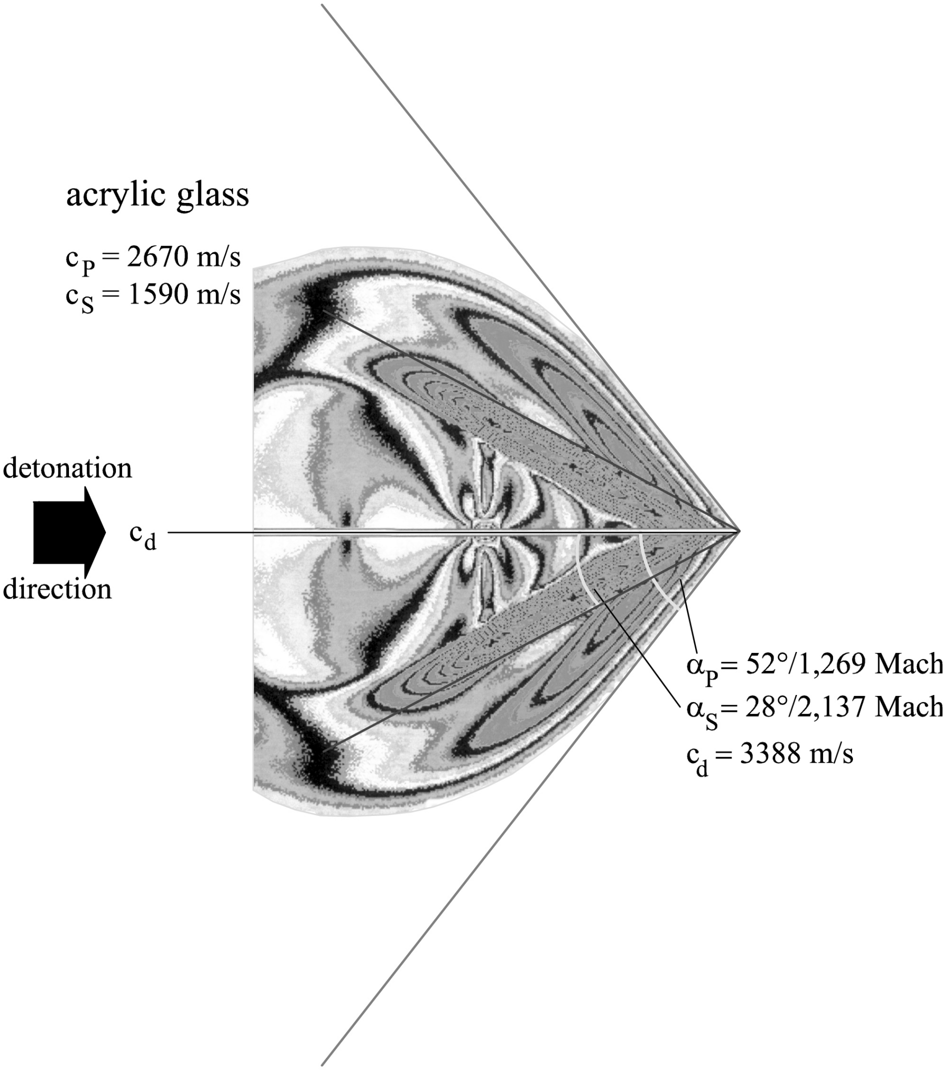
$$\frac{c_F}{c_P} = \frac{624\ \text{m/s}}{340} = 1{,}835\ \text{Mach}$$

$$\frac{c_P}{c_F} = \sin 33° = 0{,}5446$$

Figure 2. Sonic effect in the air caused by a projectile according to E. Mach (Young & Freedmann 2004).

be to achieve a transonic or even supersonic effect. Blasting vibrations are generated by the detonation recoil and the duration of the effect. Vibrations are mechanical excitations which are caused by various natural and anthropogenic sources in the subsoil or underground. They propagate as P-waves (longitudinal, pressure or primary waves), S-waves (transverse, shear or secondary waves), and especially as surface waves. Surface waves in the form of Rayleigh waves are the most important ones regarding the spread and evaluation of vibration immissions (Figure 1). When longitudinal waves and vertically polarized shear waves interact, Rayleigh waves arise with a retrograde elliptical orbit of particle motion (Figure 5). The attenuation of Rayleigh waves is about $\frac{1}{r}$ and is much lower than that of P waves, which

is estimated to be about $\sqrt{\frac{1}{r}}$ (r = distance between place of emission and place of immission). No S-waves – and hence no Rayleigh waves – arise in water-saturated granular soils, water or air. In all of these wave-mechanical



$$\frac{c_d}{c_P} = \frac{3388}{2670} = 1{,}2689 \text{ Mach} \qquad \frac{c_P}{c_d} = \sin 52°$$

$$\frac{c_d}{c_S} = \frac{3388}{1590} = 2{,}131 \text{ Mach} \qquad \frac{c_S}{c_d} = \sin 28°$$

Figure. 3. Supersonic effect in rock caused by the shock wave of the detonating explosive (P- and S-Mach cone according to Rossmanith 1998).

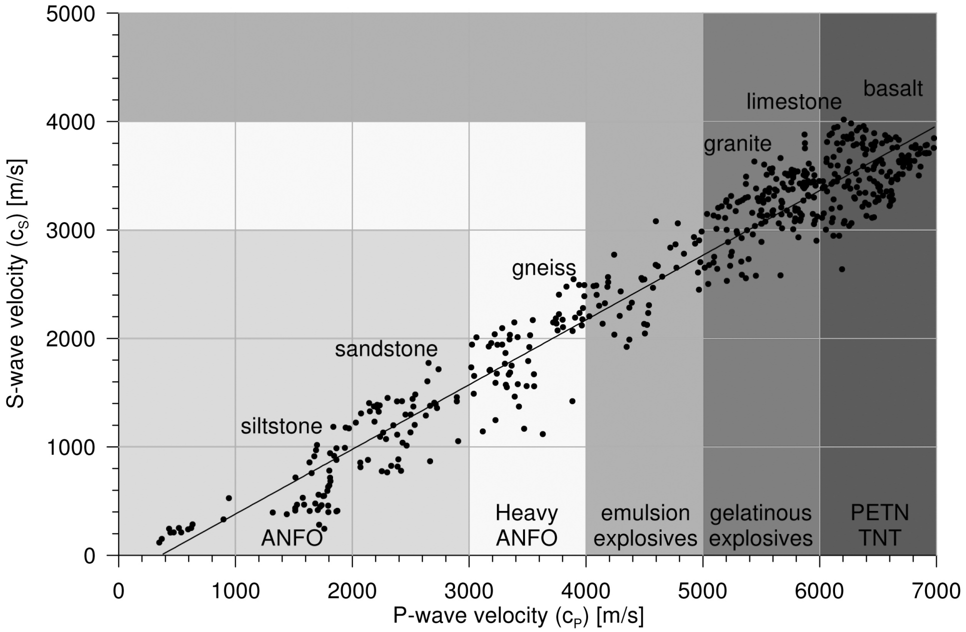


Figure 4. Correlation of the P- and S-wave velocities of various types of rock and the detonation velocity ranges of prominent explosives.

processes, note that the passage of shock waves is weakened by cracks, fissures, cavities and sudden discontinuities such as cavities filled with clay. The fault structure and the blasting conditions with respect to bedding conditions are factors affecting blasting which must be taken into account when calculating drilling and blasting parameters (Müller 1999).

Practical conclusions:

- the sonic effect is of fundamental, universal importance for blasting technology (Figures 1, 3 & 4)
- there are clear correlations between vibration immissions into the surroundings, the fragmentation of the muck pile, and successful throw above and below ground (Figure 1)
- the type of explosive should be chosen depending on the rock's P- and S-wave velocities
- wave-mechanical reasons mean that the explosives used must be uniform for the medium to be blasted
- the sonic effect is weakened by faults, crevices and material discontinuities

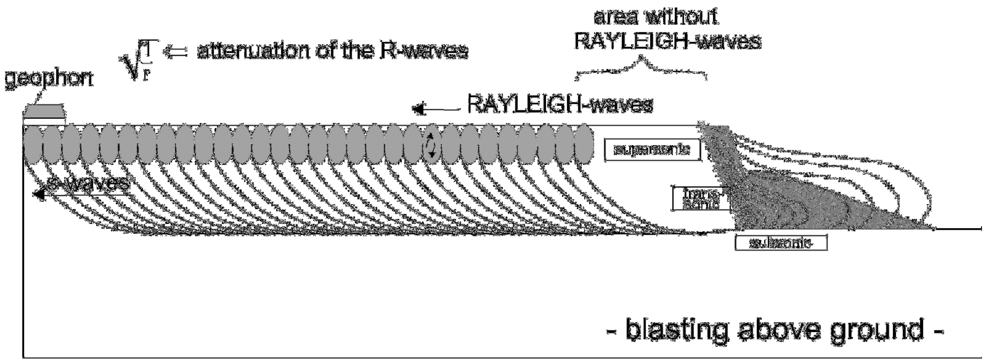


Figure 5. Diagram of Rayleigh waves arising behind a blasting array.

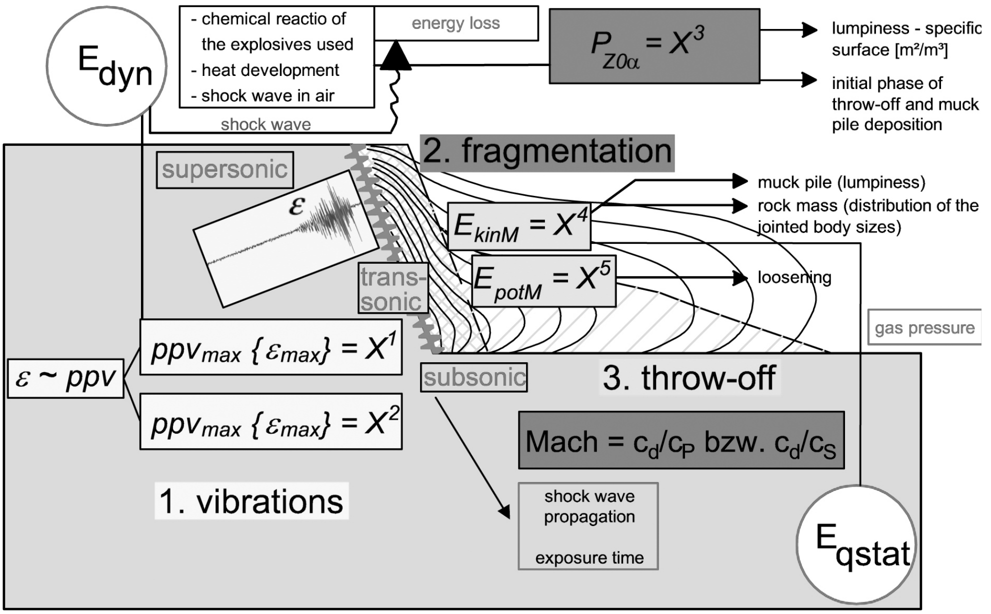


Figure 6. The blasting model above ground.

- vibrations propagate in the form of Rayleigh waves; special assessment methods must be used for water-saturated materials, water and air, where there are no S-waves.

3 THE BLASTING MODEL DEVELOPED FOR SURFACE AND UNDERGROUND USE

Numerous extraction blasting operations were carried out under normal production conditions and extensively measured. The findings were used to develop physically based 2D blasting models for surface use and 3D blasting models for underground use (Figures 6 & 7).

X^1 fictitious momentum - distance correlation:

$$ppv_{\max} = k\left[W_B \cdot c_d \cdot \left(\frac{r}{r_0}\right)^{-n}\right]^m \qquad (1a)$$

or

$$\varepsilon_{\max} = k'\left[W_B \cdot c_d \cdot \left(\frac{r}{r_0}\right)^{-n'}\right]^{m'} \qquad (1b)$$

X^2 fictitious energy - distance correlation:

$$ppv_{\max} = k\left[V_{SB} \cdot \xi\left(\frac{\rho_s \cdot c_d^2}{4}\right)\left(\frac{r}{r_0}\right)^{-n}\right]^m \qquad (2a)$$

or

$$\varepsilon_{\max} = k'\left[V_{SB} \cdot \xi\left(\frac{\rho_s \cdot c_d^2}{4}\right)\left(\frac{r}{r_0}\right)^{-n'}\right]^{m'} \qquad (2b)$$

X^3

$$P_{Z0\alpha} = \frac{\xi\left(\frac{\rho_S \cdot c_d^2}{4}\right)V_{S0}}{w'^2 \cdot l_{B0} \cdot (\sin\alpha_P \cdot \sin\alpha_S)^P} \qquad (3)$$

X^4

$$E_{kinM} = m_M \cdot \frac{c_M^{\ 2}}{2} \qquad (4)$$

X^5

$$E_{potM} = m_M \cdot g \cdot \Delta h_w \qquad (5)$$

$P_{Z0\alpha}$ = fictitious, effective detonation pressure taking into account the sonic effect (N/mm²)

P_{Z0} = fictitious, effective detonation pressure per unit volume without the sonic effect (N/mm²)

ξ = filling ratio

c_d = detonation velocity (m/s)

ρ_S = explosive density (kg/m³)

V_{S0} = volume of explosive charge per unit volume of rock (m³)

w' = detonated burden (m)

l_{B0} = unit length of blast hole (1 m)

$\sin \alpha_P = \frac{c_P}{c_d}$ $\quad \sin \alpha_S = \frac{c_S}{c_d}$

P = exponent P with a value of 1, 1.5 or 2 depending on detonation

ppv_{max} = maximum peak particle velocity (mm/s)

ε_{max} = maximum dynamic strain (µm/m)

W_B = charge weight per blast hole (kg)

r = distance between maximum charge weight per blast hole and measuring point (m)

r_0 = correction factor for dimension reduction (1 m)

V_{SB} = volume of explosive charge in a blast hole (m³)

k, k´, n, n´

m, m´ = exponents and factors statistically calculated using regression analysis

E_{kinM} = kinetic energy of the muck pile (Nm)

E_{potM} = potential energy of the muck pile (Nm)

m_M = muck pile mass (blasting volume × rock density) (kg)

c_M = blow-out velocity of the muck pile (m/s)

h_W = wall height (m)

Blasting above ground occurs in a series of phases (Figure. 6):

1. *Vibrations* - are created by recoil/momentum or energy input into the remaining sock directly in connection with the detonation of explosives and are expressed by the prediction correlations (1a or 1b) and (2a or 2b) (Müller, Litschko & Pippig 2013a).

2. *Fragmentation* - is caused by the effective, fictitious detonation pressure (3) and the parameters it contains as well as the sonic effect.

3. *Throw and loosening* - are seen as the last phase under the impact of the gas pressure with the correlations (4) and (5).

In 3D blasting underground, the following phases can be identified resulting from the 3D stress field (Figure 7):

1. *Vibrations* - R-waves on the toe of the underground cavity caused by recoil/momentum or energy input taking the form of vibrations which can also be assessed and calculated using the prediction correlations (1a or 1b) and (2a or 2b).

2. *Fragmentation* - is controllable and can be calculated using the effective, fictitious detonation pressure (3) and the parameters it contains as well as the sonic effect.

3. *Ejection effect in rock mass* - is directly associated with the throw and the duration of ejection. The impact of blasting disrupts the previously balanced stress of about 2–5 s such that considerable strain of 0.5–3 mm/m is measured on mine pillars and in the remaining rock (Baumann *et al.* 2014) (Figure 8). This strain multiplied by the rock's static modulus of elasticity often results in tensile stresses which exceed tensile strength, causing local collapse in unstable conditions. A method of calculating this effect has not yet been developed.

4. *Throw and loosening* - is evaluated and calculated as with surface blasting (4) and (5).

The models show that there is a direct relationship between vibrations and the fictitious, effective detonation pressure (Figure 9). This important finding for blasting technology was to be expected from a physical consideration of the sonic effect (Müller, Litschko & Pippig 2013a).

The higher the detonation pressure, the greater the vibrations. If the action of the detonation pressure is shortened and its sonic effect increased, the vibrational excitation decreases.

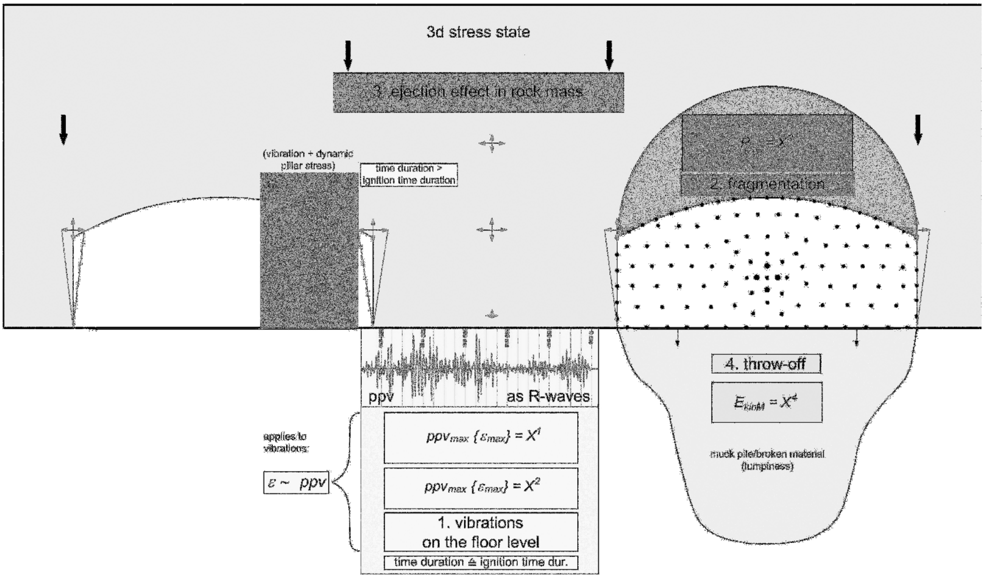


Figure 7. The blasting model underground, formulae X^1 to X^4 see under Figure 6.

4 SAFE BLASTING

Based on the correlations described and the surface and underground blasting models presented here, safe rock blasting can be planned by applying the following principles:

- the blasting array must be precisely measured
- a uniform explosive must be chosen and tweaked to achieve the best sonic effect in accordance with Figure 4
- the specific explosive consumption must be derived based on the fissure frequency for surface blasting (Müller 1999) or the excavation strength and excavation area for underground blasting (Müller, Lange & Pippig 2011a)
- the blast holes should if possible be completely filled with explosive charge with the charge as flush as possible with the rock
- the width-to-length ratio of blast hole spacing should ideally be between 1 and 1.3
- in surface blasting, the critical burden must be observed in the first row
- 2D surface blasting should be designed as a multi-row blasting array while 3D underground blasting should preferably be carried out as a parallel cut using between two and four large blast holes in the area of the cut
- 2D blasting requires even, harmonious, progressive detonation in accordance with momentum theory; 3D blasting requires the spiral-shaped opening of the cut area and a partial, mutually simultaneous detonation sequence in the auxiliary hole area or the simultaneous detonation of several contour and toe holes
- a decisive role in the formation of vibrations is played in fragmentation blasting by the charge weight per blast hole and in split blasting by the total charge weight in the contour and toe holes in supersonic blasting arrays.

The correlations shown in Figures 6 & 7 enable blasting arrays to be tweaked and tailored in order to achieve the aims of blasting.

5 CORRECT VIBRATION FORECASTING

Previous formulae for predicting blasting vibrations have the following shortcomings (Müller, Lange & Pippig 2011a; Müller, Litschko & Pippig 2013a):

- they focus on the charge weight per round, whereas it is in fact the maximum charge weight of a blast hole which determines the scale of the vibrations
- they only consider the mass of explosive but not its density or detonation velocity

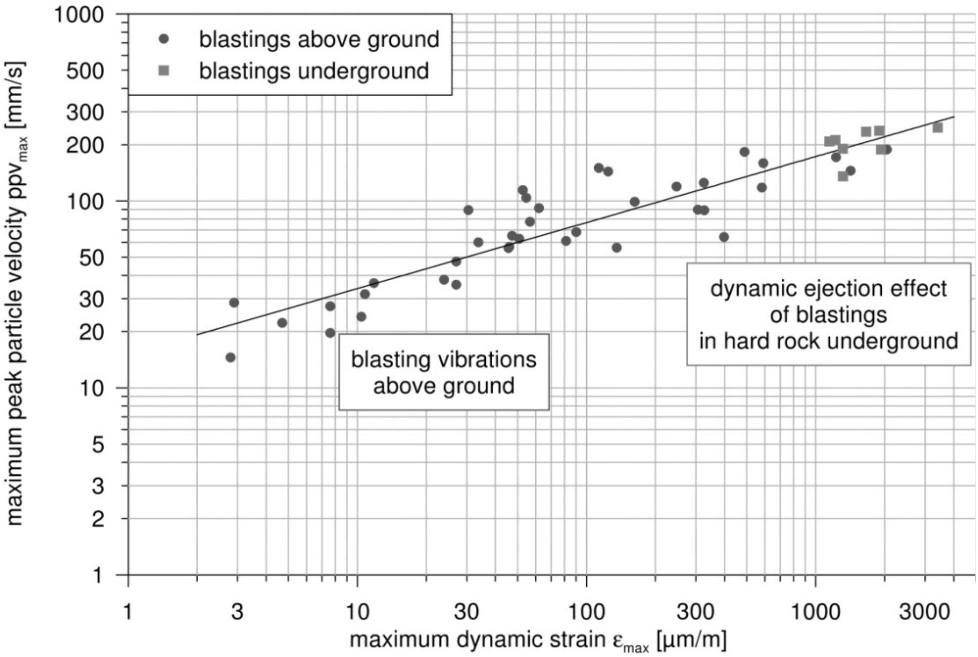


Figure 8. The physical correlation ascertained by measurements between peak particle velocity and dynamic strain; the measurements shown in red are strain measurements on underground pillars and are regarded as the dynamic ejection effect during underground drilling and blasting.

- the sonic effect (including the complex reciprocal relationship between fragmentation and vibration) is ignored
- the factors and exponents of the prediction formulae are empirically determined or specified.

The blasting models described here along with the correlations and influences identified enable statistically and physically sound formulae for predicting blasting vibrations to be developed on the basis of measurements (Figures 6 and 7, part 1).

For this purpose, several blasting operations have to be carried out and the following parameters measured:

- peak particle velocity with the related frequencies measured at various distances from the blasting array
- if required, a fibre Bragg grating sensor is to be used nearby and combined with a three-component geophone to measure strain
- the density of the explosive and the detonation velocity should if possible be measured *in situ*
- the filling ratio of the holes is to be determined
- the distance from the measuring point to the blast hole with the maximum charge weight is to be determined to within an accuracy of 1 m
- the detonation sequence should be based on the above principles, although which detonation method is used is irrelevant (Figure 10) as the type of detonator does not affect the scale of the vibrations
- measurement analysis must take into account the existing anisotropy of the rock and the main propagation direction of the vibrations. The vibrations are caused by wave-mechanical processes and do not propagate evenly in all directions.

The measured or otherwise determined individual values are statistically analysed using multiple correlation. This gives a correlation between fictitious momentum (or fictitious energy) and distance (Figures 6, 7 and 11). In Figure 11, the fictitious energy–distance correlations are shown before and after optimisation and the resulting improvements to blasting in an opencast lime-marlstone pit. The main changes were the use of pumped emulsion instead of powdered ANFO (ammonium nitrate/fuel oil) mixed with

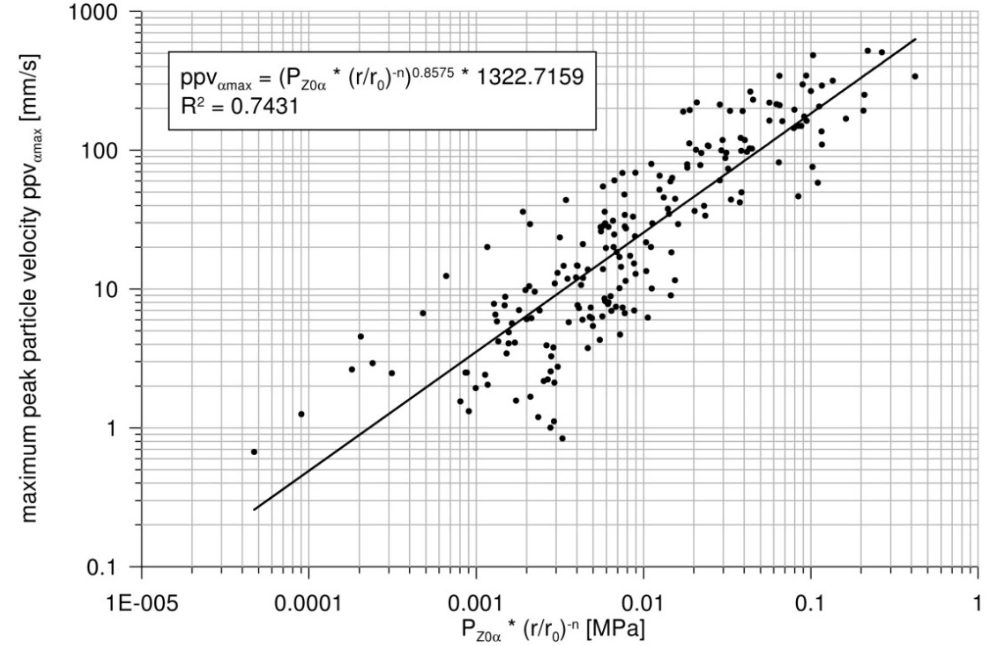


Figure 9. Vibrations are affected by the fictitious, effective detonation pressure.

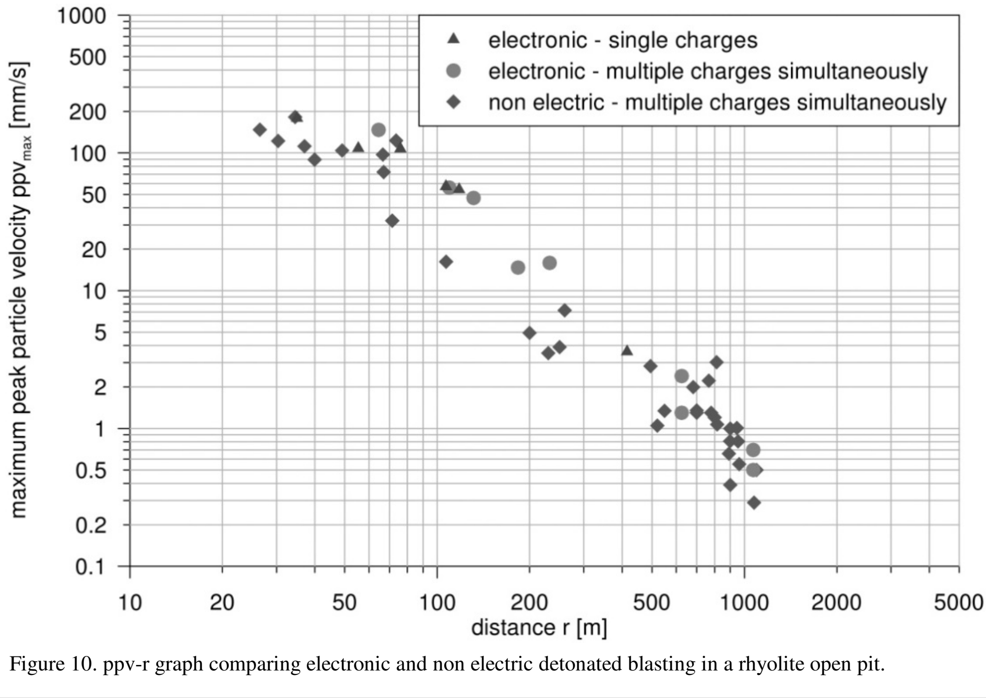


Figure 10. ppv-r graph comparing electronic and non electric detonated blasting in a rhyolite open pit.

gelatinous, cartridge explosive, and the expansion of the blast hole pattern. This optimised drilling and blasting resulted in the increased fragmentation of the muck pile despite the energy input remaining unchanged and the vibrations being substantially reduced.

The statistically based formulae for blasting vibrations allow the environmental impact to be controlled and if need be improved. Blasting arrays can be increased in size as desired without increasing the vibration immissions.

6 SCIENTIFICALLY BASED GUIDELINE VALUES

The possibility of statistically comparing peak particle velocity measurements with strain measurements allows the impact on the fabric of a building to be objectively assessed (Figure 8). The *permissible guideline values* contained in DIN 4150, Part 3 were introduced empirically without being based on actual measured data. In force for more than thirty years, these values are among the lowest in the world to be used for the protection of buildings and all other types of structures.

In order to objectively derive realistic limit values at which cracking could start occurring to building materials and structures, various observations and measurements were considered:

- dynamic building damage caused by earthquakes was analysed taking into account measured peak particle velocities (Müller, Litschko & Pippig 2014)
- vibration displacement was calculated taking into account the measured peak particle velocities and frequencies causing dynamic structural damage
- the dynamic characteristics of building materials and rock were determined
- the unconfined compressive strength, tensile strength and acoustic impedance (P-wave) were compared in order to determine the minimum tensile strength of building materials (Figure 12)
- the ultimate tensile strength of various building materials was concluded by taking into account peak particle velocity at low frequencies and breaking strain based on long-term measurements and *in situ* tests (Figures 12 & 13).

From these different, complex correlations and

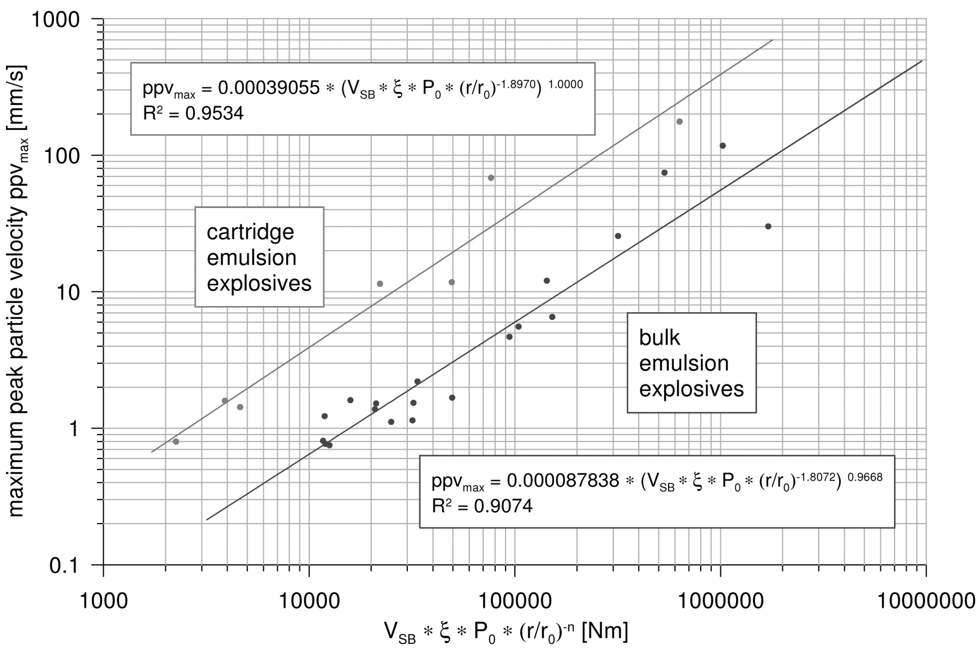


Figure 11. Improving the fictitious energy–distance correlation before and after the optimisation of drilling, blasting and detonation equipment resulted in reduced vibrations.

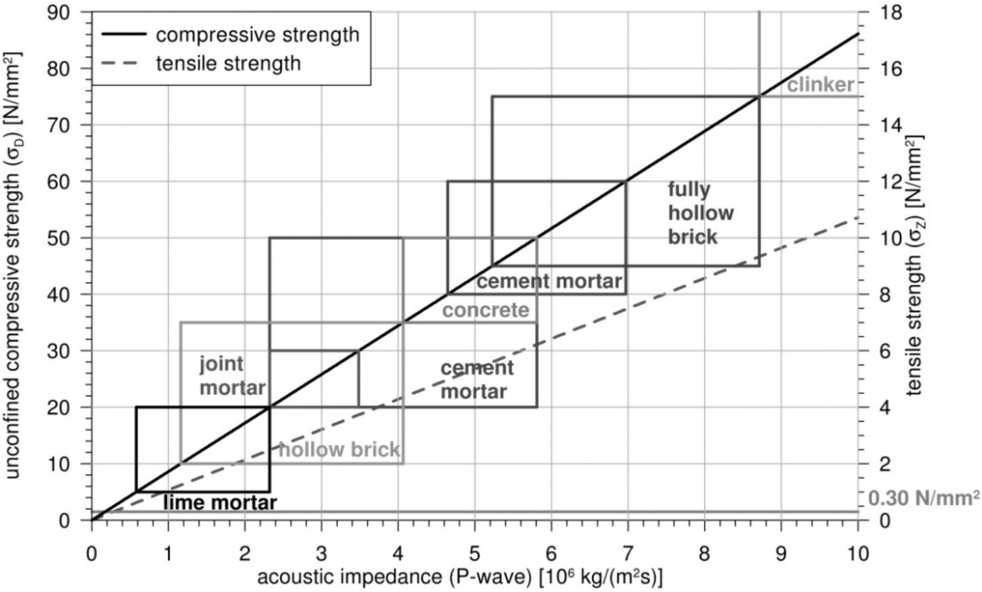


Figure 12. Correlation between unconfined compressive strength/tensile strength and acoustic impedance (P-wave) of various building materials.

observations on structures, an attempt was made to objectively ascertain incipient structural damage caused by blasting by considering the mechanics of breakage (Figure 13). The turbulent behaviour of dispersion and absorption in the propagation of waves is concealed in the complex value of the dynamic modulus of elasticity (Figure 14). The frequency-dependent value of the dynamic modulus of elasticity is always higher than the static modulus, which describes the alleged deformation behaviour as load increases as a function of time, and at high elasticity coincides with the static modulus of elasticity. The lowest limit of the margin of error of the dynamic modulus of elasticity approximately coincides with the size of the static modulus of elasticity (Figure 14). The mechanical behaviour of rocks and building materials subjected to dynamic action may be graded in a simplified fashion in accordance with Figure 14.

Statistical evaluation of the dynamic characteristics of rock and building materials shows that the properties of the entire range of possible materials are interdependent and allow an objective assessment of their fracture behaviour (Müller, Litschko & Pippig 2014). If the tensile and compressive strengths of the materials are known, the breaking strain can be determined from correlations based on the mechanics of breakage. Under a tensile load of 0.3 N/mm², cracking starts in mortar, the building material with the lowest strength (Figures 12 & 13). By using the measurement-based correlation between ε_{max} and ppv_{max} in Figure 13, the peak particle velocities corresponding to the strains were calculated.

Table 1. Increase in critical peak particle velocity as the frequency rises with constant vibration displacement.

Vibration displacement	Critical peak particle velocity	Frequency
2 mm	90 mm/s	7 Hz
2 mm	126 mm/s	10 Hz
2 mm	251 mm/s	20 Hz

This method enabled the lowest tensile strength of building materials and rock to be objectively shown in different ways. As the frequency increases while the peak particle velocity remains constant, the vibration displacement for assumed sinusoidal oscillations decreases significantly,

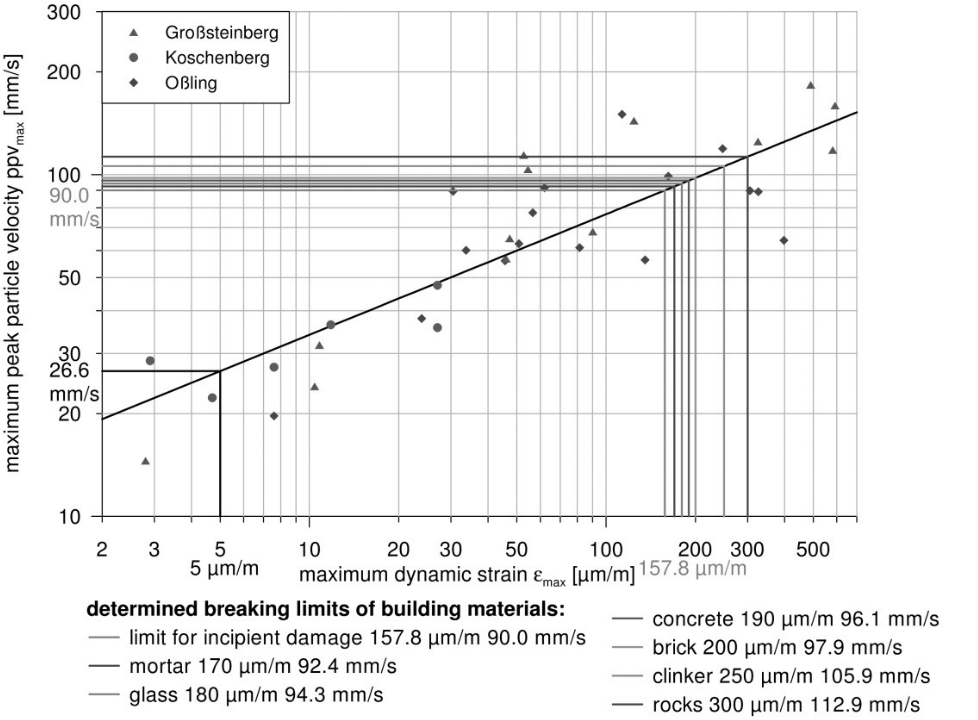


Figure 13. Correlation between measured ppv_{max} (maximum peak particle velocity) and ε_{max} (maximum strain); specification of limit values with possible incipient damage to building materials.

causing the ppv limit parameters to rise substantially at higher frequencies (Table 1).

As the incoming peak particle velocity becomes as it were less hazardous with increasing frequency, frequency-dependent peak particle velocities need to specified. The breaking limits of building materials given in Figure 13 apply to frequencies <10 Hz.

In the following Tables. 2 & 3, permissible guideline values derived from the mechanics of breakage are proposed for short-term vibrations (blasting ≤ 2 s). The '*lines*' referred to in DIN 4150, Part 3 are replaced by the more apt term '*object classes'* (OK) for buildings, structures, roads, sensitive equipment and piping and sub divided into short-term (k) ≤ 2 s and long-term (d) ≥ 2 s exposure.

The figures in Tables 2 & 3 should be used to make the far-too-low empirical figures in DIN 4150, Parts 1 and 3 more realistic. If the procedures backed up by physics and measurements shown here are applied, a substantial improvement in the economic efficiency and safety of drilling, blasting and detonation both on the surface and underground can be expected.

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Table 2. Permissible guideline values of peak particle velocity/frequency and maximum strain (parallel to direction of propagation) for short-term blasting ≤ 2 s above and below ground.

Object class (OK)	Building type, structure, road, sensitive equipment	Guideline values for peak particle velocity vi/mm/s — Vibrations in the foundations or the lowest floor of the structure/ground level – frequencies for vx, vy, vz: 1 to 10 Hz	10 to 50 Hz	50 to ≥ 100 Hz	Top floor (ceiling) – vx, vy at all frequencies	Guideline values (εmax) of max. strain (parallel to direction of propagation) in µm/m
1 (k)	Roads, bituminous, railways	100	100–120	120	–	213–357
2 (k)	Reinforced concrete structures, concrete roads, steel masts, bridges, underground structures, tunnels, caverns, underground galleries with pillars	60	60–80	80–100	–	50–213
3 (k)	Industrial buildings and similar structures; underground structures e.g. tunnels, caverns, galleries with masonry supports or without supports	25	25–40	40–60	60	5–50
4 (k)	Apartment buildings, commercially used and equivalent structures, computer equipment and systems	15	15–20	20–25	25	1–5
5 (k)	Buildings known to be sensitive to vibrations, sensitive facilities and equipment	10	10–12.5	12.5–15	15	0.3–1

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Table 3. Permissible guideline values of peak particle velocity and maximum strain on buried pipes for short-term blasting ≤ 2 s.

Object class (OK)	Pipe material	Guideline values for peak particle velocity vi in mm/s	Guideline values for max. strain εmax in µm/m on the pipe
I (k)	High-quality plastic pipes (e.g. polythene)	120	357
II (k)	Welded steel	100	213
III (k)	Stoneware, concrete, reinforced concrete, metal (with or without flange)	80	113
IV (k)	Masonry, old pipes (at least 40 years old)	60	50

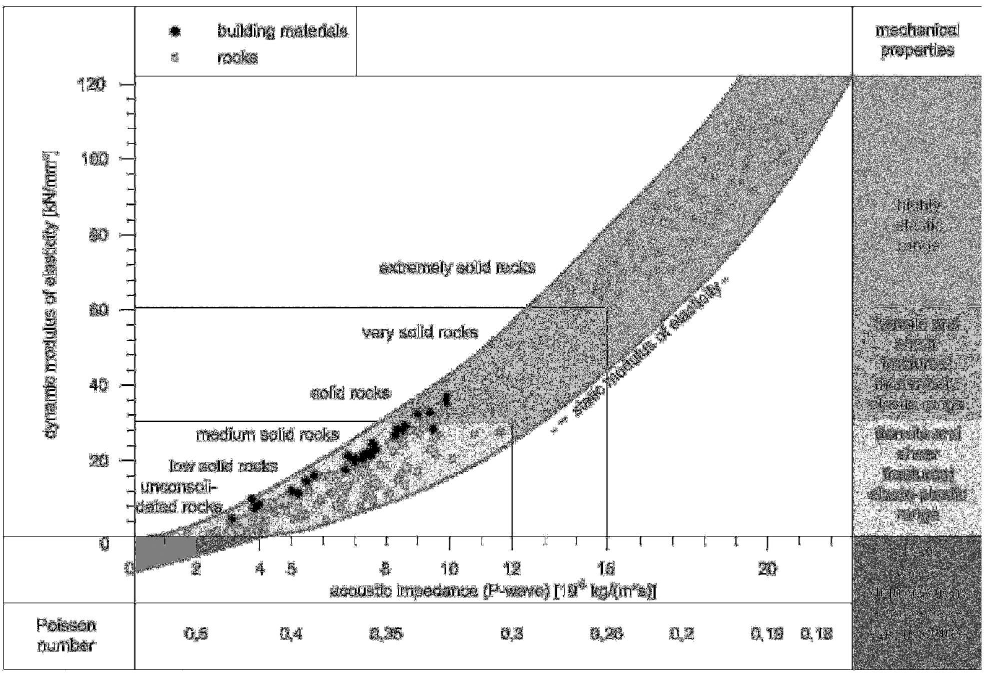

Figure 14. Correlation between dynamic modulus of elasticity and acoustic impedance with the classification of mechanical behaviour and Poisson's ratios of rock and building materials.

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Blast demolition of the AfE-Tower in Frankfurt

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ABSTRACT: This 117 m high skyscraper was constructed of reinforced concrete. The separate *skeleton* collapsed and was followed 3 seconds later by the *core*, brought down by explosive demolition in a confined, bordered area on February 2nd 2014. The 50,000 ton structure caused moderate vibrations because of the energy divergence by self-destroying and because of the longer time to input the energy into the soil. The waste heap was only 90 m long, 50 m wide and 8 m in depth. There was no remarkable damage to surrounding structures. It was the highest building blast in Germany and also, it's believed, in Europe.

1 SITUATION

The 117 m tall AfE-Tower in the centre of Frankfurt, surrounded by neighbouring buildings, avenues and subway lines had to be demolished in 2013. Because of the adjacent, tree-lined Senckenberganlage avenue demolition by excavators was ruled out. Dismantling by cranes would have been very expensive, so the decision was taken to use blasting demolition of the building.

2 THE BLAST OBJECT

The AfE-Tower was constructed in monolithic reinforced concrete. All the 32 floor slabs and its 20 columns were the *skeleton* part. The central lift and stair tower was the *core*.

The height of the building was 117 m (see Figure 1).

The two basement floors had a depth of about 9 m. In this basement the columns had a thickness of 1.5 m. The mass of the tower was 49,500 t. Its cross-section was a square of 33.4 m. Figure 1 shows to the right the avenue Senckenberganlage, with two subway tunnels at a depth of 8 m and a distance of only 20 m from the tower. This was the strongest challenge for the demolition company AWR, the blast company Reisch and the design engineer Dr. Melzer. The closest structure which

Figure 1. AfE-Tower from south.

required protection was only 37m from the tower.

3 BLAST STRATEGY AND DETAILS

The *skeleton* part of the building was able to collapse completely after a blast of its basement columns. But to the contrary, the *core* tower, constructed in walls, cannot be collapsed but must be tilted or folded. This building suggested such a blast demolition strategy of a first vertical collapse of the skeleton part and a following double folding of the core. The first vertical collapse was caused by short time delayed blasting of all 20 columns in five floors (Figure 2). But probably it would be enough to blast only 2 floors.

In all column charges were placed non electric short time detonators. The three seconds later core folding (Figure 3) should complete the building demolition. The upper part should tilt to the south and the under part should be tilting to the north. The three second time displacement was decided so that dropping slabs were sheltering the upper core blast mouth in its detonation yet.

The walls of the blast mouths in the 5th and the 14th floor had to be weakened. The bore holes were bored in longitudinal direction and detonation cord was placed in it (see Figure 4).

About 400 electronic detonator charges were placed in the blast mouth. Each *skeleton* floor and each *core* blast mouths were redundant initiated with electronic detonators and very careful double applied 5 g detonation cord circles. In all 950 kg of explosives were applied in 1,400 boreholes. Water filled ‘big bags’ on the roof were used to help to control the dust.

4 THE BLAST

In 2014 February 2nd the blast demolition of the 117 m tall AfE Tower in the centre of Frankfurt was carried out as a combination of skeleton collapse and core folding. A 250 m exclusion zone was established around the tower. The impressive demolition of the building took only 10 seconds.

The predicted vibrations in the neighbouring subway tunnels, 20 m from the tower, were estimated at 15 mm/s, the same as finally measured. These moderate vibrations were caused by the energy divergence by self-destroying and the longer time to input the energy into the soil. No damages or unexpected results of the blast were realised. The white building next to the tower (Figure 6) was used as shelter only and it was to be demolished too. An only 8 m high debris heap with a total length of about 90 m and a breadth of about 50 m was exactly the aimed result.

5 CONCLUSIONS

The blast demolition of the 117 m tall AfE Tower as shown should be in Europe a record of blast demolition height. A blast demolition of a high rising building should be executed according to its construction principles. It should be a combination of skeleton collapse and core folding.

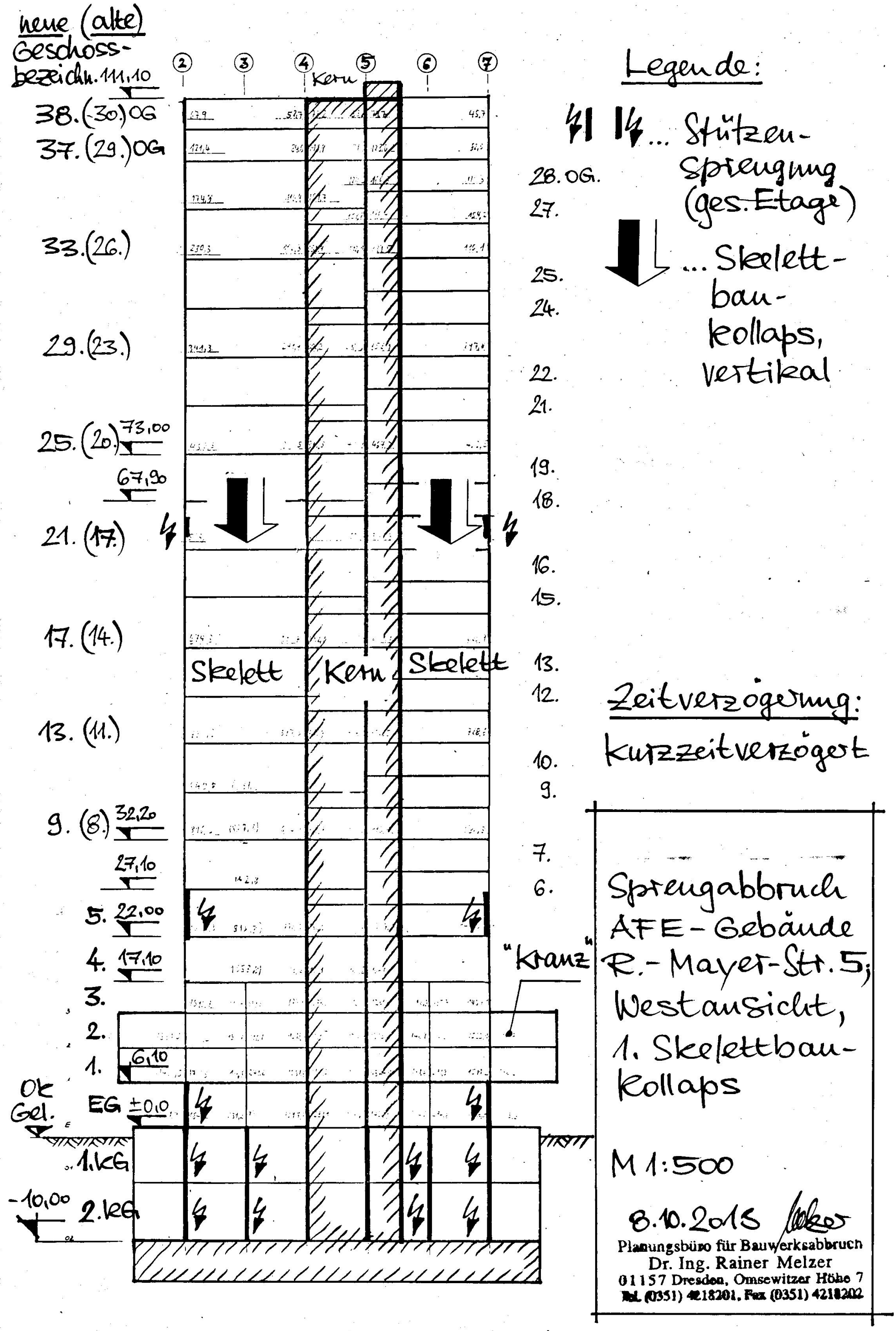

Figure 2. Vertical collapse of the skeleton.

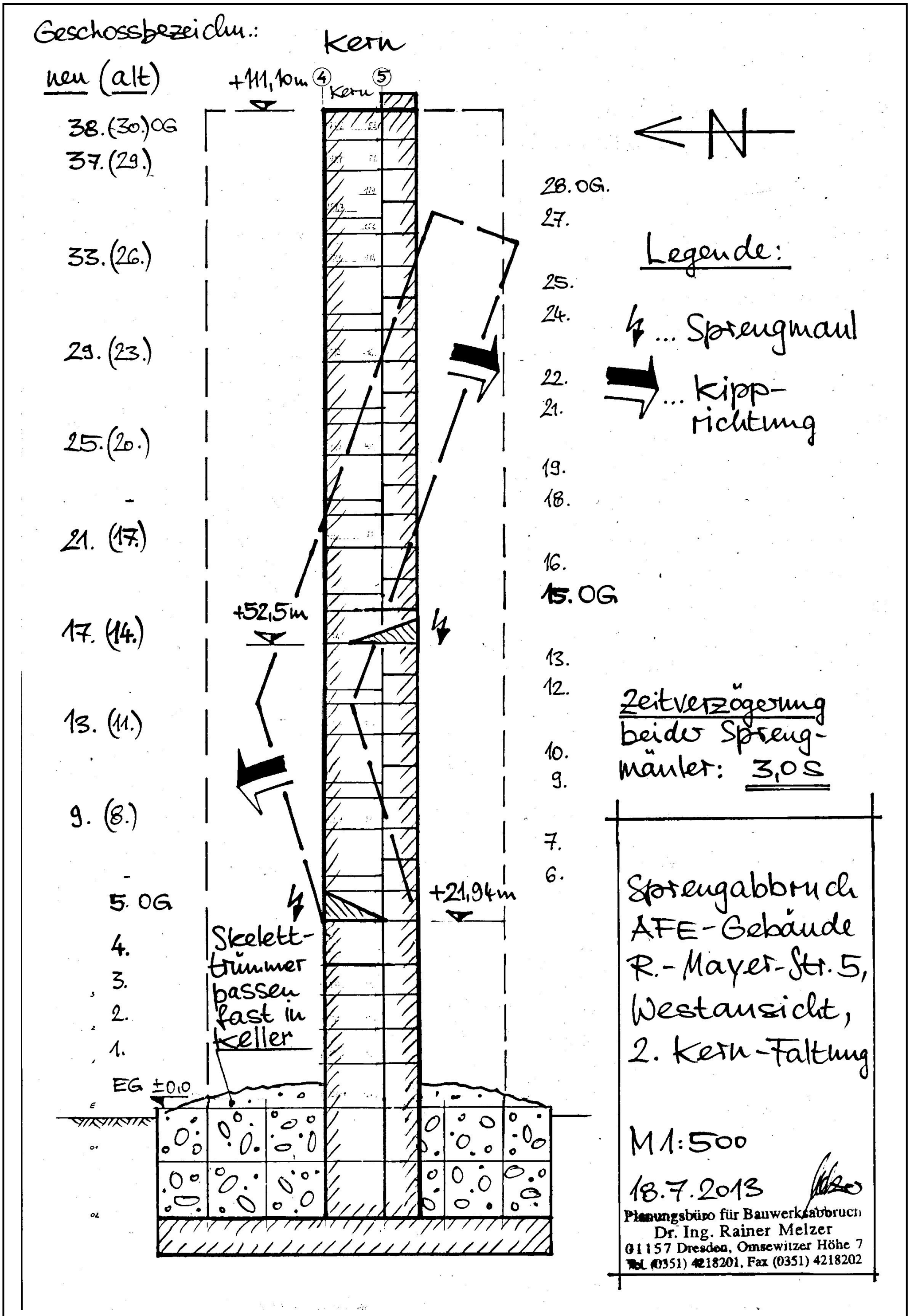

Figure 3. The double folding of the core.

Figure 4. Saw cut opening in the blast mouth.

Figure 5. The *skeleton* part is collapsing.

Figure 6: The result.

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Vibration controlled blast design and monitoring close to a dam

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ABSTRACT: The controlled blasting method implemented for a highway cut project near a rock-fill water storage dam is presented. Signature-hole blasts were done at particular regions of the planned excavation area where the distances to the structures are the shortest, and the farthest. By using the information on varying distances, charge weights and the measured vibration values obtained from these small scale test blasts, frequency and attenuation characteristics of the ground in different directions were determined and an empirical relationship between scaled distances and measured peak particle velocity (PPV) values were established. To eliminate the risk of damage, maximum amount of explosive that can be detonated at certain distances were calculated and PPV values were estimated. The whole excavation area was divided into 4 different regions based on the distance to the sensitive structures. Different blast designs were assigned for these four regions based on the calculated amount of explosives allowed to be shot per delay.

1 INTRODUCTION AND PROJECT OVERVIEW

General Directorate of Highways of Turkey planned to construct a highway cut on Konya-Beysehir roadway between kilometres 21.0 and 21.47. As a result of bidding, this work was assigned to a construction company. The construction company requested a consultancy work for safe blasting between the aforementioned kilometres as the General Directorate of Turkish State Waterworks does not allow blasting within 200 meters of a dam. As a result of this consultancy work it was found that between kilometres 21 and 21.47 there needed a vibration controlled blast design and practice not to cause any damage to the dam and its features. Between the aforementioned kilometres, strict vibration controlled blast design was also found to be necessary and to be implemented carefully not to cause any risk of damage to the impervious clay coating of the reservoir of the dam. The distances between the excavation area and the closest cut-off point of the dam ranges from 470 m to 40 m

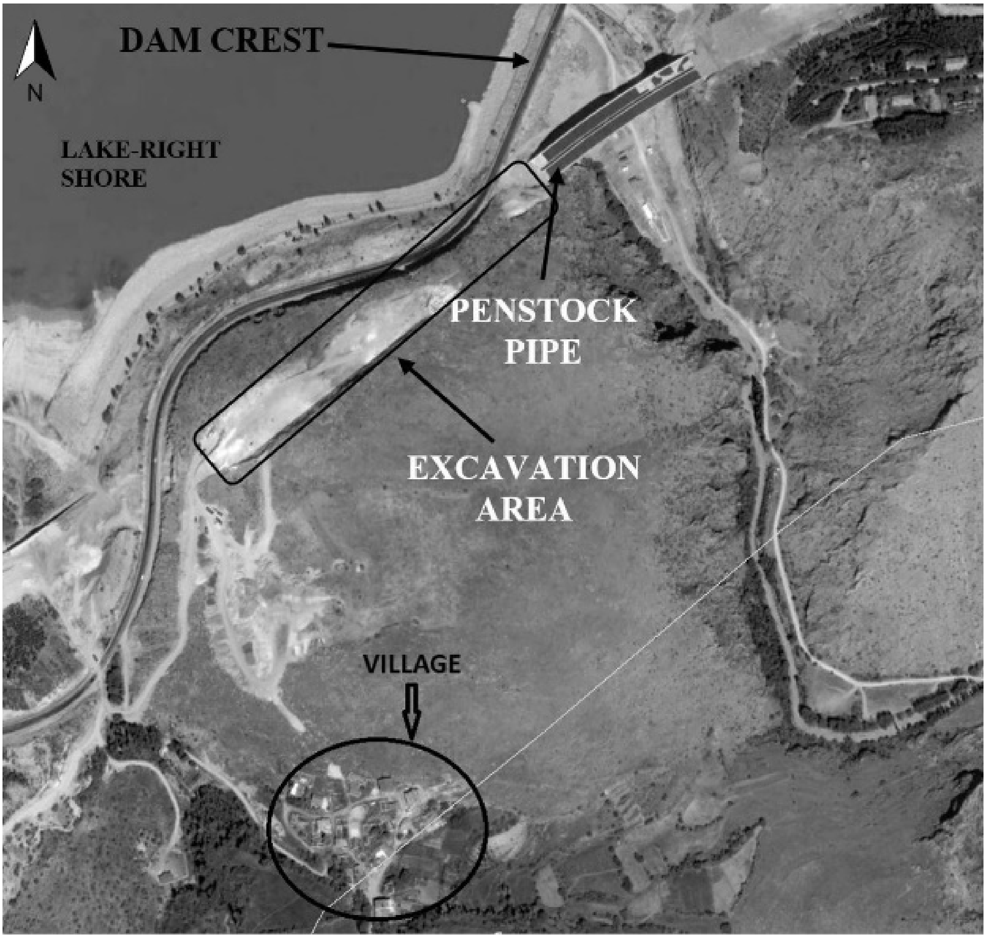

Figure 1. Planned excavation area and the sensitive structures around.

between kilometres 21 and 21.47. And, the distance between the excavation area and the clay coating on the right shore of the reservoir ranges from 40 m to 175 m between kilometres 21 and 21.47. The third sensitive site around the excavation area was the nearby Salarli village. Its existence was also taken into consideration.

2 TEST BLASTS AND MONITORING

Test blasts were carried out at different regions. Locations for these were based on the sensitive structures to be protected. In this project the sensitive structures around the blast area were the dam and its features, coating of the lake and the nearby village. These structures are shown in Figure 1.

To understand the attenuation characteristics of the vibration waves towards each sensitive structure, different amounts of explosives were blasted in different regions. In order to obtain the attenuation characteristics of the ground vibrations towards the dam and penstock pipe, test blasts were shot at distances of 40 m - 56 m to cut-off point at the right shore and 69 m - 89 m to the penstock pipe of the dam. Vibrations were monitored over the ground on top of the penstock pipe and on the dam crest. Two geophones were used to monitor the ground vibrations on the dam and one geophone was used to measure ground vibrations on the penstock pipe. These measurements were later used for obtaining a mathematical relationship between the intensity of the ground vibrations, distances and charge amounts blasted in test blasts. Amounts of explosives blasted in this region were 2.05 kg, 2.30 kg, 2.90 kg, 4.10 kg, 4.20 kg, 5.90 kg and 6.50 kg. The blast area along with monitoring points is shown in Figure 2.

A different region within the excavation area was chosen to carry out test blasts to assess the attenuation characteristics of the ground between the excavation area and the village. Two seismographs were located between the excavation area and the village to monitor ground vibrations induced by test blasts towards the village. Another set of two seismographs were also located linearly between the test blast area and the right shore of the lake. Test blast region and the location of the seismographs are shown in Figure 3.

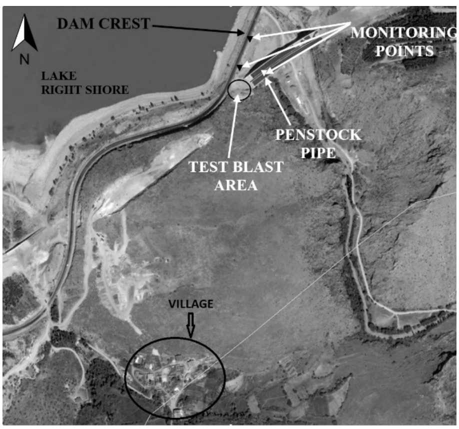

Figure 2. Area of the test blasts done for dam and penstock pipe directions.

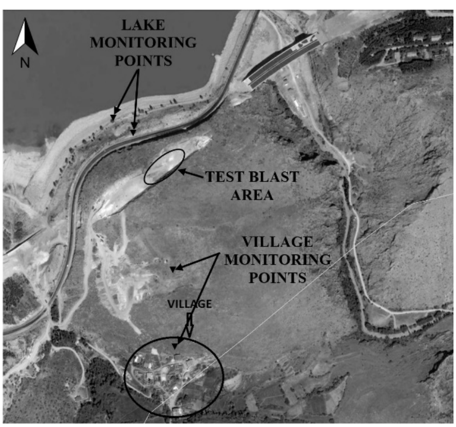

Figure 3. Location of the test blast area for lake and village directions.

In these test blasts explosive amounts ranging between 12.5 kg and 18.0 kg were blasted.

3 ANALYSES OF MEASURED VIBRATION VALUES OBTAINED FROM TEST BLASTS

3.1 Analyses of vibration measurements done on penstock pipe

As previously mentioned, a seismograph was located on the ground at top of the penstock pipe. In total, 10 events were recorded within the seismograph located on the pipe in the test blasts done nearby the penstock pipe and the dam crest. Vibration values recorded on the pipe are presented in Table 1.

In Table 1 it is seen that the maximum peak particle velocity (PPV) measured on top of the penstock pipe is 11.00 mm/s. This vibration value was measured when 5.9 kg of explosive was detonated at a distance of 73.27 m to the pipe. In DIN-4153 standard the maximum allowable ground vibration value for a steel welded pipeline is stated as 100 mm/s. The measured value is nearly 11% of the maximum allowable ground vibration value that is stated in DIN-4153 standard. In Austria the standard for blasting close to pipelines, the maximum allowable ground vibration value that a steel welded pipeline can be subjected to, is stated as 75 mm/s. The measured value is almost 15% of the allowed value stated in Austrian standards. Since the vibration values were well below the allowable values stated in both Austrian and German DIN-4153 standards and no leakage or damage was reported, 11 mm/s vibration value was considered to be a safe vibration value for the pipeline, although it was built a long time ago. The second maximum vibration value measured coming after 11 mm/s is 4.71 mm/s and this vibration value was measured when 6.5 kg of explosives were detonated at a distance of 89.66 m to the pipe.

On the other hand, unlike gas pipelines which are buried, penstock pipes are fixed in a concrete lined tunnel under the body of dam. So, not only the steel welded pipe but also the concrete lined tunnel should not be damaged as well. It is stated in the literature that no observable damage occurs in tunnel when the vibration level is below 200 mm/s (Dowding & Rozen 1978) or is below 263 mm/s (Kaslik *et al.* 2001). The maximum measured PPV on the pipe is 5.5% of the value stated by Dowding & Rozen(1978), and 4.2% of

Table 1. Ground vibration values recorded on top of the penstock pipe.

Peak Particle Velocity mm/s	Max. Charge Per Delay Q (kg)	Distance D (m)	Scaled Distance SD	Dominant Frequency (Hz)	Date
4.62	4.10	81.09	40.047	53.10	25.07.2013
4.71	6.50	89.66	35.168	33.90	25.07.2013
11.00	5.90	73.27	30.165	52.90	25.07.2013
2.40	2.30	86.40	56.970	59.50	23.07.2013
3.54	2.05	80.96	56.545	63.00	23.07.2013
2.17	2.30	84.99	56.041	55.50	23.07.2013
3.51	2.90	69.59	40.865	52.60	23.07.2013
3.30	4.20	80.17	39.119	54.50	23.07.2013
0.75	15.50	349.12	88.677	12.50	24.07.2013
0.70	18.00	380.29	89.635	13.40	24.07.2013

the value given by Kaslik *et al*. (2001), at which the lining concrete starts to crack. These values are considered to be safe values and it was concluded that the test blasts did not damage both the pipe and the surrounding concrete lining.

3.2 Analyses of the measurements done on the dam crest

Since the displacement and the ground acceleration are reported to be most important parameters in dam design in the literature and it was known that General Directorate of Turkish Waterworks, who constructed the dam, took account of the earthquake zone where the dam was constructed, acceleration and displacement values caused by the test blasts were also assessed in this section. Velocity, displacement and acceleration values obtained from measurements done on the dam are presented in Table 2.

Maximum PPV measured on the crest due to test blasts was 3.048 mm/s. This value was measured when 6.5 kg of explosive was detonated at a distance of 74.71 m towards the crest. The dominant frequency measured was 16.75 Hz. Even if there was a residential structure on the place where the seismograph was located, there wouldn’t be any risk of damage since the allowable ground vibration level for 16 Hz frequency in the Turkish regulation is stated as 29.85 mm/s and the measured value is well below the allowable value and complies with the regulation.

As for acceleration analysis, the maximum acceleration value measured was 0.063 g. The acceleration of 0.063 g was measured when 6.5 kg of explosive was detonated at a distance of 74.71 m. When the acceleration values given in Table 2 are analysed further, an interesting fact is noticed such that the acceleration value of 0.043 g measured when 4.1 kg of explosive was detonated, was higher than that of measured, which is 0.040 g, when 5.9 kg of explosive was detonated. The reason for this case is considered to be the existence of excessive burden distance for the hole with 4.1 kg charge per delay. Since the dam is located in a fourth-degree seismic zone where all kinds of structures are to be built to withstand to 0.10 g earthquake acceleration at minimum, it was assessed that there is no possibility of risk of damage to the dam.

The maximum displacement was measured as 0.032 mm. This level of displacement forms instantaneously and is an elastic displacement. The measured level is almost 3% of millimetre and assessed to be so low to cause no damage to the dam.

3.3 Analyses of the measurements done in the lake right shore direction

Clay coating at bottom of lake at the right shore is not a fixed structure like a building or a concrete lined tunnel and a steel pipe inside. Due to this, the utilisation of PPV in the assessment of blast induced seismic waves was not found to be

Table 2 Ground vibration levels recorded in crest of the dam direction.

Peak Particle Velocity mm/s	Max. Charge Per Delay Q (kg)	Distance D (m)	Scaled Distance SD	Dominant Frequency (Hz)	Date	Acceleration (g)	Displacement (mm)
2.159	4.10	69.36	34.254	29.81	25.07.2013	0.043	0.017
1.397	4.10	114.83	56.710	29.88	25.07.2013	0.027	0.013
3.048	6.50	74.71	29.304	16.75	25.07.2013	0.063	0.032
1.778	6.50	120.75	47.362	16.63	25.07.2013	0.027	0.017
2.159	5.90	72.55	29.868	17.56	25.07.2013	0.040	0.021
1.651	5.90	115.66	47.616	10.13	25.07.2013	0.027	0.017
0.762	2.30	80.26	52.922	18.44	23.07.2013	0.017	0.007
0.508	2.30	125.04	82.449	10.63	23.07.2013	0.013	0.006
1.143	2.05	77.93	54.429	22.81	23.07.2013	0.023	0.010
0.635	2.05	121.91	85.146	31.63	23.07.2013	0.013	0.005
0.889	2.30	81.58	53.792	14.75	23.07.2013	0.017	0.006
0.508	2.30	125.79	82.943	16.50	23.07.2013	0.007	0.004
1.397	2.90	69.59	40.865	29.81	23.07.2013	0.027	0.009
0.889	2.90	114.08	66.990	26.75	23.07.2013	0.013	0.007
1.016	4.20	79.58	38.831	22.50	23.07.2013	0.020	0.020
0.635	4.20	123.00	60.018	28.75	23.07.2013	0.013	0.005

appropriate. Clay coating, was laid on the slope of the right shore before impoundment and is a compressed material. Type of failure might be similar to the landslides which can be seen in natural slopes. Landslides may stem from two reasons. The first one is extreme ground acceleration and the second one is extreme displacement. Therefore, stability of the clay coating on the right shore was assessed based on the displacement and acceleration values caused by blasting. In fact, clay coating on the right shore is not a loose material and it was compressed after laying it down, also remains imprisoned with the hydrostatic pressure of the reservoir water. Therefore it is not possible for it to easily fail.

Measurement values taken towards the right shore of the lake are given in Table 3. The maximum acceleration level was 0.013 g and it was measured when 10.1 kg was detonated at a distance of 127.38 m. The highest acceleration values measured coming after the highest (0.013 g) is 0.010 g. Other measured acceleration values are much lower than these values. In the earthquake literature it is stated that the landslides that take place in the existence of a material which has the freedom of movement occurs when the ground acceleration is over 0.05g. Considering that the clay coating is imprisoned with the hydrostatic pressure of the water in the lake, measured acceleration value which was 0.013 g is calculated as 26% of 0.05g. This much of acceleration value was assessed to not to cause any rupture, tearing or sliding on clay coating.

The maximum displacement was measured as 0.006 mm. This level is so low and considering the applied hydrostatic pressure and imprisonment effect there is no instability expected.

3.4 Analyses of the measurements done in village direction

Most of the buildings existing in the village were constructed of rubble stone using clay mortar with a few exceptions. There are only a few, newly constructed buildings which can be considered to be built with modern techniques. Foundations of the buildings in the village are assessed to be done by digging a shallow soil cover and placed on a rock

Table 3 Ground vibration measurements done in right shore direction.

Peak Particle Velocity mm/s	Max. Charge Per Delay Q (kg)	Distance D (m)	Scaled Distance SD	Date	Acceleration (g)	Displacement (mm)
0.841	10.10	127.38	40.081	13.06.2013	0.013	0.006
0.508	10.10	143.54	45.166	13.06.2013	0.007	0.006
0.381	10.10	155.55	48.945	13.06.2013	0.007	0.003
0.587	5.90	124.80	51.379	13.06.2013	0.010	0.004
0.508	5.90	140.87	57.995	13.06.2013	0.007	0.005
0.381	5.90	152.85	62.927	13.06.2013	0.007	0.003
0.667	4.70	128.20	59.134	13.06.2013	0.013	0.005
0.254	4.70	144.28	66.551	13.06.2013	0.007	0.002
0.254	4.10	126.74	62.592	13.06.2013	0.008	0.002
0.286	3.50	126.47	67.601	13.06.2013	0.008	0.002
0.381	3.50	142.52	76.180	13.06.2013	0.007	0.003
0.302	2.90	126.54	74.307	13.06.2013	0.008	0.002
0.254	2.90	142.55	83.708	13.06.2013	0.007	0.003
0.254	2.90	154.49	90.720	13.06.2013	0.003	0.002
0.222	2.30	126.69	83.537	13.06.2013	0.008	0.002

foundation. Nevertheless, since the majority of the buildings are assessed to be very sensitive buildings, the vibration value not to be exceeded at the ground in the village was determined as 5 mm/s considering the worst case scenario, which is the existence of 1 Hz dominant frequency. Test blasts were designed considering 5 mm/s vibration limitation.

When Table 4 is analysed, the maximum PPV was 0.508 mm/s and this was measured when 18 kg of explosive was detonated at a distance of 345 m to the village. This value is 10.16% of the value which is permitted for 1 Hz case and assessed to be as a safe value.

4 ATTENUATION RELATIONS OBTAINED IN DIRECTIONS

Best fit regression analysis was used to determine the level of ground vibration between the excavation area and the sensitive structures. The seismographs were located along a path between the blast area and the structures. Vibration data that were presented in Table 1, Table 2, Table 3 and Table 4 were analysed and the mathematical relations between PPVs and Scaled Distances were determined by plotting the vibration data on a logarithmic plot.

There are a number of vibration predictors proposed by different researchers. In this research, the vibration predictor invented by United States Bureau of Mines (USBM) (Siskind *et al.* 1980) was used. USBM equation is as follows:

$$\mathbf{PPV} = \mathbf{K}\left(\frac{R}{W_d^{\frac{1}{2}}}\right) - \boldsymbol{\beta} \qquad (1)$$

$R/W_d^{\frac{1}{2}}$ in the equation is the Scaled Distance (SD), K and β constants, which are site specific constants, can be obtained by plotting the PPV and SD values in Table 1 on a log-log graph.

When SD values used in test blasts and corresponding PPV values are plotted in a log-log graph, the intercept and the slope of the best fit line gives those K and β values respectively. Konya & Walter (1990) states that a minimum number of 5 shots serve as a starting point with

Table 4. Ground vibration measurements done in village direction.

Peak Particle Velocity mm/s	Max. Charge Per Delay Q (kg)	Distance D (m)	Scaled Distance SD	Dominant Frequency (Hz)	Date
2.667	15.50	206.12	52.355	13.56	23.07.2013
0.254	15.50	356.03	90.432	7.13	23.07.2013
3.175	18.00	199.16	46.942	12.88	23.07.2013
0.508	18.00	345.42	81.416	13.00	23.07.2013
1.778	12.50	210.95	59.666	14.88	23.07.2013
0.254	12.50	362.04	102.400	21.13	23.07.2013
0.762	15.50	225.09	57.173	16.44	23.07.2013
1.397	15.50	225.48	57.272	16.19	23.07.2013
0.381	15.50	377.05	95.771	15.75	23.07.2013
1.397	15.00	241.65	62.394	15.31	23.07.2013
0.254	15.00	393.26	101.539	8.00	23.07.2013

Table 5. Predictor equations for each direction.

Village	Penstock Pipe	Dam Crest	Clay Coating
$10^6 x SD^{-3.183}$	$4693.5 x SD^{-1.757}$	$460.28 x SD^{-1.419}$	$170.04 x SD^{-1.375}$

more data to be added. When the scatter of vibration values is concerned, instead of using the median line, using a higher degree confidence line, which is 95% confidence line in this study, would be safer.

When measured SD and PPV values in Table 1 are plotted on a log-log graph, the relation shown in Figure 4 was obtained for the attenuation of ground vibrations towards the penstock pipe. Other attenuation graphs are presented in Figure 5, 6 and 7 for different directions by using the values in Table 2, 3 and 4 respectively.

By using the equation obtained from a 95% confidence line the following equations in Table 5 were obtained for different directions.

5 CALCULATION OF SAFE AMOUNT OF EXPLOSIVES

To calculate the amount of explosives that should not be exceeded, a reference vibration or acceleration level had to be selected. This value was selected as 20 mm/s for the pipes, 5 mm/s for the buildings in the village, 0.1 g for the dam and 0.05g for the clay coating.

The distance between the excavation area and the village is greater than 300 m. For this reason, the frequency of the blast waves generated from blasting may be as low as 10 Hz or even less. In Table 4 when the distance is greater than 300 m it is seen that the frequency drops down to 7.13 and 8.0 Hz. Nonetheless, since the quality of the buildings in the village is so low, it was thought that setting the maximum value as 5 mm/s by considering the worst case scenario, which is the existence of 1 Hz frequency, would be a good approach. So, even for the minimum distance which is 300 m, the calculated maximum amount of explosive becomes 41.73 kg. Since it was thought that the most critical structure among all the others is the dam and the old penstock pipes, the calculations for blast design were not done by considering the vibration limitations for the village and clay coating, instead, they were done by considering the vibration limitations for the dam.

The excavation area depending on the distances

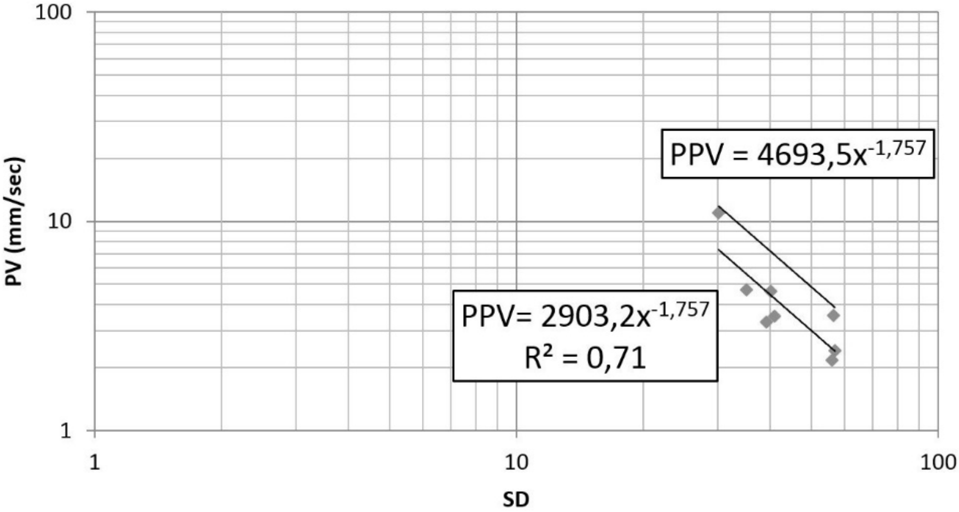

Figure 4. Attenuation plot in penstock pipe direction (Bilgin & Dagasan 2013).

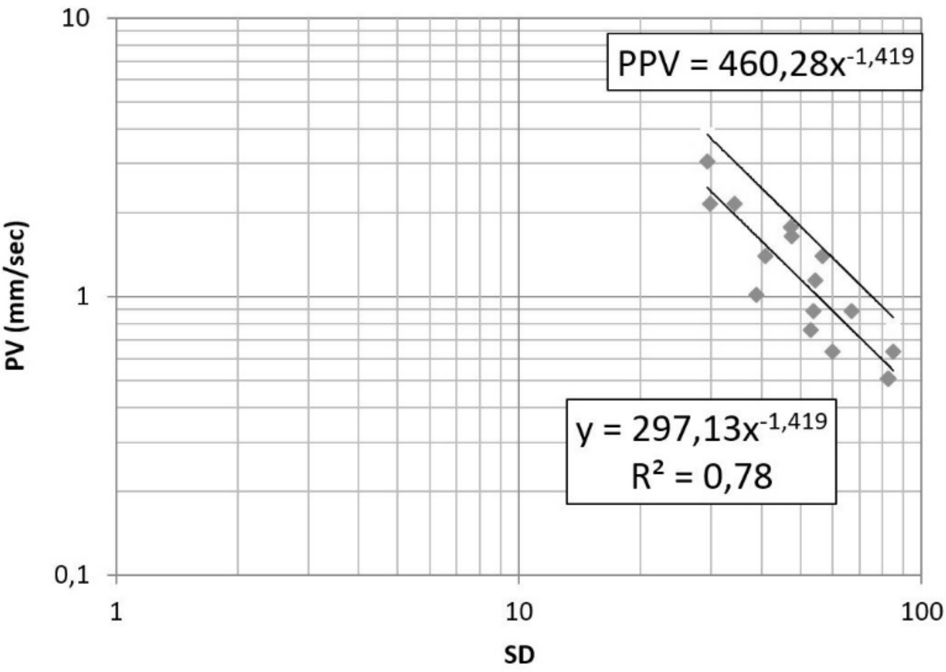

Figure 5. Attenuation plot in dam crest direction (Bilgin & Dagasan 2013).

to the nearby structures was divided into 4 different regions by using the vibration prediction equations obtained. The area where the distance to the dam is greater than 120 m is named as region 1, the one between 90 m and 120 m was named as region 2, between 60 m and 90 m was named as region 3 and less than 60 m was named as region 4. For each region, depending on the distance to

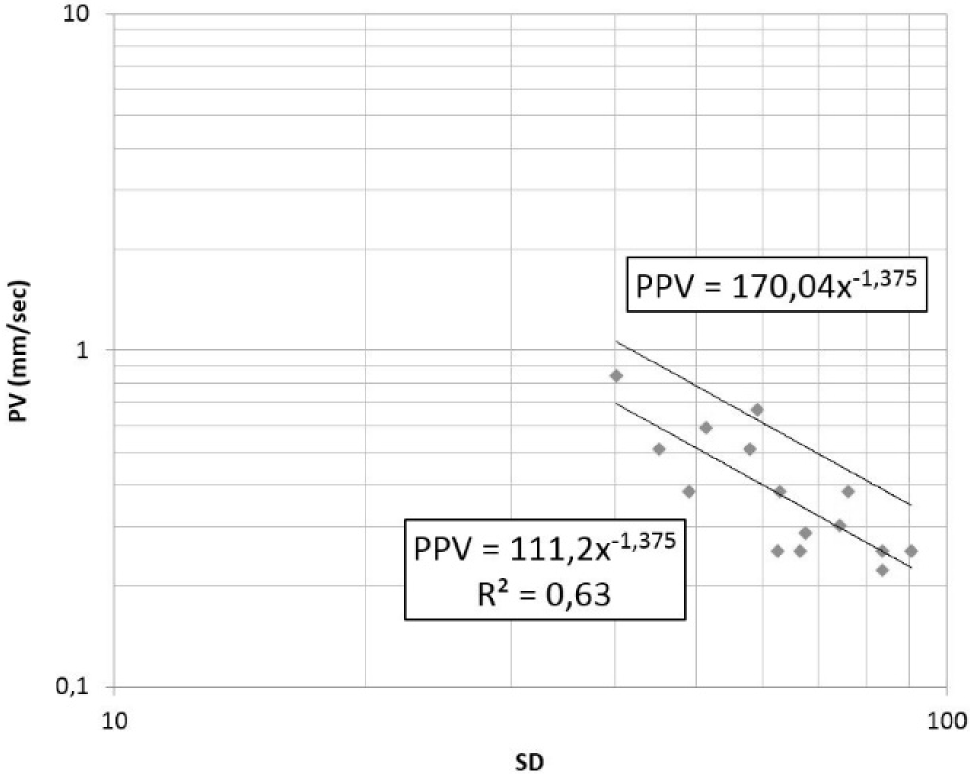

Figure 6. Attenuation plot in clay coating direction (Bilgin & Dagasan 2013).

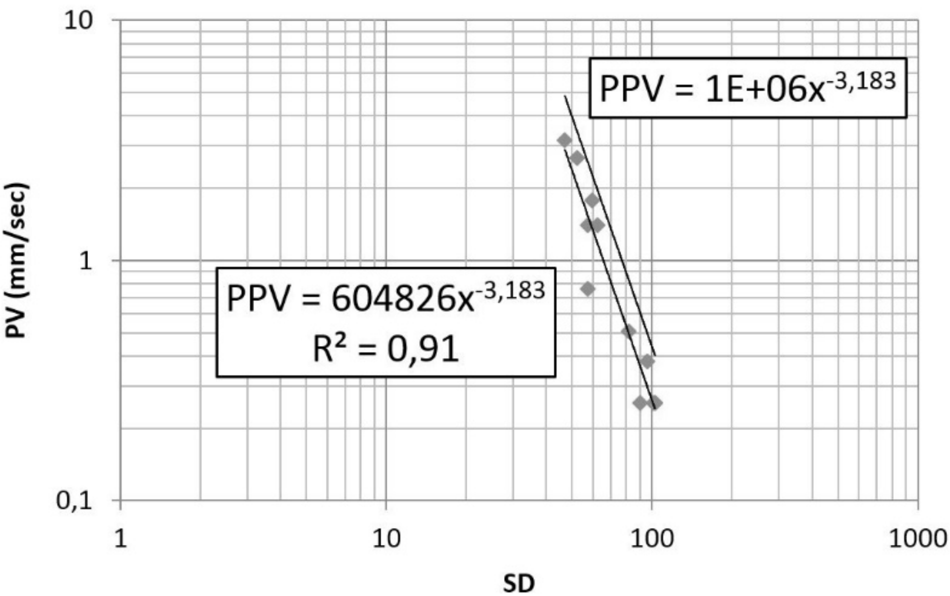

Figure 7. Attenuation relation in village direction (Bilgin & Dagasan 2013).

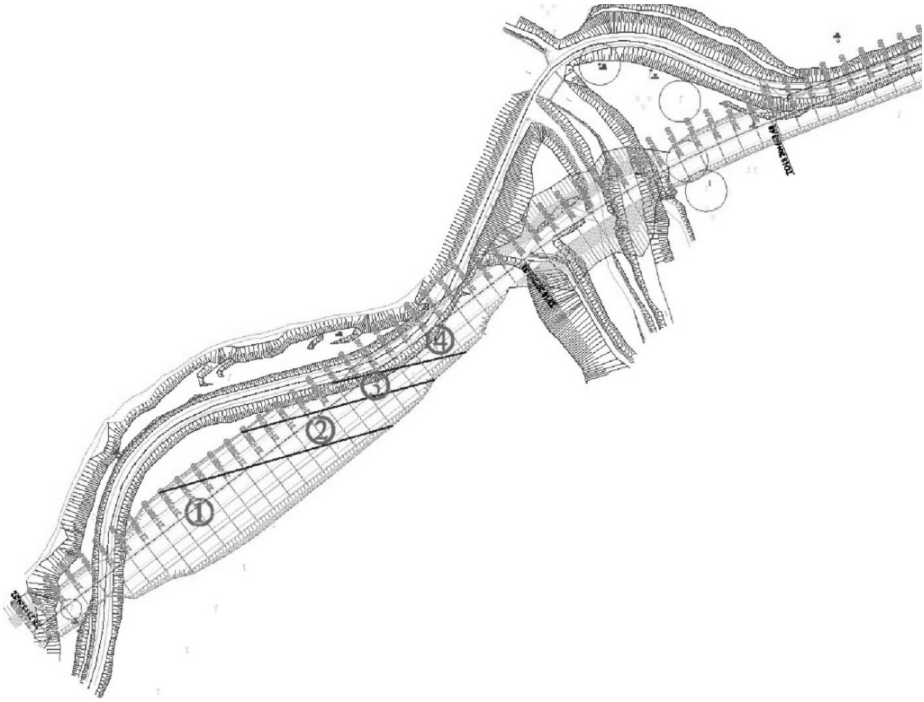

Figure 8. Excavation area was divided into 4 blasting regions (Bilgin & Dagasan 2013).

Table 6. Blast design for each region.

Regions	Max Kg	Hole Dia (mm)	Burden (m)	Spacing (m)	Bench H. (m)	Hole Length (m)	Stemming (m)	Stem Deck (m)
Region 1	25.5	89.0	3.0	3.5	7.5	8.4	3.3	NO
					15.0	15.9	2.9	2.8
Region 2	12.5	89.0	2.5	2.9	6.0	6.8	4.2	NO
					12.0	12.8	3.7	4.0
Region 3	6.5	76.0	1.9	2.2	5.0	5.6	3.8	NO
					10.0	10.6	4.0	3.0
Region 4	2.9	76.0	1.5	1.8	2.5	3.0	2.2	NO
					5.0	5.5	2.0	1.9

Table 7. Initiation plans suggested.

Delay Milliseconds	1 Row		2 Rows		3 Rows	
	Inhole	Surface	Inhole	Surface	Inhole	Surface
Single Deck	500 ms	42-59 ms	500 ms	42-59 ms	500 ms	42-59 ms
Double Deck	450-500 ms	42-59 ms	450-500 ms	42-59 ms	-	-

the dam, a maximum safe amount of explosive that can be detonated per delay was calculated and blast designs were done based on this information.

6 BLAST DESIGNS AND FIRING PLANS

Blast plans for different regions were designed by using the vibration prediction equations obtained. Given a specified vibration level and a distance, safe charge amounts per delay were calculated, and blast designs were based on those charge amounts. Blast plans designed for different regions are illustrated in Table 6.

Strict control of the ground vibrations by controlling the safe amount of explosive per delay was a must. For this reason, different initiation plans were also prepared to blast different group of holes with NONEL type initiation system. Suggested initiation plans are presented in Table 7.

These initiation plans were carried out in such a way that no more than a single blast-hole is detonated within 8ms time window.

In Table 7 various initiation plans for different rows of blast-holes were suggested. To eliminate the errors in timing, no double decking was allowed for more than two rows of blastholes. Inter-hole delays were chosen as 42 ms and inter-row delays were chosen as 59 ms, which is obtained by adding 17 ms and 42 ms detonators consecutively.

7 CONCLUSION

Because of the increasing requirement for earthwork near sensitive structures in recent years, elimination of the undesirable effects of blasting has become an unavoidable part of the operation. To control the effects of blasting, particularly the ground vibrations, monitoring is crucial in terms of understanding the current situation and the rock and attenuation characteristics of the vibrations.

In this research, sensitive structures around the blast area were determined and two groups of test blasts in different regions of the excavation area were carried out. The first group of test blasts was done to obtain the attenuation characteristics towards the penstock pipe and the dam crest and the second group of test blasts was done to obtain attenuation characteristics towards the clay coating at the bottom of the lake and the Salarli village. Before doing the attenuation calculations, the measured vibration, acceleration and displacement values and the frequency ranges of waves were analysed, and it was determined that test blasts didn't cause any damage to the nearby sensitive areas and no damage or leakage was reported. This conclusion shed light on the applicability and the design of vibration controlled, economical excavation methods by blasting.

Attenuation characteristics of the ground vibration waves were assessed by determining the site specific constants in USBM equation by vibration monitoring. Accelerations were taken into consideration for the stability of the dam and clay coating. PPV levels were assessed for the buildings in the village and the penstock pipe. Analyses showed that the most sensitive structure in terms of the vibration attenuation and the structure condition was the penstock pipes and the dam itself. For this reason, allowable vibration levels for these were referenced in calculation of the safe charge amounts per delay.

Based on the calculations, the excavation area was divided into 4 regions and different maximum allowable amount of explosive per delay values were assigned to each region based on the distance to the dam. Based on the maximum charge amount different blast designs were prepared for different regions.

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ABSTRACT: To improve quality of demolition works the German Demolition Association has created the ‘Quality Mark Demolition Works RAL 509’. This acknowledged hallmark of good quality has been extended to demolition by explosives. The profile of the demanded standards concerning site, staff, equipment and insurance is described. The auditing will be carried out every year by an independent and experienced specialist. The requirements are shown as well as interesting practical examples – bad and good results of demolition blasts will illustrate the value of this mark of quality.

1 THE NEED FOR QUALITY

These are ugly pictures, we need successful blast operations.

2 SEARCHING FOR A QUALITY MANAGEMENT SYSTEM

We all know the ISO standards 9000 and

Figure 1. Unsuccessful blast of a bank building.

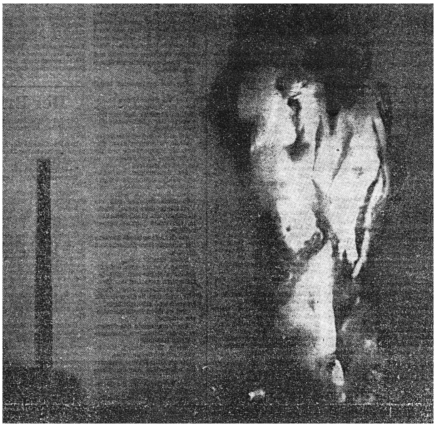

Figure 2. Secondary explosion of chemical dust after the blast of a chimney.

following. But this system is not suitable for our industry. In an exaggerated fashion we say: if you produce bad results, with ISO 9000 etc. you will have certificated bad results (normally we use some more drastic words).

SCC – certification is not fitting to blasting. It has its importance in the chemical industry.

The German Demolition Association found another quality management system, which was established in Germany 90 years ago: the RAL Guetezeichen (RAL Quality Mark). It was created in 1925 in order to get acknowledged standards for industry and trade. RAL means ‘Imperial committee for terms of supply’. Don’t worry about the term ‘imperial’ – but RAL has a long tradition. The objective of RAL is the acknowledgement of strong conditions for products and performances and the control of them by a neutral surveying system. The RAL-Institute awards 170 quality marks for ~ 9000 companies in Germany and abroad. The majority of the companies belong to the building and construction industry. The German Demolition Association was prompted by a member, which also works as a sewer construction company.

The quality mark ‘Demolition’ now has more than 60 members, 4 of them with the special mark: demolition blasting.

3 THE STRUCTURE OF THE RAL QUALITY MARK 509 DEMOLITION

There are 7 groups as set out in Table 1.

3.1 Jobs

Blasting is filed into the group ‘constructions > 20 m’, the most demanding group for normal demolition works. It contains all blast operations for demolition with a height of 20 m and more and with a distance to neighbouring buildings of < ½ of the height of the blast subject.

3.2 Demands for the site

A responsible site manager, who must be a licensed blaster, must be present permanently on the site. His task is to survey the operation and he is not allowed to do charging or other jobs on the site. He must have an experience in the job of at least 5 years. His licence must of course include the allowance for demolition blasts.

3.3 Demands for the staff of the company

The company must employ (permanently) at least:

– 1 qualified engineer or blaster with at least 5 years of experience
– 2 blasters licenced for demolition blasting
– 2 (trained and qualified) helpers.

These are minimal demands. The capacity of staff has to correspond to the job. The staff must have sufficient knowledge of electronic and non-electric initiation systems and must be trained for handling shaped charges.

This has to be proved by showing organization charts, description of functions of the employees, evidence of certificates/licences, experience, nomination of functions, proof of repeat training

Table 1. Structure of groups of RAL Quality Mark.

Demolition of constructions <10 m	<20 m	>20 m	Demolition in embedded surroundings	Demolition in contaminated areas	Demolition by diamond drilling and sawing	Demolition by explosives
HA 1	HA 2	HA 3	AB	AK	AB Drilling and sawing	HA 3 Explosives

courses etc.

3.4 Demands for the equipment

The company must have at its disposal the following equipment:

- 2 exploders which are suitable for detonators of class IV (including test devices)
- 2 circuit testers (ohmmeters) with the suitability to test shunts (lost of voltage)
- 1 instrument to measure stray current
- exploders for electronic and nonelectric detonators
- 3 vibration monitoring instruments
- 6 walkie–talkies
- suitable signalling
- warning flags warning waistcoats
- range-finder
- drilling tools including aggregates (hand held or rigs)
- 1 core drilling machine
- 1 oxygen lance equipment
- securing equipment for working in heights
- materials for protection against fly rock (i.e. fleeces, mash wire, blast mats).

Some instruments of the equipment need regular control (i.e.: exploders, ohmmeters, vibration monitors). This must be evidenced.

Literature: The applicant must also own the relevant literature, as full text of (current) laws and regulations, the specialised literature, product information from the manufacturers, safety instructions, technical information etc.

3.5 Insurance

The insurance must cover at least an amount of € 5,000,000 (five million) for legal liability. It must not have any exclusion zone (this means: a zero metre covering starting at the explosion spot). The payment of the actual insurance policy must be proven (i.e. by showing the bank account). Additionally a sufficient environmental insurance covering is demanded. By the way: the first million (€) of insurance cover is the most expensive.

3.6 Site examination

In addition to a desk based examination at the office of the applicant an on-site examination of the job is performed. Plans and calculations for the blast operations as calculation of charges and the initiation system, static calculations, a risk analysis, report to the authorities, realisation of the safety distance, secure storage of explosives etc. are objectives of this examination. The instruments used must have been calibrated and/or tested (proof of certificate). Instruments for substitution must be available. If necessary (and mostly it is necessary) the protection against flyrock has to be examined, as well as other protection measurements (oppression of dust, air blast, reduction of vibrations).

3.7 Documentation and critical back view

All measurements have to be recorded – and a critical back view is absolute. Written information about behaviour after misfires is strongly recommended. When the operator of an excavator is changing, it is not automatically sure that information about handling misfires is communicated.

3.8 The auditor

The auditors are specialists with real experience in this field. They are independent and rotate every two years.

3.9 Expenses

The membership fee for the organisation is € 300. The annual auditing normally takes a day at the office and another day on the site and costs for members € 1600 and for external companies € 3000. The annual repeat examination is € 1200 for members and € 2200 for externals. This should be affordable.

4 REMARKS

Nearly all the demands are matters of course. But practice shows, that a lot of competitors / colleagues do not fulfil these requirements. And we regard it as a disconcerting development that some colleagues are better in marketing than in blasting.

We have open markets in Europe and very often the price is the most important criteria for an order. Unfortunately, a lot of demolition contractors look mostly at the price. They want the car with the famous star for a penny price.

The ‘Quality Mark RAL 509 Demolition Blasting’ is the attempt to have an acknowledged proof of quality. Until now the grade of penetration (this is a term from economics) is still

Figure 3. Collapse of skyscraper at Hamburg (photos: Melzer).

Figure 4. Sequence of collapse of two buildings in Leonding (Austria) (photo: TSG).

Figure 5. Partial view of the blast of a 770 m long viaduct close to a new bridge (photo: TSG).

much too low, but I wish that we can extend it to Europe in some way. May be the ESSEEM project can help to make progress with the idea of excellent practice.

And then we can be happy about such pictures:

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Global studies of the levels of risk of flyrock

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ABSTRACT: After an accident, or in the event of a new project, quarries and mines are compelled to estimate the risks created by their activity in the neighbourhood; among which flyrock, because it is potentially fatal, is surely the most significant risk. A model has been developed to estimate risk levels of flyrock for an entire quarry or public works project. It therefore foresees the variability of geological and geometric blasting parameters within a large volume. This model is supported by a statistical estimation of the confinement capacity of the rock mass, quantifying the variations of the confinement geometry and of the explosive energy based on audits of the equipment and manpower available to carry out and inspect blasting. These components converge to determine risk levels, compared to regulation limits. Technical services of public administration authorities rely on these results to validate the approach presented by the owner and to authorise the resumption of operations.

1 INTRODUCTION

A blast from a quarry in the South of France was the cause of accidental flyrock to a factory employing several hundred people. As a protective measure, French authorities immediately called a halt to the blasting and thus to quarrying operations. Before activities could be resumed, the authorities required that the quarry owner submit proposals on how to improve blasting operations and mining control processes. Following requests by local residents, the quarry was especially requested to guarantee a high level of safety for the duration of future operations.

In this article, we deal solely with the risk assessment of the overall production. However, the processes relating to blast pattern designs, verification of explosives loading, measurements of the geometry of the blasts, procedures of blasting operations controls, and procedures for processing anomalies or misfires could certainly justify a paper in themselves.

Considering the urgency to provide a rapid response to the authorities in order to resume quarrying operations promptly, there is a great temptation to set up flyrock calculation and checking tools for every blast. However, most cases of flyrock that we have had the opportunity to analyse over more than fifteen years result from unusual variations of both the blasting parameters and the rockmass. Risks relating to the overall production of a quarry over a long period can thus not be assessed through calculation methods, however sophisticated they may be, which deal with every single blast on the basis of the nominal characteristics of the geometry, the explosives and the rockmass. Besides, if the extraction organisation is not integrated into the assessment process, there is a high risk of accepting blasting situations with abnormally high constraints and thus considerable costs.

Having detailed the hypotheses of the risk assessment model, developed by Egide and which has already been published (Blanchier 2012, Blanchier 2013), we return in more detail to the case of the previous site to examine the implications of the method on the choices of operations.

2 EGIDE FLYROCK MODEL

Flyrock, or 'wild flyrock' if we refer to the terminology used by Little & Blair 2010, corresponds to the propulsion of a rock fragment of varying size over a large distance from the blast, more precisely exceeding the acceptable distance or 'exclusion zone limits' that have been determined or estimated by the blaster.

This propulsion depends on the explosive energy used, the geometry of the confining rock mass and the explosive charges as well as the way the rock mass control the explosive detonation. The detonation timing of the different explosive charges used in the blast is also an important factor in the occurrence of flyrock in so far as it is likely to modify the way the explosive charges function and to affect the geometry of the faces developed during the blast dynamics.

Flyrock risk is, therefore, linked to controlling these different parameters during the entire operation. Explosive energy and geometric blasting parameters seem to be controllable parameters as much as the confinement capacity of the rock mass tends to vary considerably over the term of the project.

The model should determine a risk level to be compared to acceptable thresholds possibly stated in local regulations.

2.1 Blasting plan parameters

Our flyrock investigations inevitably begin by examining the real blasting conditions or prescribed conditions. This includes, not only drilling equipment, the choice of explosives, initiation and geometric parameters, but also methods for inspecting these parameters and the teams' working methods.

The most easily controllable parameters in blasting plans are the explosive energy and the use of delays. On the other hand, even if the height of the benches is generally an easily controlled parameter, it is not the same case for rock thickness around (confining) explosive charges. These varying thicknesses depend on the structure of the massif and on the orientation of the faces within this discontinued volume, on the blasting plan being adapted to these conditions, and also, on the accuracy of the drilling already carried out.

Controlling these variations mainly depends on the level of equipment used to check the burdens for every blast.

Over and above the instruments used to check thicknesses, the human factor remains one of the most important factors in geometry variability, insofar as the operator's care and choice of burden variation which above a certain level a change of explosive charge would need to be envisaged. When carrying out flyrock surveys that lead to an increased awareness of these risks among the companies' employees, whether they are due to a regulatory requirement or the result of an accident, we find ourselves most often working in situations in which relatively high importance is placed on checking rock thickness.

Finally, blasting delays, controlling the blast dynamics, can also influence the quality of confinement.

Initial blasting condition audits make it possible for us to quantify the energy used and the variability of the geometric confinement of the charges.

2.2 Consideration of the rock mass to be blasted

The flyrock estimation model should cover all types of geology and geological structures likely to be encountered at each stage of the operation and the models to determine the different possible configurations of the rock mass are still only in development phase. For this reason, considering the limited knowledge of the rock mass at the survey stage, its behaviour can only be taken into account statistically. This approach is not surprising since initial surveys of vibration impact or airblast are generally carried out in the same manner using statistical laws of propagation.

In this study, we are interested in flyrock relating to infrequent events and which, in most cases, are therefore linked to particular geological situations and high-risk situations, significantly different from the situations commonly encountered in operations. Such high-risk situations are likely to appear in different geological contexts even if they are of a different nature. Thus, karsts or cavities in limestone massifs, areas of weathering in granites, faults or open joints, etc. could be encountered.

Considering the lack of systematic recording of flyrock connected with precise blasting parameter measurements, there is insufficient information from past work to differentiate between the geological contexts and even the broad geological formations. At first approximation, each geological situation appears to present the same risk levels: almost the same percentage of accidental flyrock can be found in the different main geological formations.

2.3 Choice of flyrock model

As a general rule, flyrock can come from either the upper zone of the blast (flyrock generated from the head of drilling holes), or the lateral clearance zones (flyrock generated from the face) as is the case for bench blasts.

Flyrock generated from the head of drilling holes follows a bell-shaped trajectory and can travel in any direction; however, its range is comparatively short for blasts carried out in accordance with good practices (that comply with the depth and quality of the stemming material etc.).

Flyrock generated from the face follows a straight trajectory if it is positioned towards the front of the face (a half-space opposite the blast) and travels a relatively long distance for bench blasts carried out in accordance with good practices. Risk linked to this type of flyrock can be completely eliminated by choosing appropriate orientations of the face.

Based on our experience of accident analysis, long-distance flyrock comes from isolated blocks or in a small number of cases which, for this reason, interact with each other very little once ejected from the original rock mass.

The effect of the air on the movement of blocks is complex. Indeed, if the air drag slows down the movement of a block, the air can create phenomena of lift for flat elements. Besides, the wind can favour or hinder the movement. These contradictory effects of the air will be taken into account statistically. The trajectories of the cast blocks can therefore be represented as parabolas and the flyrock will therefore be determined entirely through its speed and initial orientation, at the time of the blast.

2.4 Estimation of flyrock range

The variability of rock mass confinement ability, of the thickness of rock confining explosive charges and of blasting situations prompted us to find a model that was both stable and simple to determine flyrock parameters.

The formula put forward by Frank Chiapetta (1983) allows us to obtain a good estimation of the flyrock speed of the blocks coming from the face. It can easily be adapted for flyrock produced from the blasting surface. This formula is as follows:

$$V = K \cdot \left[\frac{B}{\sqrt[3]{E_l}} \right]^{-1.17} \qquad (1)$$

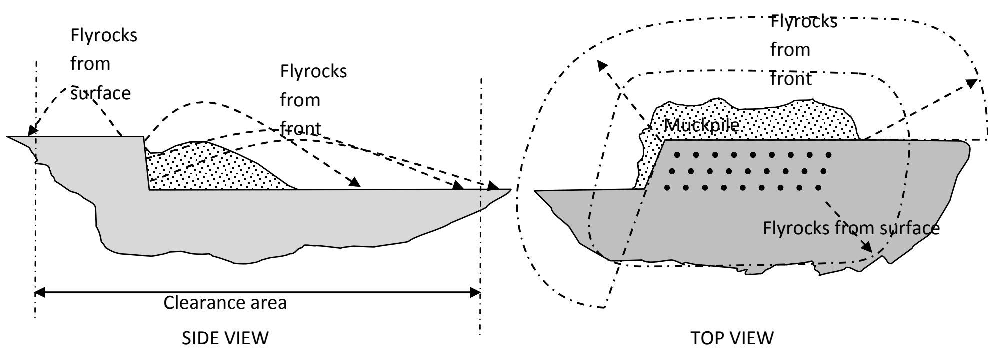

Figure 1. Areas affected by flyrock generated from blast faces.

Where V is the flyrock speed expressed in m/s, B is the burden or more precisely the thickness of the rock perpendicular to the explosive expressed in m, E_l is the linear energy of the explosive charge expressed in MJ/m and K is a coefficient expressing the probability of attaining the estimated speed.

This relation is dependent on the explosive energy being implemented, the rock depth and on coefficient K which represents the blasting situation, and particularly the rock mass characteristics, as in the coefficient in the laws of propagation of vibrations and airblast. Our own experiments lead us to slightly modify K factor from original one.

This approach of the rock can therefore be expressed through a statistical variation of the coefficient K. The first estimation of this variation was established assuming that there was a normal distribution of deviations around a mean value based on studies carried out in the United States since the 1980s: the evaluation of the speed of moving fragments from the working face through high speed imaging (Chiapetta *et al.* 1983. Mining Resource Engineering limited 1983.)

The variation of coefficient K varies depending on the level of probability according to a normal distribution. This variation is expressed in the following table:

Table 1. Evolution of K with probability.

Probability of speed attainment	50 %	5%	1%	0.1%	0.01 %
K	14	25	32	40.7	50.4

The movement illustrated in each block is regarded as ballistic. The trajectory of a block, subjected to the initial speed of V at an angle of α on horizontal ground and situated at a height of h with relation to the landing surface of the block, is therefore defined by the following parametric relationships according time t:

$$\begin{cases} X = V \cdot \cos\alpha \cdot t \\ Z = V \cdot \sin\alpha \cdot t - \frac{1}{2} g t^2 + h \end{cases} \qquad (2)$$

The trajectory of a block, subjected to the initial speed of V, at an angle of α on horizontal ground and situated at a height of h with relation to the landing surface of the block, can also be expressed in the following form:

$$X = \frac{V \cdot \cos\alpha}{g} \cdot \left[V \cdot \sin\alpha + \sqrt{V^2 \cdot \sin^2\alpha + 2gh} \right] \qquad (3)$$

Here X represents the maximum range of flyrock and g the acceleration of the weight at an estimated point.

In these estimations, we take angle α as that corresponding to the maximum flyrock distance d. It is an unfavourable hypothesis.

The distances of the flyrock depend on the relative altitude of the explosive charge and on the potential recipient.

2.5 Impact probabilities

In our model based on a normal distribution of flyrock distances around a mean value, there is no maximal flyrock distance. In reality, the explosive energy implemented is a limited, known quantity and the flyrock range is bounded. But considering the small number of inventories of long-distance flyrock, it is difficult to establish the effect of a maximal distance by substituting the normal distribution by a bell-shaped distribution.

Based on the exploitation hypotheses prescribed for a site, the previous model makes it possible to determine:

– the distance of maximal flyrock for each hole according to the level of probability
– the probability that a person is impacted by the flyrock for this hole
– the annual probability of impact of a person considering the number of holes per year blasted in the corresponding direction.

The different formulas used in the model are fully detailed in papers previously presented during Fragblast and ISEE conferences (Blanchier 2012, Blanchier 2013).

2.6 Risk and acceptability

In classic pyrotechnic risk analyses, like those defined by NATO regulations utilised at a European level, the probability of a pyrotechnic accident occurring and the effects of this accident on people are analysed separately. These effects, whether those of pressure or thermal effects from accidental explosions, decrease according to the distance from the accident zone.

In the case of accidental flyrock, the triggering event is the blasting. In addition, the effects of flyrock do not decrease with distance: a 200-gram projectile can be fatal at 20 m, as at 1,000 m.

Consequently, the approach to risk is noticeably different from those of other hazards: such as the risk of accidental explosion of an explosive storage magazine (in which the effect varies considerably depending on the distance); such as an airborne shockwave where the pressure decreases with the distance. The effect of flyrock does not change markedly according to the distance; it is only the probability that changes. Indeed, the probability of impact decreases with distance and at the same time the impact zone increases with distance.

In fact, the risk of fatality is the product of the probability of an accident by the fatal probability in a defined danger zone, knowing that an accident has occurred. In our case, this risk corresponds to the probability of impacting a person at a given place, since we have presumed that each impact was fatal.

These risks are compared to the risk of annual 'natural' mortality. In the case of France, the probability of death is given in the following graph. The values are similar to those from a number of other countries.

The lowest annual risk of death (between 5 and 14 years of age according to French statistics) is in the region of 10^{-4}. Added-on risks that increase the probability of death by less than 1% are considered as being unacceptable. Levels of negligible risk can also be defined.

In this way, the NATO rulings integrated in the main into different European regulations accept a maximal risk of 10^{-6} (for a pair of probability event D/P1 and limit of the danger zone Z2) for the external environment. These limits are reinforced for areas with a high-density population for which the maximal risk of 10^{-8} is generally accepted.

The same flyrock leading to significant effects on people only lead to minor damage on infrastructures. The main risks are indeed risks of glazing breakage or damage to roofs or unsturdy partitions.

To translate these results in the same formalism as the French regulatory documents, the risks will be expressed as a pair of the probability of an event E and the boundary of the danger zone Zi (E.Zi) leading to the maximal constraints pertaining to the regulations in force.

3 RESUMPTION OF OPERATIONS IN A LIMESTONE QUARRY

Let us return to the quarry in the South of France. Accidental flyrock from a blast to a nearby engineering factory led to the authorities suspending the blasting rights in the quarry. We carried out a reassessment of the risks connected

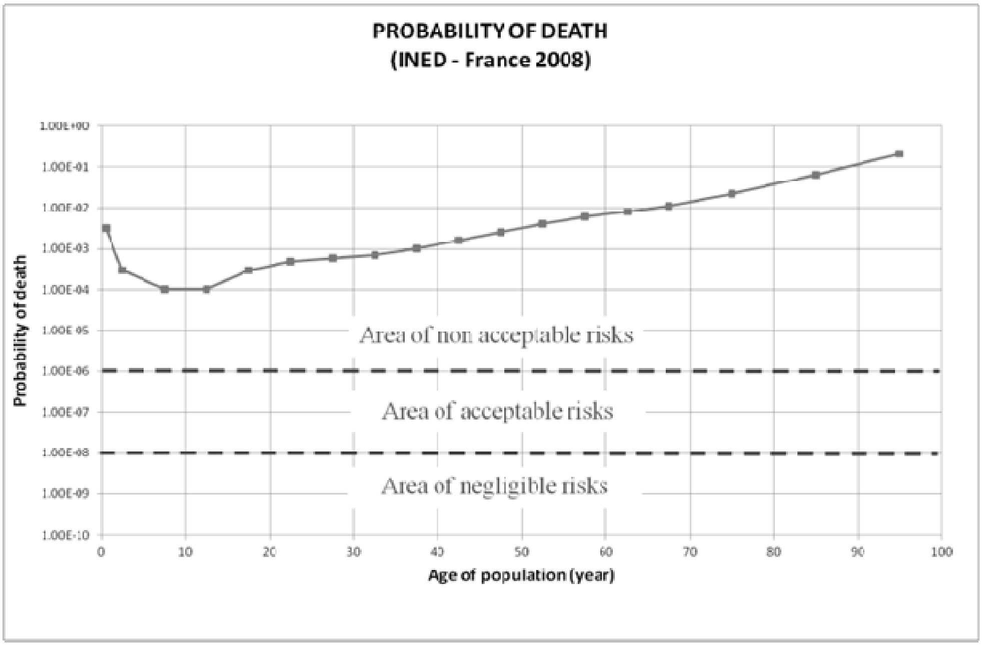

Figure 2. Probability of death, France – INED 2008.

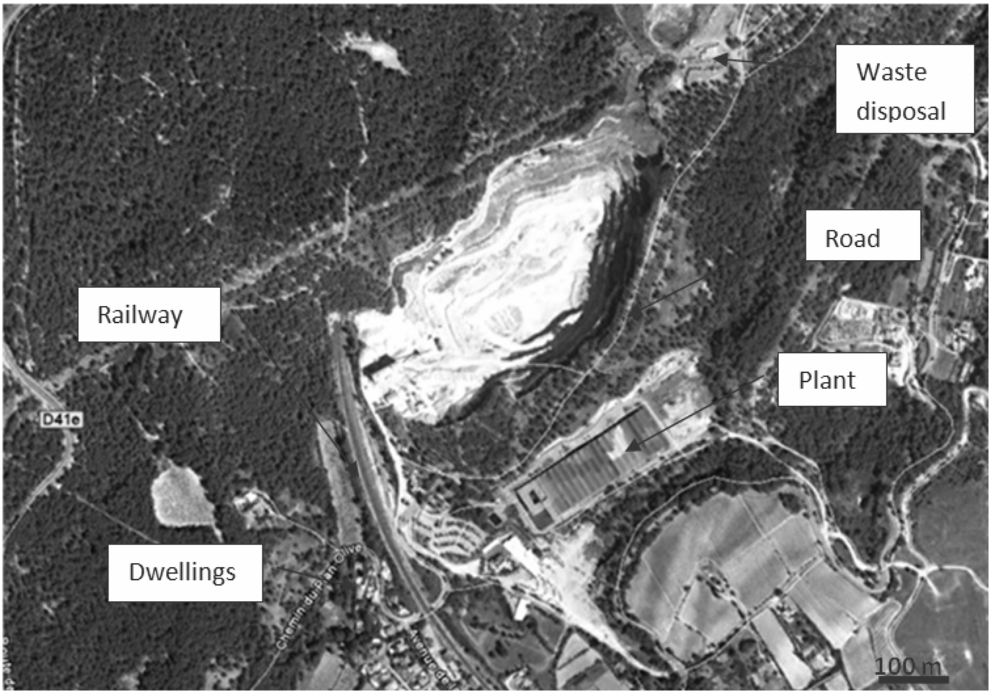

Figure 3. Map of the quarry and its neighbourhood.

to the blasting operations at the request of the owner in order to meet the requirements of the regulatory authority and to resume the blasting.

3.1 Neighbouring structures and infrastructures

This quarry operates on six benches of a 15 m hillside in a limestone deposit (Figure 3). A town of 10,000 inhabitants is situated further down to the south, with the first houses being at a distance of 210 m away. The quarry is also surrounded by a waste collection center at 350 m to the northeast, an engineering factory 125 m to the southeast and a busy railway 45 m away to the west. Furthermore, the service road to the waste disposal center follows the quarry from the south to the northeast.

The first phase of the analysis is to describe the functioning and general organisation of the quarry. This includes in particular:

– the description of external neighbouring activities
– the extraction organisation based on operating constraints specific to the site
– phasing and direction of current and intended extraction
– envisaged blasting patterns on the various levels of the quarry to reach these goals.

Having verified the coherence of the project, concerning the constraints and the production, all relevant information is quantified then introduced into the model, namely:

– the relative positions in terms of altitude and distance from the potential receivers with relation to the various blasting zones planned
– the blast characteristics and in particular the explosive energy used, the drilling diameter, the pattern, the height of the bench, the overdrilling, the stemmings, the drilling deviations, the state of face, the number of holes for each blast, the number of holes in the first rows.

This information is completed by all other factors making it possible to specify the variability of the parameters introduced into the model, such as the perceived variations of the explosive charges per metre due to the deformation of holes and cartridges, the various methods of priming and the various rocky faces of the quarry.

Table 2 – Relative position of the blasts and the receivers.

Area	East part of the quarry	West part of the quarry
Blast patterns	12 m to 15 m high bench blasts + some surface blasts	3 m to 8 m deep surface blasts + 12 m to 15 m high bench blasts for lower level
Benches elevation (m)	50/65, 65/ 80, 80/95, 95/110, 110/125 et 125/140	
Minimum distance to plant Altitude: 141 m NGF	125 m	138 m
Minimum distance to railway Altitude: 128/130 m NGF	180 m	44 m
Minimum distance to housing estate - Altitude : 210 m NGF	430 m	210 m
Closest distance to waste collection site - Altitude : 105/136 m NGF	350 m	780 m

3.2 Impact probabilities

The following step is to determine the levels of risk generated by the mining project.

For every blasting situation, that is for every front, every blasting orientation, every blast pattern and every receiver, the risk of impact from flyrock originating from the blasting surface and face is then calculated according to the distance, while taking into account possible screens if required. For each of these blasting situations, safe distances associated with the standard levels of risk as defined by NATO, respected and even expanded by French regulations, are determined.

Table 3 represents an example with well-defined blasting situations, the flyrock distances corresponding to standard levels of risk according to NATO rules (and the French regulations) expressed in the form of E.Zi pairs. The situations non-attainable, due to the distances between the blasts and the receivers, are shaded in the table, and the unacceptable situations are noted in bold.

3.3 Risk and acceptability

The compliance of the situation of every receiver with the current local legislation, in this particular case the French regulations, is then estimated for the various blast patterns according to the number of exposed people and for the various levels of risk. In our example, the compliance check is presented for the engineering factory in Table 4.

Whenever the situation does not comply with the regulatory requirements, corrective actions are proposed, such as:

– changing the orientation of the fronts to bench blasts
– changing the pattern to bench blasts
– modifying the explosive charges
– modifying the top stemming
– replacing bench blasting by surface blasting
– implementing protection for surface blasts (i.e. blasts mats).

Table 3. Limits of the safety zones in the case of surface blasts loaded with Emulstar 6000 in the West part of the quarry and flyrocks from the surface of the blasts.

Receiver	Receiver altitude m NGF	Bench altitude m NGF	Minimum distance (m)	Levels of risk				
				E.Z1	E.Z2	E.Z3	E.Z4	E.Z5
Plant	141	140	260	65	106	136	170	209
	141	125	160	57	99	128	163	201
	141	110	160	47	90	120	154	193
	141	95	160	32	79	110	145	184
	141	80	160	-	66	99	135	175
	141	65	160	-	48	86	124	164
Housing estate	105	140	220	81	123	153	188	227
	105	125	230	74	116	146	180	219
	105	110	240	68	109	139	173	212
	105	95	250	61	102	132	166	204
	105	80	260	51	93	123	158	196
	105	65	270	39	84	114	149	188
Railway	128	140	45	**71**	**112**	142	177	215
	128	125	55	**64**	**105**	135	169	208
	128	110	65	56	**97**	127	162	200
	128	95	75	45	**88**	119	153	192
	128	80	85	29	78	109	144	183
	128	65	95		64	98	134	173

Table 4. Plant situation before remedies.

Blast situation	Pair «probability of event / effect zone»	Number of persons permanently exposed	Authorised number of persons	Compliance of receiver situation to regulation
Bench blasts Quarry West part	**E. Z2**	**230**	**0**	**NO**
Bench blasts Quarry East part	**E. Z3**	**230**	**< 100**	**NO**
Surface blasts Quarry West part	E. «hors Z5»	230	No restriction	yes
Surface blasts Quarry East part	E. Z4	230	< 1000	yes

The incidence of every corrective action on the level of risk is estimated as previously. The owner for his part estimates the interest of every proposed solution and its financial impact in terms of implementation cost, block size and thus costs relating to loss of productivity and production, as

Table 5. Global situation of receivers after remedies.

Pair «probability of event / effect zone»	Number of persons permanently exposed	Authorised number of persons	Compliance of receiver situation to regulation
E.Z3	88.2	<100	yes
E.Z4	640	<1000	yes
E.Z5	687	No restriction	yes

well as operating costs. If necessary, the developer can decide to abandon part of the deposit if operations are deemed unprofitable.

Finally, the situation of all receivers and blasts, calculated as the addition of the situation of every individual receiver, is evaluated and presented to the supervisory authority (Table 5).

The authority's technical services rely on these results to validate the approach presented by the owner and to authorise the resumption of operations.

4 CONCLUSION

Quarry and mines are compelled to estimate the risks induced by their activity in the neighbourhood, among which flyrock, because it is potentially fatal, is surely the most significant risk.

In our experience, long-distance flyrock generally corresponds to particular situations of rock confinement in which it is difficult to predict the occurrence with precision but which can possibly be estimated from a statistical model based on cases already recorded.

A flyrock model making it possible to estimate risk levels in the environment has been built using a similar approach to that used in classic pyrotechnic risk studies. It is intended to estimate the risk level for an entire quarry or public works project and therefore foresees the variability of geological and geometric blasting parameters within a large volume. It is therefore significantly different from the model designed to estimate swelling or even flyrock for a single shot.

This model is supported by:

– a statistical estimation of the confinement capacity of the rock mass
– quantifying the variations of the confinement geometry and of the explosive energy based on audits of the equipment and manpower available to carry out and inspect blasting
– determining flyrock parameters with the help of a simple, stable model.

These components converge to determine risk levels, compared to the annual death rate of the population.

This flyrock model, which is as simple to use as are the laws of propagation for vibrations or airblast, could be put in place in numerous quarry or public works sites and make it possible to improve knowledge on the variability of rock mass confinement.

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A Delay timing between explosive charges as a new parameter to predict and control vibrations

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ABSTRACT: There are a number of techniques to minimize blast generated vibration levels on nearby structures. These include the use of Electronic Blasting Systems (EBS), lower density explosives, multiple explosives decks and presplitting. The company's clients have benefitted from the use of these techniques when their requirements demanded it and, as a result, an inverse relationship was found between delay timings and this can now be precisely controlled using EBS. This paper presents the blast trials that have been conducted in two Portuguese quarries as the basis for the development of this relationship. All blasts were monitored with calibrated seismometers, testing the different timings between charges, to avoid delay timings that may cause overlapping with the natural frequency of the rock layers and respective amplitude amplifications. The trial blasts were carried out in different combinations with up to 3 explosives decks (respectively delays) with and without presplitting.

1 MINIMISING BLAST VIBRATION LEVELS ON NEARBY STRUCTURES

Nowadays it is common that excavation works can encroach closer to structures which are sometimes sensitive from the shape, content or the patrimonial value, points of view. In these cases, there are several mitigating measures, which can be used to prevent damage from vibration levels in these structures. In this framework there are usually, several techniques that can be applied to different groups:

– systematic techniques should be considered in every excavation cycle because they can be used without interfering with the normal face advance, namely in terms of cycle times
– sporadic techniques, considered only in some blasts, when the conditions are more critical, for example from the reduced distance point of view, even if these will cause some delays in the average face advance timing due to the extra procedures involved.

In the first group (systematic techniques), there are usually two methods to be considered:

– the use of EBS, to have absolute control on the delays and therefore control the amplitude (avoiding superimpositions of wave peaks, resulting from different drill holes to be blasted) and frequency (avoiding the emission of waves with critical frequencies, depending on the delays to be used, that can be found unchanged in small distance range)
– the use of lower density explosives (reduced explosive charge per meter of blasthole) to control the explosive linear charge (kg/m) applied in the drill hole, reducing the charge per delay parameter, essential to determine the vibration velocity, at a set distance.

In the second group (sporadic techniques), there are usually another two methods to be considered:

– the use of multiple explosives decks (several charges and initiation points, with different timings, in each blasthole) to reduce further the charge per delay, for example in long drill holes
– the use of presplitting, to introduce a physical barrier to the wave propagation in the rock mass, through the creation of a void in the direction of a plane, previously defined by a series of closely drilled holes charged with smaller charges per length and to be blasted simultaneously.

The additional procedures mentioned, in the previous two examples are caused by:

– multiple explosive decks force the blasters to subdivide explosive charges per hole (usually in two different timings, although more can be used) and ensuring that they introduce the necessary amounts of non-reactive material (such as drill cuttings) in order to avoid sympathetic propagation between different charges (this coupled with the operation of extra priming is time consuming)
– the use of presplitting requires increased drilling, usually with spacing between drill holes no greater than 1 m, this is also time consuming with resultant increased cycle times.

All of these techniques are to be considered within:

– environmental protection, which is one of the primary mining requirements of the modern mining industry coupled with other priorities such as *safety first*, economic feasibility and good recovery of the reserves
– latest technologies, a sound rule of our industry in addition to a good balance of the mining fundamentals, global economy orientation and the optimisation of groups of sequential operations.

2 PROPAGATION LAWS (AN EVOLUTION APPROACH)

For many years the Langefors-Kihlström formula (Equation 1) has been used to predict vibrations, upon a result of the scaled distance:

$$v = k\sqrt{\frac{Q}{D^{3/2}}} \tag{1}$$

where: v is the vibration velocity (mm/s), Q is the maximum charge per delay (kg), D is the distance between the maximum charge and the monitored structure (m), $Q/D^{3/2}$ is the so called scaled distance and k an empirical parameter, to be adjusted to each situation.

The main disadvantage of this formula is to force both independent variables (Q and D) to the same power, which is found to be limiting, namely, today, where several explosive types can be used and justify those different powers, for both parameters (Q and D). As a result of this approach the so called Johnson formula (2) has been used, more recently, because it gives the user of the formula, looking for an equation that describes better the propagation in the rock mass, a degree of freedom.

$$v = a.Q^{b} \cdot D^{c} \tag{2}$$

However, this equation is still questionable, because it doesn't consider the different contributions of different explosive types used in the same blasthole, namely, the discrepancy between bottom charges (BC), used essentially to fracture the rock mass (in the first stage of the rock blasting mechanism – dynamic phase) and column charges (CC), used mainly to push the fragmented volumes in the first phase through gas expansion (second stage of the rock blasting mechanism – *quasi-static* phase). Thus, using Equation 2 is, from the vibration generation point of view, the same blasting more BC and less CC or the opposite, just quantifying those (BC and CC) by the sum (in kg of explosive), which doesn't make sense if the (usually) totally different detonation pressures (of both, BC and CC) are considered.

For that reason, in this paper a different approach is also proposed, through the use of Equation 3, a more complete one, that includes these new variables W and T:

$$v = a.W^b.D^c.T^d \qquad (3)$$

where: W is the maximum charge per delay, weighted with the detonation pressure of the explosives used (kg) and T is the delay timing used between explosive charges (ms). The parameters 'a', 'b', 'c' and 'd' are empirical constants, to be adjusted to each situation. It is considered that, this new equation (Equation 3) describes the measured trial results, for vibration prediction, in both quarries, better than Equation 2, which is underlined also by the improved correlation coefficients (R).

So, the parameter W replaces the maximum charge per delay (Q, kg), by the maximum charge per delay (as the sum of both BC (kg) and CC (kg) used in the hole with more explosive), weighted with the detonation pressure of the explosives used in the drill hole (W, kg – Equations 4 and 5). An equation like this (using W) is applied in the second case study presented in this paper, since in the first case study the BC is almost irrelevant, due to the soft character of the rock mass, blasted in that situation. Both approaches are compared and analysed.

$$W = \left(\frac{P_d BC}{P_d CC} \cdot \frac{BC}{Q} + \frac{P_d CC}{P_d CC} \cdot \frac{CC}{Q} \right) . Q \qquad (4)$$

Table 1. Programme of the tests with different techniques, used to control vibrations.

Trial (#)	Day	Mitigation measures used to reduce vibration levels: Systematic techniques – EBS (Electronic Blasting Systems)	Systematic techniques – Lower density explosives	Sporadic techniques – Multiple initiation	Sporadic techniques – Presplitting
1	1st	Yes	Yes	No	No
2	1st	Yes	Yes	No	No
3	2nd	Yes	Yes	Yes (2 dets./hole)	No
4	2nd	Yes	Yes	Yes (2 dets./hole)	No
5	3rd	Yes	Yes	Yes (3 dets./hole)	No
6	3rd	Yes	Yes	Yes (3 dets./hole)	No
7	4th	Yes	Yes	No	Yes
8	5th	Yes	Yes	Yes (2 dets./hole)	Yes
Remarks:		The timing has been changed, in each trial, to evaluate its importance in the vibrations propagated	Only in column charge (CC), with percentages from 85% to 98.5% of the total charge (Q)	As a way to reduce charges per delay, but not affecting the production requirements	Studied the influence of this technique with the multiple initiation

where: P_dBC is the detonation pressure of the bottom charge (Pa) and P_dCC is the detonation pressure of the column charge (Pa). The lower detonation pressure (always P_dCC) is considered the reference, which makes W always bigger than Q and therefore the Equation 4 can be rewritten and simplified (Equation 5):

$$W = \frac{P_d BC}{P_d CC} . BC + CC \qquad (5)$$

At the same time this new Equation (2) uses an extra variable (T, ms), since a negative relationship (negative power) was found, when the delay timing (used between explosive charges) is compared with the resultant vibration velocity (meaning less amplitude of vibrations when more time between charges is used). This situation will be analysed in both case studies.

3 FIELD TESTS

For the purposes of this investigation, a series of soft rock mass production blasts were monitored in two different quarries, using several seismographs per blast. The seismographs were placed at increasing distances to the blasts and, when possible, near structures in the surroundings. The parameters measured and controlled were: v, Q, D, W and T (in different arrangements, divided in two trials: A and B).

3.1 Field test A

The first series of trials were conducted in a quarry of a soft (marl, with some clay) limestone.

The criterion to define the timings to be used was found upon the natural frequencies of the limestone layers. For that purpose, the natural frequency of the layers (crossing the volume including the blasting site the seismographs

Table 2. Delays and maximum charge per delay used in each trial.

Trial (#)	Quarry level	Drill hole length (m)	T - delay (ms)	Detonators per hole	Q (kg/delay)	Remarks: On Q	Remarks: On T and multiple initiation
1	3	12	13	1	41.36	Similar to the baseline situation in that quarry	Low delay
2	2	16	25	1	61.82		Usual delay
3	2	16	25	2	31.14	Multiple initiation: 2 detonators per hole	
4	3	12	33	2	20.91		High delay
5	2	15	25	3	18.86	Multiple initiation: 3 detonators per hole	Usual delay
6	3	12	37	3	12.73		Highest delay
7	4	8	37	1	25.00	Presplitting	Without multiple initiation
8	4	8	37	2	12.73		With multiple initiation

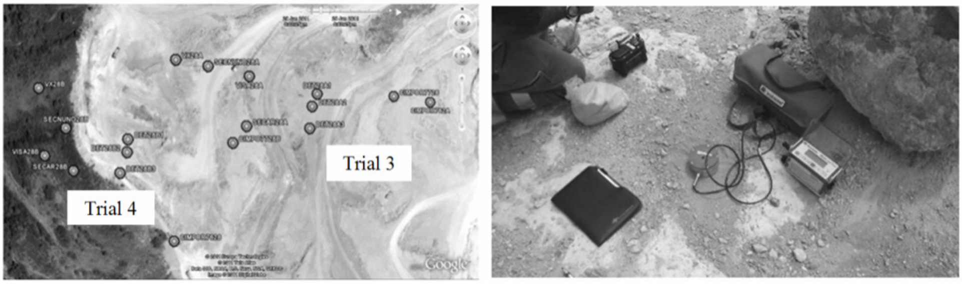


Figure 1. Location of some blasts (*Google Earth*©) and respective seismographs (INSTANTEL).

location), which had a thickness (H) not bigger than 2 m in a rock mass, previously known from the dynamic point of view, showing a propagation velocity of P (longitudinal - C_p) waves not lower than 1.400 m/s. These (layer) features and the following equation (Bernardo 2004):

$$f_n = \frac{C_p}{2.\pi.H} \tag{6}$$

allowed the determination of a natural frequency (f_n) of the layer around 111 Hz, that can be converted in a delay (trough: $T=1/f_n$) of about 0.009 s (9 ms), critical and therefore to be avoided in these tests (a delay always bigger than 6 ms was chosen, to avoid local amplifying phenomena, causing variation in vibrations).

Figure 1 shows an example of the distribution of the seismographs in 2 trials and a detail of a seismograph used (INSTANTEL).

The monitoring results of each blast are presented just by the respective PVS (*Peak Vector Sum,* mm/s), since this is the parameter limited by law (vibration standard) in Portugal (where this quarry was located). SEC 1 and 2, VISA and ORICA are references (regarding the owners) of each seismograph used in this study.

Two analyses were conducted. The first analysis is only considering the situations measured on the back, without any obstacle imposed to the wave propagation (first 6 trials), meaning no presplitting used. So, having 6 trials analysed by 4 seismographs lead us to 24 values (of: PVS,Q,D). Analysing this group of data (24 points), 3 *outliers* were found (3 in 24, meaning, 12.5% of total data), which can be considered valid due to the experimental procedure uncertain. This choice was careful and made according to the distribution of the vibration velocity values (v) *versus* distance (D), for the same range of (Q) charge per delay (Table 4).

Table 3. Results (vibration amplitudes – PVS, mm/s) obtained in each seismograph.

Trial (#)	SEC 1 (mm/s)	Distance (m)	SEC 2 (mm/s)	Distance (m)	VISA (mm/s)	Distance (m)	ORICA (mm/s)	Distance (m)	Remarks:
1	167	21	61.4	55.4	59.9	84.3	27.47	103.9	Without presplitting
2	47.3	43.3	21.6	97.3	38.5	69.8	7.03	157.4	
3	19.1	67.8	9.29	119.8	19.1	75.5	4.21	154.9	
4	30.5	51.8	16.3	67.2	48.1	87.4	12.69	112.8	
5	18.7	79.8	15.9	86.1	71.7	34.5	8.38	104.1	
6	47	35.2	26.5	86.3	53.9	59.2	18.52	103.6	
7	89.8	20.1	44	25.8	152	24.1	24.68	104.8	With presplitting
8	57.3	19.5	35.5	24.5	Not used in this day (5^{th})		Not used in this day (5^{th})		

Table 4. Relevant results of the trials (presented by increasing Q).

Trial (#)	T - delay (ms)	Q (kg / delay)	v (PVS – mm/s)	Distance (m)
6	37	12.73	47	35.2
6	37	12.73	26.5	86.3
6	37	12.73	53.9*	59.2
6	37	12.73	18.52	103.6
5	25	18.86	18.7	79.8
5	25	18.86	15.9	86.1
5	25	18.86	71.7	34.5
5	25	18.86	8.38	104.1
4	33	20.91	30.5	51.8
4	33	20.91	16.3	67.2
4	33	20.91	48.1*	87.4
4	33	20.91	12.69	112.8
3	25	31.14	19.1	67.8
3	25	31.14	9.29	119.8
3	25	31.14	19.1	75.5
3	25	31.14	4.21	154.9
1	13	41.36	167	21
1	13	41.36	61.4	55.4
1	13	41.36	59.9*	84.3
1	13	41.36	27.47	103.9
2	25	61.82	47.3	43.3
2	25	61.82	21.6	97.3
2	25	61.82	38.5	69.8
2	25	61.82	7.03	157.4

*Outliers - value out of the expected range of vibration velocity, due to some operational problem, for example: seismograph installation.

This way, working only with the remaining 21 values (of: PVS,Q,D), excluding those 3 outliers, a computer code (MLINREG, using a Multiple Linear Regression) was used to find the empirical constants 'a' (=10^b_0), 'b' (=b_1), 'c' (=b_2) and 'd' (=b_3), adjusted to this specific situation.

$$v = a.Q^{b}.D^{c}.T^{d} \Leftrightarrow \log(v)=\log(a)+b.\log(Q)+c.\log(D)+d.\log(T) \Leftrightarrow Y=b_0+b_1.X_1+b_2.X_2+b_3.X_3 \quad (7)$$

From the previous table it can be stated that increasing delay between blastholes will mean decreasing vibration velocities, for the same distances (D) and charges per delay. In fact, the trials evolved to that same conclusion, since the delays were increasing from 13 ms until 37 ms (Table 2), used in the last trials, to find a relationship between v, Q, D and T. This is the great advantage of using an EBS (Figure 3), since it allows to iterate more until an optimum value of delay is found (which most probably will not be available in the standard pyrotechnic delays offered in the market). This optimum delay will:

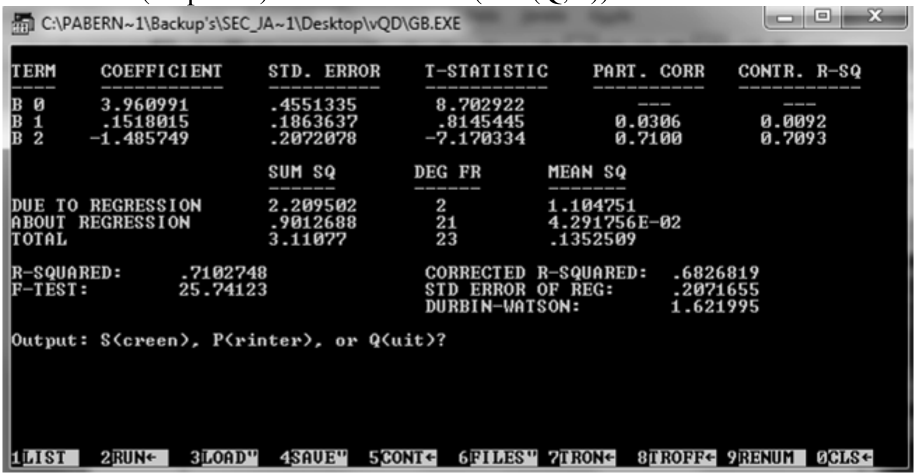
– control the vibration, with more parameters, as observed in this case study (situation D in Figure 2B)
– avoid superimpose the natural frequency of layers involved in the blast or nearby prone structures, which can cause local dynamic amplifications, well-known from seismic studies
– prevent the decoupling of packaged explosive charges, causing possible misfires
– not compromise the fragmentation of the volume to be blasted.

Perhaps this value (37 ms) should be optimised further, but in this trial it was necessary to stabilise it, in order to proceed to the next stage (trials 7 and 8, with presplitting), without introducing more variables. Anyway, the (opposite) relationship between the delay (timing between explosive charges per delay and vibration velocity) was proved to be found.

The second analysis of this field test (A) was regarding the influence of the presplitting technique on vibration reduction. As expected a significant reduction takes place, when the blast production holes are intermediated with a line of drill holes (blast in the first place and simultaneously) in the direction of the monitoring points (seismograph locations), as Figure 4 is showing.

The reduction that was found is in the range of 38%, when compared with the continuous propagation (first 6 trials). The importance of this technique is clarified in Figure 5, where the curves regarding the first 6 trials (for 3 different structure sensitiveness) are compared with 4 points obtained with this technique. In fact, for the same distance range a much bigger charge per delay can be used, obtaining less vibration velocities.

A. All data (24 points) with 3 variables (v=f (Q,D))



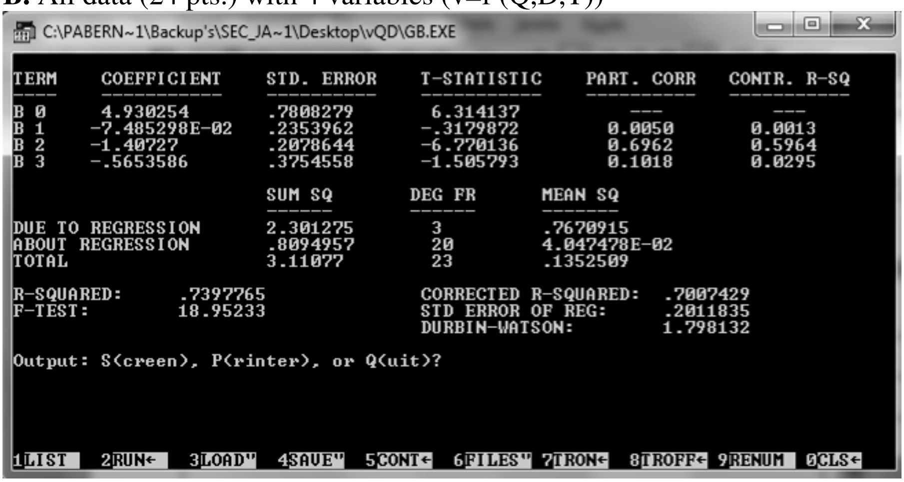
```
C:\PABERN~1\Backup's\SEC_JA~1\Desktop\vQD\GB.EXE

TERM     COEFFICIENT     STD. ERROR     T-STATISTIC     PART. CORR     CONTR. R-SQ
----     -----------     ----------     -----------     ----------     -----------
B 0      3.960991        .4551335        8.702922          ---            ---
B 1      .1518015        .1863637        .8145445         0.0306         0.0092
B 2     -1.485749        .2072078       -7.170334         0.7100         0.7093

                         SUM SQ         DEG FR       MEAN SQ
                         ------         ------       -------
DUE TO REGRESSION        2.209502        2           1.104751
ABOUT REGRESSION         .9012688        21          4.291756E-02
TOTAL                    3.11077         23          .1352509

R-SQUARED:      .7102748            CORRECTED R-SQUARED:   .6826819
F-TEST:         25.74123            STD ERROR OF REG:      .2071655
                                    DURBIN-WATSON:         1.621995

Output: S(creen), P(rinter), or Q(uit)?

1LIST  2RUN←  3LOAD"  4SAVE"  5CONT←  6FILES"  7TRON←  8TROFF←  9RENUM  0CLS←
```

b_0=3.960991 | b_1=0.1518015 | b_2=–1.485749 | b_3= n.a.
(regression coefficient 68.3%: low)

C. Without outliers (21 points) with 3 var. (v=f (Q,D))
b_0=3.898573 | b_1=0.2067259 | b_2=–1.522239 | b_3= n.a.
(regression coefficient 82.3%: much better)
$\therefore\ v = 7762.Q^{0,21}.D^{-1,52}$

Figure 2A. Results of code MLINREG applied to the data (first 6 trials).

B. All data (24 pts.) with 4 variables (v=f (Q,D,T))



```
C:\PABERN~1\Backup's\SEC_JA~1\Desktop\vQD\GB.EXE

TERM     COEFFICIENT     STD. ERROR     T-STATISTIC     PART. CORR     CONTR. R-SQ
----     -----------     ----------     -----------     ----------     -----------
B 0      4.930254        .7808279        6.314137          ---            ---
B 1     -7.485298E-02    .2353962       -.3179872         0.0050         0.0013
B 2     -1.40727         .2078644       -6.770136         0.6962         0.5964
B 3     -.5653586        .3754558       -1.505793         0.1018         0.0295

                         SUM SQ         DEG FR       MEAN SQ
                         ------         ------       -------
DUE TO REGRESSION        2.301275        3           .7670915
ABOUT REGRESSION         .8094957        20          4.047478E-02
TOTAL                    3.11077         23          .1352509

R-SQUARED:      .7397765            CORRECTED R-SQUARED:   .7007429
F-TEST:         18.95233            STD ERROR OF REG:      .2011835
                                    DURBIN-WATSON:         1.798132

Output: S(creen), P(rinter), or Q(uit)?

1LIST  2RUN←  3LOAD"  4SAVE"  5CONT←  6FILES"  7TRON←  8TROFF←  9RENUM  0CLS←
```

b_0=4.930254 | b_1=–0.0748298 | b_2=–1.40727 | b_3=–0.5653586
(regression coefficient 70.1%, but b_1<0: impossible)

D. Without outliers (21 pts.) with 4 var. (v=f (Q,D,T))
b_0=4.628269 | b_1=0.05177043 | b_2=–1.455094 | b_3=–0.451067
(regression coefficient 83.3%: even slightly better)
$\therefore\ v = 42658.Q^{0,05}.D^{-1,46}.T^{-0,45}$

Figure 2B. Results of code MLINREG applied to the data (first 6 trials).

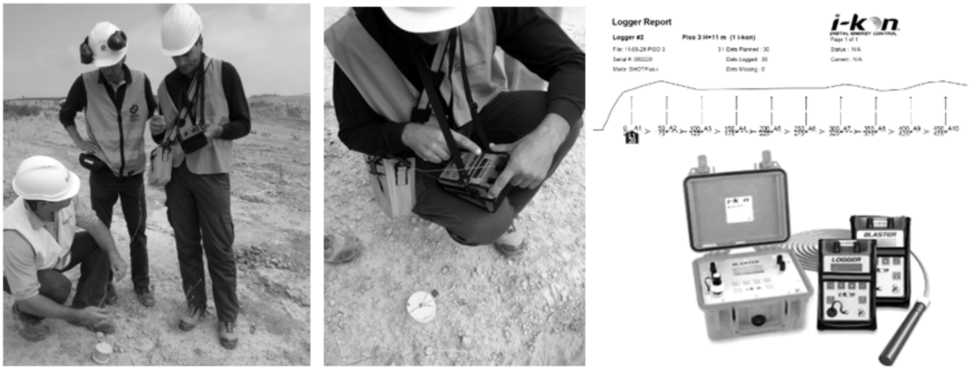


Figure 3. Some aspects of the setting of the EBS and respective equipment used.

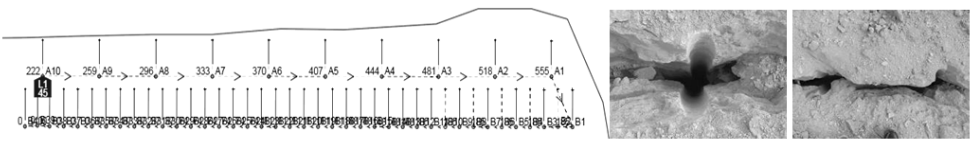


Figure 4. Some aspects of the blasting pattern, using presplitting technique and the field result.

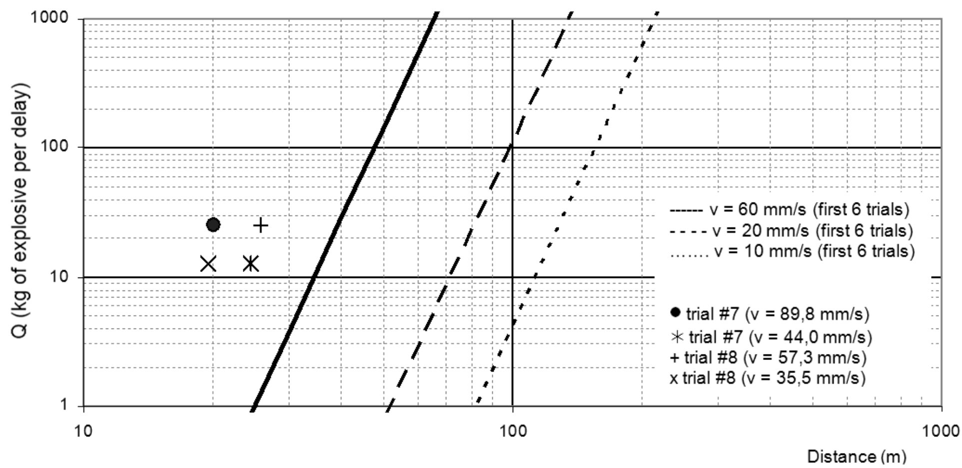


Figure 5. Comparison between the first 6 trials and the last 2 (with presplit – trials 7 and 8).

3.2 Field test B

Some other tests were made, on another limestone quarry, but more resistant, with the usage of higher content BC (bottom charge, around 35%) then in the previous test field (See remark on Table 1). In this situation both equations (2 and 3) were used and compared. To use Equation 3 the BC and CC parameters indicated in Table 5 were considered.

In field test (B) 130 blasts were considered (Table 6) in 3 different series (with the references indicated):

- –NED - the first used Non Electric Detonators and smaller blast volumes, without multiple initiation
- –EBS1 - the second used EBS and similar blast volumes, also without multiple initiation
- –EBS2 - the third also used EBS, but with bigger blast volumes and with multiple initiation.

Table 5. Thermodynamic parameters of the explosives used as BC and CC in field test B.

Explosive		Density (kg/m^3)	VOD (m/s)	Detonation pressure (GPa)
BC	SENATEL Ultrex™	1.200	6.220	11.61
CC	SENATEL Powerpac™	980	5.490	7.38

Table 6. Characteristics of the 3 series in field test B.

Series of trials in field test B	Number of blasts		Average values without *outliers*				
	Total	Without *outliers*	PVS (mm/s)	Q (kg/delay)	Distance (m)	Average blast size (number of drill holes per blast)	Total charge (kg of explosive used per blast)
NED	63	56 (88.9%)	1.78	83.3	510.9	8.9	557.2
EBS1	49	43 (87.8%)	0.72	43.4	548.6	11.4	506.4
EBS2	18	16 (89.9%)	1.94	30.4	224.7	20.8	909.4

Table 7. – Empirical constants adjusted (with respective regression coefficients) to each series of field test B.

Multiple Linear Regressions	Series	a	b	c	d	R (regression coefficient)
Equation 2 ($v = a.Q^b.D^c$)	NED	397.54	0.23	-1.07	-	0.79
	EBS1	430.38	0.23	-1.19	-	0.81
	EBS2	197.72	0.18	-0.97	-	0.78
Equation 7 ($v = a.Q^b.W^c$)	NED	418.51	0.21	-1.07	-	0.79
	EBS1	381.57	0.26	-1.19	-	0.81
	EBS2	153.94	0.24	-0.97	-	0.78
Equation 3 ($v = a.Q^b.W^c.T^d$)	NED	-	-	-	-	-
	EBS1	916.95	0.27	-1.22	-0.21	0.81
	EBS2	187.91	0.46	-0.95	-0.40	0.81

Table 7 shows the differences found in the processing (Multiple Linear Regressions) when equations 2 and 3 are applied and in the case of equation 3, with and without the delay (variable T). When using non electric initiation (NED series), variable T is not used since no precise control on timing is possible.

Two different analyses can be made upon the previous table. The first is related with the comparison between both systems of initiation (non electric – NED and EBS). Both lines regarding EBS appear above non electric (pyrotechnic delay) system, which means that, for the same distance, more charge per delay can be used, considering the same vibration velocity (in the case of Figure 6, all lines are for 10 mm/s of v). EBS2 is above EBS1 (although closer), because smaller values of charge per delay (Q) were used in this series (Table 6).

The second analysis (Figure 7) is based on the isovalues of velocity, out of Table 7, in this case for a vibration velocity of 5 mm/s and for a series of trials (EBS2) that was found more interesting to this quarry (large size blasts, even if multiple initiation is needed). Three different types of curves can be found, in terms of the respective gradients, which justify the approach. In the range of the charges per delay used (smaller than 90 kg/delay), EBS2 (without weighing the maximum charge per delay with the detonation pressure and not considering delays) is the most limiting scenario (meaning that: for the same distance - D

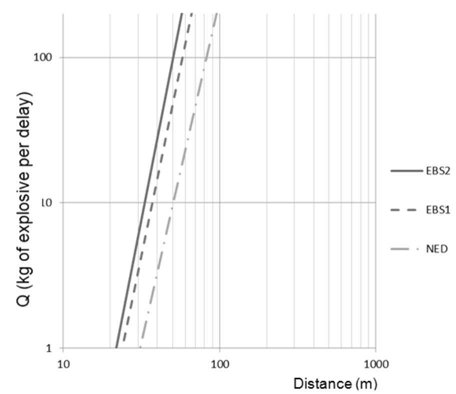


Figure 6. Isovalues of velocity (v = 10 mm/s) with different initiation systems.

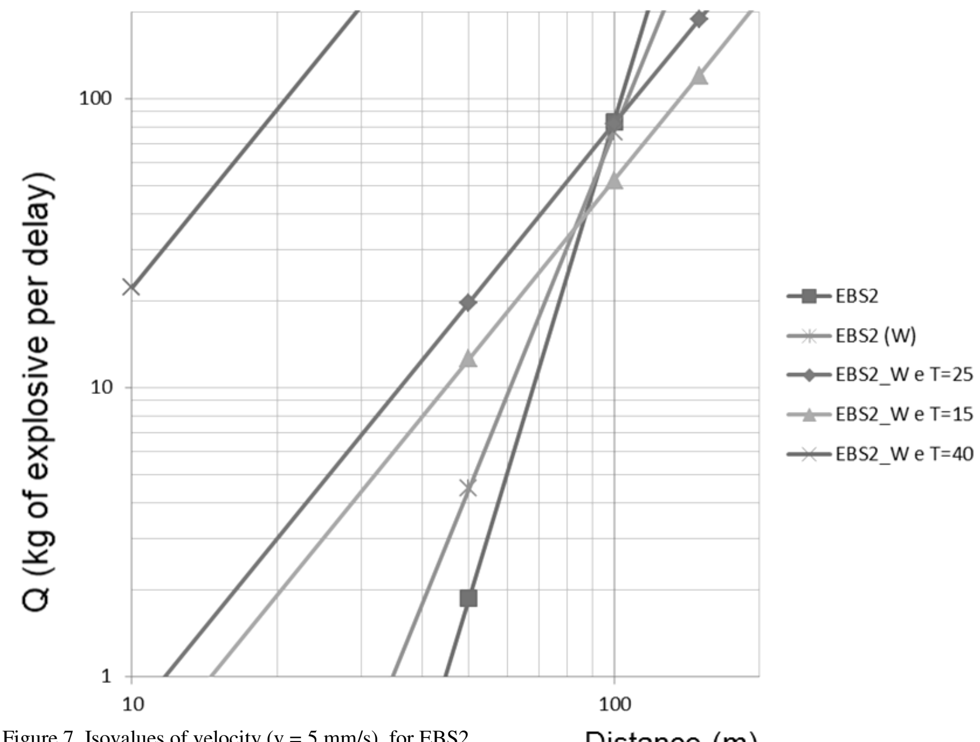


Figure 7. Isovalues of velocity (v = 5 mm/s), for EBS2, with different processing approaches.

smaller charges per delay - Q, can be used). When replacing the Q variable, by the W variable, an increase in the charges per delay, can be found, for the same distance. Adding delays (variable T) big improvements can be observed, namely when the delays increase (from 15 ms to 40 ms), meaning much bigger the charges per delay, can be found, for the same distance.

4 CONCLUSIONS

It was proved, from the field case studies presented in this paper, that different techniques to reduce vibrations and an improved approach to processing the data from the monitoring (in order to explain better the vibration propagation in rock masses), can be applied to reduce vibration velocities in the vicinity of blasts.

As a direct result of this analysis more trials were found necessary in the first case study, due to the limited number of blasts that were possible (in a first stage) and that bigger blast sizes, even with multiple initiation were preferred in the second case study, since a direct relationship between each blast and complaints from neighbours can be found, which makes the scenario of 1 blast per month much better than 2 blasts per month, when the vibration targets defined by the quarry management is fulfilled.

5 ACKNOWLEDGMENTS

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Rock fragmentation by blasting risk management - 20 ways to create value

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ABSTRACT: The aim of any rock breaking activity using explosives is to achieve overall project success, this involves managing hazard, technical and business risks. This applies to one-off projects and for on-going operations. The first national standard for risk management in Australia was AS/NZS 4360:1995 and due to this early leadership position it has been influential in shaping much of the ISO 31000 international standard that was released in 2009.

The current paper identifies and explains 20 ways to create value using effective risk management strategies and processes. They are compatible with ISO 31000 and are discussed in a blasting context. These are: risk strategy; risk framework; level of detail and audience; risk terminology; multi-level application; risk continuum; appropriate risk tools; managing interfaces; systems integration; role and responsibility; risk facilitation; risk communication and stakeholder consultation; accountability for risks; acceptability of risk; risk culture; residual risk management; priorities for action; insurance; monitoring, audit, review and reporting; and organisational learning and continuous improvement.

In addition three cases studies are presented: the first study flyrock risk using a quantitative Fault Tree Analysis method, the second will involve elaborating and graphical representation of a business risk model applied to blasting, with the final case focusing on the use of a risk scenario generator for explosives security.

The conclusion of this paper is that organisations that are effective in the way they use risk thinking have greater control over their own growth and sustainability and this is essential when conducting operations that use highly energetic explosives materials.

1 INTRODUCTION

Companies do not start out to take risks. They embark on a course of action based on their business objectives and strategies which involve both risk and reward. This paper applies equally to drill and blast contractors, blasting consultants and mining companies that use or advise on drill and blast operations.

There are three features of drill and blast operations that make them unique. Interestingly, they align well to the three faces of the risk continuum introduced in Section 2.2. The first feature is that the consequences of incidents may be catastrophic with the direct cause of any damage being beyond any doubt. Because of this feature both explosives manufacture, storage and transport, and blasting operations are highly regulated and human error is of particular concern. Secondly, feedback on design and implementation performance, good or bad, is rapid - days or weeks. In contrast, feedback on geotechnical design and implementation can take years or decades. This, coupled with the fact that we are dealing with natural geological materials, means there is still a place for trial and error methods (assisted by measurement and instrumentation) to validate designs and provide information for continuous improvement initiatives. The final unique feature of drill and blast operations is that they occur early in the value chain and the blast results impact many subsequent processes and their costs. One of the implications of this final feature is that blast designs can be influenced strongly by internal and external customer requirements - good communication is essential. Figure 1.1 illustrates the four main categories of blasting objectives, namely: fragmentation control blasting; muckpile control blasting; damage control blasting; and grade control blasting. Also shown are some generic target measures and other factors that need to be balanced (kept within acceptable limits). Note that for each blasting objective the internal customers may be different.

The importance of risk management is growing particularly in hazardous industries with occasional catastrophic events. At least five categories of factors are at play. Firstly, legislation is getting more extensive and tougher. Company officers can be jailed for corporate offences, and fines can be high. Some legislation in Australia requires companies to develop principal hazard management plans for potential multi-fatality events (even cumulative). Secondly, insurance is more expensive and more difficult to attain (see further trend information in Section 2.18). Thirdly, customer risk attitudes are changing. Corporate customers want to pass legal responsibilities to their suppliers; consumers are more litigious and less likely to accept product failure; and shareholders are more aware of risk. A fourth factor is that the public are becoming more critical and expects higher standards of corporate behaviour than before, this encourages companies to avoid risking public's hostility. Finally, managements risk attitudes are changing. These changes have come about because: management has learnt from disasters; companies are becoming more professional; companies are becoming more global; and growing private-sector involvement in projects as governments withdraw.

There are a number of possible pitfalls when implementing a risk management framework within an organisation. The principle ones are:

– the framework gets unwieldy and bureaucratic
– the framework is implemented it for the wrong

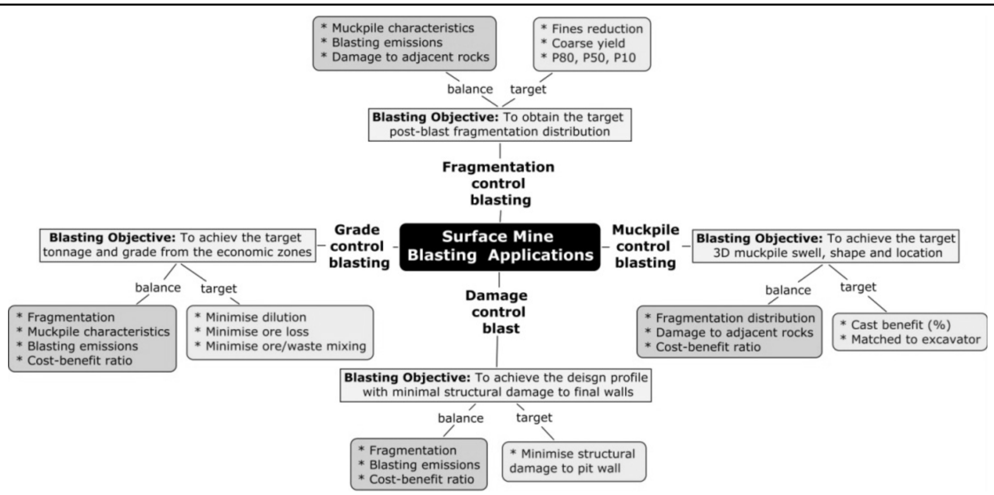


Figure 1. Surface mine blasting applications with the four main categories of blasting objectives.

reasons - externally imposed
– the framework does not gain credibility
– the framework becomes routine and ossified - that it will fail to anticipate new dangers.

To avoid the first two pitfalls implementing a risk management framework should be done with a light touch, and in a way that educates the staff. With regard to the third pitfall the framework should conform to a recognised standard and subject to audit and continual improvement. This yardstick tells stakeholders that the framework is set at a meaningful level. The final pitfall can be avoided by implementing a framework that allows and even encourages ‘blue sky’ thinking. This can be facilitated by using a model as depicted in Figure 2. As can be seen, some risks are largely manageable and predictable while others are largely unmanageable and unpredictable. The challenge is to ensure the framework is not too mechanistic and being overly focused on the company’s internal processes.

2 EXTRACTING AND CREATING VALUE

Provided the pitfalls of the risk management framework can be avoided, value can be created in the following twenty ways.

2.1 Creating value #1: Risk strategy

Significant value is created only if an organisation has a clear understanding of how it is going to use risk thinking. Stated differently, a risk strategy is what the organisation wants to get out of its risk management effort. One possible overall risk strategy may be to use risk thinking in order that the organisation has greater control of its own growth and development, and the achievement of its strategic business objectives. Other individual sub-strategies may include using risk thinking to:

– aid decision making at all level in the organisation
– ensure compliance and hazard protection
– provide integrate hazard management for incidents, emergencies, and business resilience
– better understand and manage operational performance
– seek opportunities for ethical growth and superior profits
– learn from success and failure

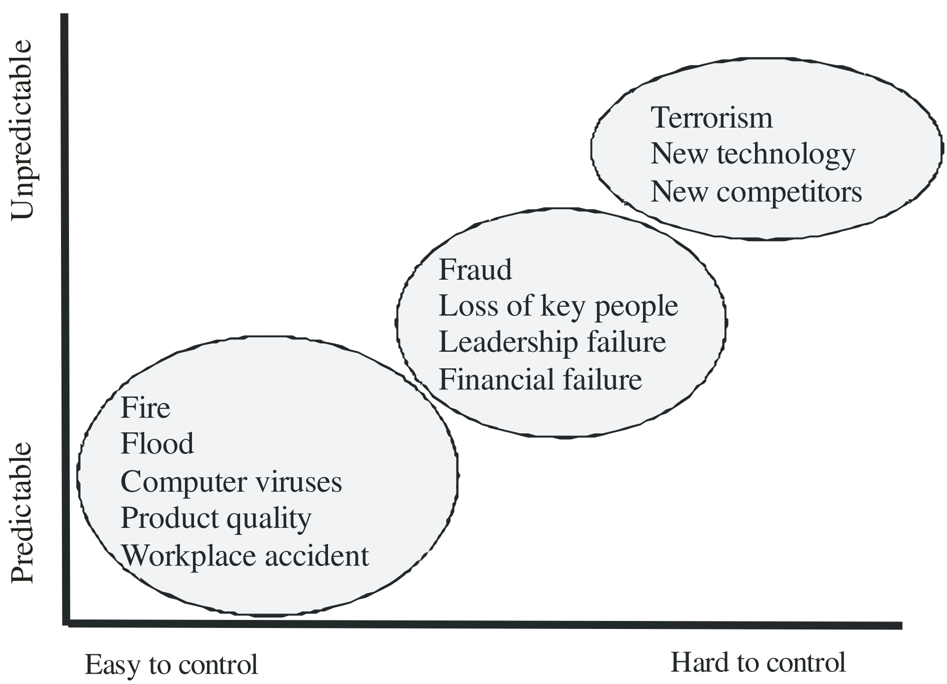


Figure 2. Predictability and controllability of risk (based on Sadgrove 2005).

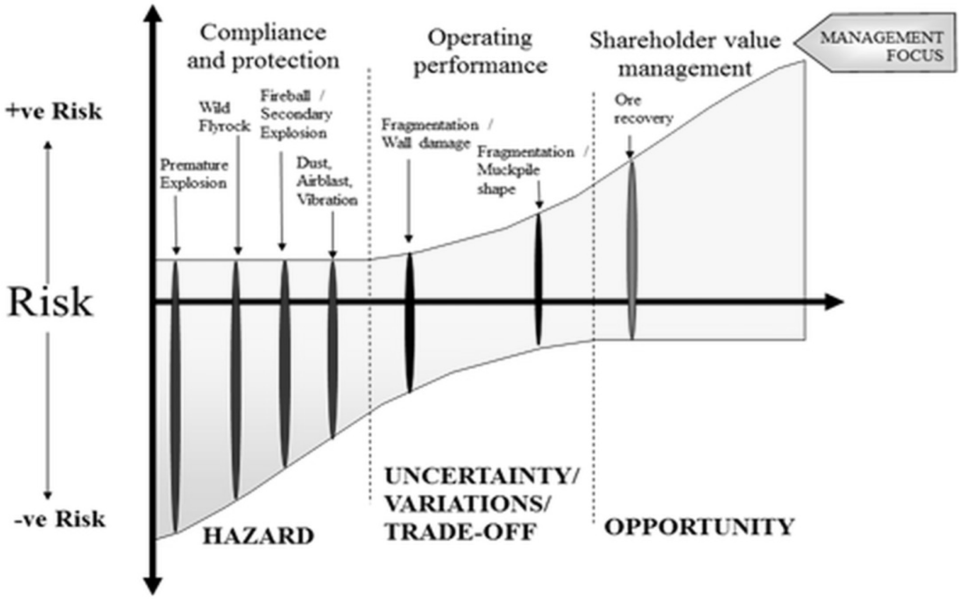


Figure 3. Application of the business risk continuum (3 faces of risk) to blasting.

Table 1. Characteristics of each of the three faces of risk with an example for wall control blasting.

Risk face 1: Hazard / Threat (-ve consequence risk)	Risk face 2: Variation / Trade-off (±risk)	Risk face 3: Opportunity (+ve consequence risk)
Focus: Traditional focus. **Nature:** Defensive in nature. **Purpose:** To allocate resources to reduce the probability or impact of adverse events. **Action:** Life and property protected, e.g. reduce wall damage. **Inaction:** Survival in question eg possible wall failures.	**Focus:** Control on the distribution of outcomes. **Nature:** Hedging in nature. **Purpose:** To reduce the variance between anticipated and actual outcomes. **Action:** Performance optimised, e.g. geological and operational variability managed. **Inaction:** Performance not optimised, e.g. variable to unacceptable wall damage.	**Focus:** Investment focused. **Nature:** Offensive in nature. **Purpose:** To take action to achieve positive gains. **Action:** Value enhanced, e.g. increase slope angles, more ore and less waste. **Inaction:** Lost opportunity, e.g. conservative slope angles.

– improve internal and external communications
– formulate and execute a sustainable succession plan or exit strategy.

In the current context the ability to manage risk is one of the core competencies of any organisation and its employees. Risk management is no longer being seen as an overly bureaucratic compliance process, but rather as an enabler to achieve organisational objectives. A critical component of this approach is to develop a common language for the evaluation of risk which is closely aligned with corporate key performance objectives, and an agreed risk tolerance and risk appetite for the organisation.

2.2 Creating value #2: Risk continuum

The risk management process - as outlined in AS/NZS ISO 31000 - is fairly well understood by most industry professionals. Less well understood is the concept of the business risk continuum (Price Waterhouse Coopers 1999). When management mobilise the linkage between hazard/threat management (Face 1: -ve risk), reduced volatility or uncertainty of outcomes (Face 2: ± risk) and the achievement or bettering of corporate targets (Face 3: +ve risk), the organisation's all round performance can be significantly enhanced. Figure 3 illustrates the three faces of risk in a blasting context along the business risk continuum. Also shown are the relevant management focuses. Table 1 provides the characteristics of each of the three faces of risk in terms of focus, nature, purpose, action and inaction. Value is created by using the "business risk continuum model" way of thinking.

2.3 Creating value #3: Framework, principles and process

To increase an organisations chances of achieving your business objectives it would be wise to use the risk framework, principles and process as available in ISO 31000 (see Figure 4). The purpose of the risk management framework is to provide the foundations and a common infrastructure for delivering, maintaining and governing risk management throughout the organisation. The framework:

– clearly defines the high level scope and parameters of risk management activity within the organisation, and who does what, in order to support the delivery of key strategic and operational objectives
– enables a common understanding of risk management and defines the key concepts and terminology
– ensures risk management activity takes place in a consistent, disciplined, controlled and evidence-based manner
– enables the efficient allocation of capital and resources within the organisation for risk management.

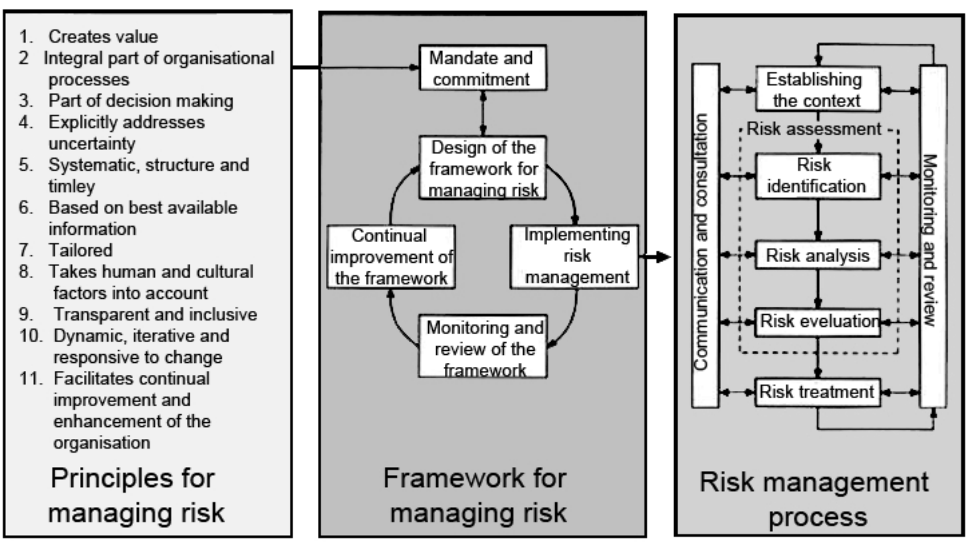


Figure 4. Framework, principles and process for managing risk (based on ISO 31000).

Table 2. Elements of a risk framework (modified from Sadgrove 2005).

Task	Rationale
Understand your risks	Leads to better decision making and provide priority for action.
Set a risk policy	Based on a business objectives and risk strategy.
Establish risk governance	Be proactive and define governance and other legal requirements.
Articulate risk appetite	Communicate risk tolerance (-ve) and risk appetite (+ve).
Decide how to deal with risk	Approved risk treatment design process and management plans.
Risk tools and training	Appropriate tools for all applications and training for users.
Communicate effectively	Make sure people are engaged and informed.
Foster a risk aware culture	Cultural development starts with the risk framework.
Assign roles & responsibilities	Clear understanding of who is responsible for managing risk.
Conduct internal audits	Ensure management of risk & framework is working as intended.
Monitor and review	Tracking and reviewing risk KPIs and control KPIs.
Develop a contingency plan	Critical business continuity risks need contingency plans.
Engage external assessors	Improve credibility if evaluated by independent external expert.
Keep records	Record and report risk register and framework developments.
Continuous improvement	Act on lessons learnt and make improvements as required.

While organisation have one risk framework and one set of guiding principles they normally has many and ongoing applications of the risk management process. Table 2 shows the key elements of a typical risk framework and the rationale for their inclusion.

2.4 Creating value #4: Risk terminology

The words we use are important. People in drill and blast organisations should make a serious attempt to understand risk terminology - just understanding the difference between inherent and residual risk, and between generic and specific risk, opens many doors. From a company perspective it is important that all employees are speaking the same risk language. The three steps to creating value are: develop an enterprise wide risk glossary as part of your Risk Framework based on the ISO definitions as much as possible; undertake awareness activities for employees and stakeholders; and insist on complete internal usage of the language.

2.5 Creating value #5: Level of detail tailored to the organisation

Value is added when your risk management processes are aligned to the organisation's size; external and internal context; and risk profile. Creating a tailored formal process, which everyone can use, is an essential undertaking. Without a formal process an organisation is subject to the usual problems of inconsistency, poor decision making, errors, shocks and surprises, and an ad hoc approach to the management of risk. Equally dangerous is when the process takes over. Here, people spend enormous amounts of time and effort following the process rather than managing the risks. For the same reason it is also important not to take your risk profiles down to excessive detail (paralysis by analysis). That would only burden the people involved, for little return.

Formalising the risk management process, therefore, must follow some simple guiding principles. These include ensuring the process is not too onerous; any scoring mechanisms being simple and not too precise, risk is manageable by those charged with their management, and ownership and accountability are present. In general, the larger and more complex the organisation the more it will benefit from risk management. However, small organisations need and will benefit from a tailored risk management framework and risk aware culture.

2.6 Creating value #6: Mutli-level risk management approach

Risk management should be used at a number of different levels within the organisation. Table 3 illustrates five risk management initiatives at four

Table 3. Levels of risk management for a single site.

Application level	Coverage	Blasting context
Level 1 Personal risk management (PRM)	Employees duty of care Fit for work Hazard reporting Unsafe behaviour	Explosives awareness Situational awareness
Level 2 Task related risk management (TRM)	Both employees and employers duty of care All task related risks Special conditions	Drilling operations Charging and tie-in Firing operations Misfire management
Level 3A Department wide risk management (DWRM)	Employers duty of care Routine activities for an organisational department Develop procedures Stakeholder consultation	Drilling and blasting procedures Blasting incidents (premature explosion, wild flyrock, magazine explosion) and emissions Blast design management practice
Level 3B Project risk management (PRM)	Employers duty of care Non-routine activities New equipment or materials	Blasting trials Mine to mill improvement projects
Level 4 Site wide risk management (SWRM)	Employers duty of care Principal hazards Principal control plans Supplier agreements	Management plans - principal hazard, explosives, security. Contract management Legal and other obligations

different levels for a single operating site. There is no single tool which is able to be used effectively at all levels.

Value can be created using multiple levels of risk management in an organisation in the following ways:

– enables full participation with risk management at the appropriate level
– aligned to the organisational structure and the various roles and responsibilities
– provides an escalation mechanism if risks are best managed at a higher level
– aligned with duty of care legal obligations - Level 1 and 2 related to employee duties and Levels 2 to 4 related to employers duties, when overlapping duties are present all duty holders must be satisfied with the proposed activities
– improved communication and awareness at all levels.

It should be noted that in large organisations it is not uncommon to have a Level 5 Business wide risk management (BWRM) and even a Level 6 Enterprise wide risk management (EWRM) initiatives in addition and above the site based initiatives. Having this multi-level approach allows for a leverage of learning and seamless transition from HSE into business risks.

2.7 Creating value #7: Appropriate risk tools

Value can be created by selecting the appropriate tool for the risk application under consideration. Over 30 recognised tools have been capture in international and other standards (IEC 31010 and HB 89). These tools relate to one or more of the following risk processes: risk identification, control analysis, risk analysis and risk evaluation. Risks can be assessed to different degrees of depth and detail using one or more techniques ranging from simple to complex. The choice of technique is highly dependent on context, the form of assessment and its output format required. When integrating or aggregating risk results from different studies, the techniques used and outputs should be compatible. In general, a suitable technique should:

- be justifiable and appropriate to the subject under consideration and depth required
- provide an output in a form which is compatible with the risk criteria
- provide results in a form which enhances understanding of the risks and how it can be treated
- meet the needs of relevant stakeholders including the employees using the tool
- be capable of use in a manner that is traceable, repeatable and verifiable.

Quantitative risk assessment should be used whenever possible. Having real numbers is important an organisation doesn’t want to be making changes based on intuition or qualitative assessments alone when real data is available. Mature risk management organisations use quantitative assessments whenever it is feasible, since they give the best insight into what is likely to happen. In the author’s experience, even quantitative risk assessments contain some degree of subjective inputs.

Guidance on tool selection can be obtained from Standards Australia HB 89-2012 (which is based on International standard IEC 31010:2009 Risk management - Risk assessment techniques and AS/NZS 3931 (withdrawn) Risk analysis of technological systems - application guide). Another useful reference (Joy and Griffiths 2007) tabulates the relationship between 12 risk deliverable and 13 common risk assessment techniques. The main 11 tools are:

– informal RA - general identification of hazards by workplace and task by applying a way of thinking, often with no documentation
– job hazard analysis (JHA) - general identification of hazards and controls in a specific task
– energy barrier analysis (EBA) - detailed analysis of phases of an event and control mechanisms
– consequence analysis - general to detailed understanding of the magnitude of unwanted events
– workplace risk assessment and control (WRAC) - general identification of priority risks, often to determine the need for further detailed study
– hazard and operability study (HAZOP) - systematic identification of hazards in a processing design
– fault tree analysis (FTA) - detailed analysis of contributors to major unwanted events
– event tree analysis (ETA) - detailed analysis of the development of major unwanted events
– failure modes effects & criticality analysis (FMECA) - analysis of component reliability risks
– human error analysis (HEA) - analysis of human factors or reliability issues

– level of protection analysis (LOPA) - a form of event tree that is optimised for determining the frequency of an unwanted event that can be protected by one or more independent protection layers.

Two other risk tools commonly used by the author are the Bow Tie Analysis which is a simple concept of describing and analysing the pathway of a risk from causes to consequence. The second tool is one developed by the author which uses a 5 by 5 matrix for rating risk, a 4 by 4 matrix for rating controls and 3 by 3 matrix for rating level of confidence (or uncertainty) this method is further discussed in Section 2.17 in terms of priority for active risk management intervention.

2.8 Creating value #8: Managing interfaces

Interface risk management is easily overlooked, however it is potentially one of the most valuable activities. Interfaces exist between departments (silos) within an organisation. For blasting all downstream functions (drilling, design, implementation) and upstream functions (digging, crushing, milling) should be involved in interface risk management. This is the basis of the 'mine to mill' and other blast driven optimisations (Grant *et al.* 1995) initiatives. External interfaces also exit between the organisation and its contractors (and sub-contractors), suppliers, customers and community stakeholders. For blasting operations, this may include: drilling contractors, explosive suppliers, customers and communities affected by blasting operations. An interface risk management plan should be established that covers the interface between the parties under contract / agreement and all risk assessment needed to identify reasonably foreseeable interface risks, and agreement on appropriate controls. This should extend to how overlapping duties of care will be coordinated.

2.9 Creating value #9: System integration and decision making

One of the key things to recognise about risk management is that it is inexorably linked to decision making. Value can be created by integrating drill and blast hazard risk management activities and decision making into other site wide systems such as health, safety and environment (HSE) management systems. This is also the case for the six main environmental emissions associated with blasting: airblast, ground vibration, dust, fumes, water pollution and flyrock. Integration of the organisations HSE hazard risk management, emergency management, and business continuity management and incident investigation are also worthwhile initiatives. All integration initiatives must be outlined as part of the risk framework. With regard to business risks a site wide risk management approach which feeds into a business wide and then an enterprise wide risk management has many benefits. Enterprise-wide risk management elevates risk management to the strategic level by broadening its application to all kinds of value creation and protection. It should be noted that for a small organisation one integrated and well designed risk register and a simple risk framework may be sufficient to support decision making. Using an integrated approach enables effective decision making based on accurate, timely and useful information. In addition, the intelligent use of risk tools and techniques by those making decisions can avoid many of the cognitive biases (e.g. groupthink, availability errors etc.) and ego related issues.

2.10 Creating value #10: Roles, responsibilities and governance

Value can be added by having clearly defined roles, responsibilities and governance. The roles and responsibilities of people involved with explosives is highly regulated and a duty of care is imposed on a number of parties in 'common law' countries. From the moment explosives arrive at a particular site there exists a risk, requiring effective controls. In Australia, explosive usage and safety is regulated by both the Mine Safety legislation and the Dangerous Goods Safety legislation. The responsibility for safety and security usually sits with the registered mine manager but is vicariously shared by: the quarry/underground manager, drill and blast supervision, the appointed shotfirer and with regard to obeying the blast plan the blast crew.

Risk governance is the structure, processes and 'tone' through which risk management is led, and accountabilities and authorities are clearly defined and assigned, so that decisions are effectively made by the correct bodies/persons, or appropriately referred. The purpose of risk governance is to ensure that structures and mechanisms are in place to enable the Board (or equivalent) to receive regular and timely feedback on the key risks and controls. Also, to provide an independent review and challenge of all aspects of risk management in the organisation and ensure the integrity and suitability of the risk management

Table 4. Risk workshop process facilitation.

Items	Facilitator	Facilitative Leader
Relation	Third party	Group leader or member
Process	Process expert	Skilled in process
Content	Content neutral	Involved in content
Decision	Not involved in content decision making	Involved in content decision making

framework. Governance is delivered through 'pulling together' a number of the risk management framework's components, for example risk strategy, risk appetite, policy, roles and responsibilities, reporting and culture.

2.11 Creating value #11: Risk facilitation

Value can be created using team based risk workshop processes that are facilitated. Often risk assessment is best done in a team environment. To get the most out of the team based process it is desirable that an experienced facilitator is utilised. Table 4 illustrates the two possible approaches to risk process group facilitation. In should be noted that risk facilitation has some unique features relative to other group facilitation activities, however this is beyond the scope of the current paper.

The facilitator role: In this role a third-party is utilised because it is difficult to act neutrally in your own group. Being substantively neutral means that facilitating the discussion without sharing opinions and so that group members cannot tell what the facilitator thinks about the group's issues. Consequently, you do not influence the group's decisions. A facilitator as a process expert, advocate the processes, structures, and behaviours necessary for effective group work, such as appropriate membership, useful task completion methods, sufficient time, and ground rules. Furthermore facilitators inquire whether the group you are working with sees any problems with your design for the facilitation. For all decisions about the facilitation process, you are partner with the group.

The facilitative leader role: Uses the core values and principles to help groups increase their effectiveness, including helping to create the conditions in which group members can also learn to use the core values and principles. It should be noted that the facilitative leaders role is the most difficult to play because they need to use their facilitative skills at the same time that they possibly have strong views about the content being discussed.

Both facilitative roles can add value to the workshop process by ensuring it is effective and efficient by: understanding the context of the organisation and its risk framework; keeping the purpose of the workshop and deliverables clear; being prepared by putting preventions in place; avoiding group think, understanding group dynamics and intervening as required; and providing a supportive environment and positive presence.

2.12 Creating value #12: Risk communication and stakeholder consultation

Value can be created by using risk communication and stakeholder consultation practices. It is a good idea to use risk based communication as internal and external stakeholders are beginning understand them and recognise their value. Four risk communication applications are discussed:

Risk communication during risk assessment: During the risk assessment process communication is essential and is used to: provide information; educate; persuade; evaluate and decide; empower, and recognise performance.

Risk communication as part of risk management: Risk communication can be used in three ways in regard to risk management. (1) Support decision making - the first is to support decision making about which risk treatment strategies and option are appropriate. This is very similar to how it is used as part of risk assessment. (2) Support implementation of risk treatments - the second use involves support of other risk treatment actions being undertaken to manage risks. Stated differently, risk communication is used to support the implementation of risk treatment decision made during risk treatment planning phase. (3) Risk treatment strategy - this involves developing and implementing a risk communication program as a risk treatment strategy in its own right. This would be a proactive approach designed to reduce the likelihood of adverse event(s) and to reduce the severity of the event if it did occur.

Alerting people to serious hazards: Issuing warnings is a complex matter. A balance must be struck between provision of useful information to the at-risk group and the creation of uncertainty and in some cases, panic. The type of event often dictates how much warning can be given. At one end of the scale, events such as earthquakes and explosions often strike without warning. At the other end of the scale, industrial unrest indicators would provide substantial warning. Pre-impact warnings - warning of significant danger can take many forms but it needs to be recognised within some previously established pattern to be taken seriously by the at risk group. The aim is to reduce losses in a controlled way. During event warnings - this type of communication may be directed at people trying to profit from a situation or could be directed at the victims themselves. The aim is to prevent further losses in a controlled way. Post-impact warnings - for events without warning, there may be a need for post-impact warnings that deal with areas to avoid and actions to take.

Outrage management: Sandman 1987, suggests the following strategies of outrage management: stake out the middle ground; acknowledge prior misbehaviour; acknowledge current problem; discuss achievements with humility; share control and be accountable; and pay attention to unvoiced concerns and underlying motive: At times emotions other than outrage may need to be considered, they include: denial; anger; and depression.

2.13 Creating value #13: Accountability for risks

Value is created when designated individuals fully accept accountability for risk, are appropriately skilled and have adequate resources to check risk controls, monitor risks, improve risk controls and communicate effectively about risks and their management to internal and external stakeholders. What is required is fully defined and fully accepted accountability for risk assessment, risk control regimes and individual risk treatment tasks. Normally this will be recorded in role descriptions, databases or information systems. The definition of risk management roles, accountabilities and responsibilities should be defined in the risk framework and part of the organisation's induction program. The organisation ensures that those who are accountable are equipped to fulfil that role by providing them with the authority, time, training, resources and skills sufficient to assume their accountabilities.

2.14 Creating value #14: Acceptability of risk

There is no zero risk situation. All actions, decisions or situations involve some level of risk. Risk acceptability/ evaluation (agreed risk tolerance and risk appetite) is a difficult issue. In addition to the reliability of a risk assessment itself there are four other factors which contribute to this dilemma. The first factor is that risk acceptability is subject to individual perception. This is a large topic in itself and beyond the scope of this paper, however the practical solution is to not rely on individuals to assess risk profile but to use team based approaches. The second confounding factor is that risk acceptability is sensitive to cultural differences. What is acceptable in one country can be quite unacceptable in another country. The main categories of cultural differences are country, industry and company. The third factor is that there are no external standards. Many regulatory frameworks require the management of risk to a level that is reasonably low, or 'as low as reasonably practical' (ALARP) but fall short of defining the specific criteria for major unwanted events such as an occupational fatality. While not eliminating the second and third factors the practical solution for these two is to define and use internal risk evaluation criteria. At least people know where you are coming from, for example: Australia, iron ore mining sector, Rio Tino. The final factor relates to who makes the call on acceptability. Legislation often allows workers to refuse work that they consider unsafe. As presented in Section 2.6 in a multi-level environment the party with the duty of care makes the call and where overlapping duties exist all parties must be happy with the call. Risks are acceptable to an organisation if they are within its risk criteria. In general external stakeholder will only intervene when an organisation is not living up to its own accepted standards. In a principal hazard management plan (PHMP) legislative regime it may be necessary to demonstrate that the residual risk level accepted (or tolerated) is ALARP. If risks are currently above acceptable levels then active risk treatment is required.

2.15 Creating value #15: Risk awareness culture

What are the benefits of a risk aware culture? Establishing and maintaining a risk aware culture add value by allowing the organisations to:

- have a full knowledge of the risks it is taking and keep risks visible
- trust everyone to take the right risks and avoid those with significant (negative) impacts
- manage their risks appropriately and tailor their processes accordingly
- have open and honest discussions about the risks
- enable anyone to raise critical issues without fear of retribution
- actively learn on a number of fronts and hence make better decisions
- control losses, maximise profits and maintain business continuity.

Table 5 provides a list of indicators of a risk aware culture.

Table 5. Indicators of a risk awareness culture.

Indicators	Description of risk aware culture element
Questioning assumptions	Everything is on the table for re-examination.
Asking for risks	Management, at all levels are not shy about asking about risk and controls.
Able to reverse decisions	Staff admit there may be a better way to do a task than the current one.
A willingness to speak out	All staff have a lack of fear of retribution.
Learning from mistakes	Questioning why minor and major decisions go wrong on a routine basis.
Constantly challenging risk management process	Question whether risk processes help (create value) or hinder (too bureaucratic) in achieving our goal of managing risks.
Risk process is not abused	Risk management not used for political or expedient purposes.
Quantitative risk assessment is used whenever it can be	When real data or real experts are available use quantitative assessments - providing the best insight into what is likely to happen.
Risk management is seen as more than just numbers	Numbers are important in risk assessments, but asking the right questions is more important.
Management is willing and able to say no	Being able to say no is the mark of an organisation with a mature risk management culture; one that is led by leaders, not managers.
Personal and collective acceptance of responsibility	Organisations and the people that comprise them accept responsibility for the risks they take as well as those they create.
Shape the future	When managing business risk occasional failure is the price paid for trying to shape the future instead of letting it shape the organisation.

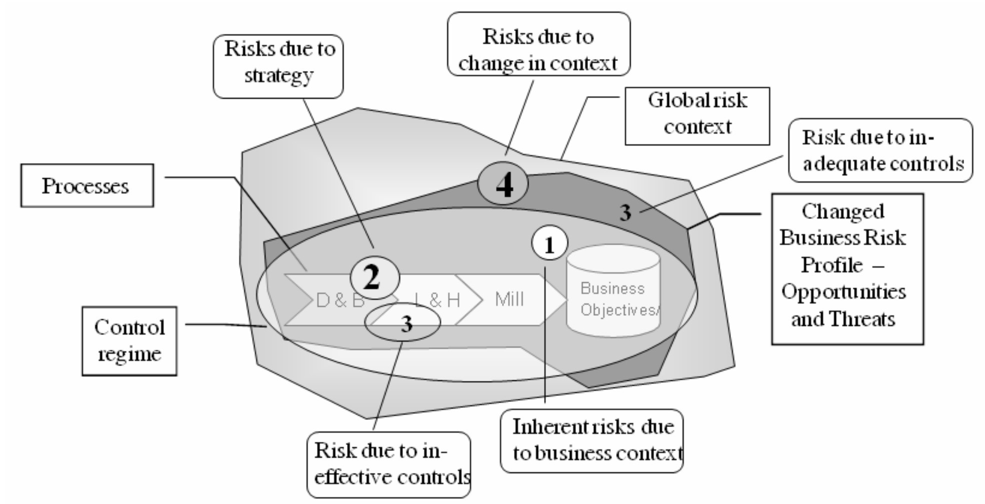


Figure 5. Diagram showing the relationship between the global risk context, business objectives, the processes introduced, the changed inherent business risk profile, and the control regime introduced.

2.16 Creating value #16: Residual risks and effectiveness of controls

Just as risk levels can be estimated so can the effectiveness of controls. A knowledge of the effectiveness of risk controls that reduce the inherent levels to residual levels has value in itself. This understanding can also give assurance that the residual risk levels are within the organisation risk appetite. An expanded view of the range of risk controls available can also support and add weight to this understanding. Leitch (2008) discusses 60 intelligent risk controls in the following five categories: controls that generate other controls; audit, review and efficient monitoring; learning and adapting; protection and inherent reliability; and checking and correcting.

Figure 5 is a risk model developed by the author which demonstrates why residual risk management is required for all blasting operations. The development of this model is shown in Section 3.2.

2.17 Creating value #17: Priorities for action

Risk thinking is relatively unique in that it enables us to deal with uncertainty and it provides us with priority for action. The most value is obtained by treating the highest risks first. You cannot do everything at once and if you try you will probably not even effectively treat the highest priority risks.

When determining priority for implementing individual risk treatment actions some guiding principles are useful. Table 6 has been developed to provide some guidance on criteria for each of the three faces of risk. It is also recommended that the risks on the risk continuum (Section 4.2) be tackled from left to right when starting any new operation or project. Once the hazards are under control it will be possible to start managing performance variations and tradeoffs. Once these two faces are under control the organisation will have built a platform for seeking opportunities.

Note that the risk treatment actions aimed at improving control ratings and reducing uncertainty can be used to motivate teams who may otherwise see no point in taking action if it does not change the risk ratings.

2.18 Creating value #18: Insurance

An organisation's risk management knowledge and practices should be used to optimise insurance coverage with the aim of maximising shareholder returns. Some recent trends with regard to insurance are:

– insurance is no longer the cheap option it once was - increased premiums
– open-ended cover is no longer widely available - adding exclusions
– insurance companies require their clients to actively manage their risks - insurer audits

Table 6. Implementation guidance.

Hazards and threat face - Action Impact	Schedule
Reduce risk rating + add net revenue	Implement immediately
Reduce risk rating + reduce operating costs (constant revenue)	Implement immediately
Reduce risk rating + improve communication/remove departmental barriers or develop trust or resolve conflict/remove fear or remove hidden agenda or provide leadership or gain commitment/ownership/empower people	Implementation priority based on highest benefit/ cost ratio
Unchanged risk rating + improve control rating or reduce uncertainty rating	Routine activities
Variations/Trade-offs Action Impact	**Schedule**
Reduce variability + add net revenue	Implement immediately
Reduce variability + reduce operating costs (constant revenue)	Implement immediately
Managing variability + improve communication/remove departmental barriers or develop trust or resolve conflict/remove fear or remove hidden agenda or provide leadership or gain commitment/ownership/empower people	Implementation priority based on highest benefit/ cost ratio
Unchanged variability + improve control rating or reduce uncertainty ratings	Routine activities
Opportunity face - Action impact	**Schedule**
Increase opportunity rating + add net revenue	Implement immediately
Increase opportunity rating + reduce operating costs	Implement immediately
Increase opportunity rating + improve communication/remove departmental barriers or develop trust or resolve conflict/remove fear or remove hidden agenda or provide leadership or gain commitment/ownership/empower people	Implementation priority based on the highest benefit/ cost ratio
Unchanged opportunity rating + improve control rating or reduce uncertainty ratings	Routine activities

- insurance may not recoup the full amount lost - exclusion clauses and reputation
– many assets cannot be insured - goodwill and reputation.

All of these trends indicate the need for more risk aware organisations and cultures, even with regard to insurance risks, and the need for an intelligent approach to integrating insurance requirements.

2.19 Creating value #19: Monitoring, audit, review and reporting

For the organisation to have a current, correct and comprehensive understanding of its risks it is necessary to have ongoing monitoring, periodic audit and review and accurate reporting. This is also required for organisational learning and continuous improvement. ISO 31000 calls for the risk framework to be monitored, along with procedures, management plans, performance, emissions, complaints, incident and compliance. Things that can change over time include: business environment/context; assumptions; new risk emerge (risk profiles); effectiveness of control measures (control regimes); occurrences of incidents and events; risk culture; risk appetite; and the need for special alerts and other risk communication. The author is using both a risk profile KPI and a control KPI for monitoring as well as to motivate work teams. Ongoing review is essential to ensure, inter alia, that the management plan remains relevant. An internal audit process should normally be accountable for providing assurance on: risk management processes, both their design and how well they are working; management of those risks classified as 'key', including the effectiveness of the controls and other responses to these; and reliable and appropriate assessment of risk and reporting of risk and control status. With regard to reporting value is added by having a specific, timely, accurate and reliable reporting, and an appropriate flow of risk information around the organisation.

2.20 Creating value #20: Organisational learning and continuous improvement

The final way to create value presented here relates to organisational learning and continuous improvement. The ability to learn is what separates the successful from the less effective organisations. Risk learning formalises the lessons learnt and relevant, project artifacts and tools, and captures that knowledge in a reusable form for reuse within the team and by the enterprise.

Continual improvement in risk management involves the setting of organisational performance goals, measurement, review and the subsequent modification of the framework, processes, resources, capability and skills. It requires explicit performance goals against which the organisation's and individual manager's performance is measured. Normally, there would be an annual review of performance and then a revision of processes, and the setting of revised performance objectives for the following period. This risk management performance assessment needs to be an integral part of the overall organisation's performance assessment and measurement system for departments and individuals to be most effective.

3 CASES OF RISK THINKING IN BLASTING CONTEXT

3.1 Case 1 Quantifying risk of damage to powerline using a Fault Tree Analysis workshop

A facilitated risk workshop has been used to quantify the total probability of damage using the following approach. The total probability of damage PoD_{total} is the sum of the PoD_{model} (e.g. standard blast design) and $PoD_{atypical}$ (e.g. excess flyrock or vibration).

PoD_{Total} = $PoD_{Model} + PoD_{Atypical}$

PoD_{Model} = Probability of damage with normal blasting conditions

= P (Flyrock range > set criteria) or P (Vibration level > set criteria)

$PoD_{Atypical}$ = Probability of damage with abnornal blasting conditions

= f(human error, design mistakes, geological anomalies)

The PoD_{total} is estimated based on input for the scenario branches (see Figure 6) collected during the FTA workshop process. The PoD_{model} values are calculated by the FTA spreadsheet based on the $PoD_{atypical}$ values. All inputs captured are based on the best available information, both tacit and explicit, from the workshop team members.

In the FTA model depicted in Figure 6, damage to powerlines is possible via three scenarios:

– *scenario 1 [Atypical] - Excessive critical flyrock:* (both range and direction) has three

branches: insufficient burden; presence of critical weak zones; and less than adequate (LTA) stemming
– *scenario 2 [Atypical] - Excessive ground vibration:* (taken to be 100 mm/s @ 100 m) also has three branches: LTA initiation design or tie-in; overcharging; and adverse travel path geology
– *scenario 3 [Normal] - Normal blast design:* has only one branch involving potential damage due to normal blasting conditions. This implies that there are no atypical occurrences.

Terms used in the current Fault Tree Analysis –

Per blast and per year considerations:
– PoOiB: Probability of occurrence of the specified branch of scenario 1 per blast
– PoOiY: Probability of one or more occurrences of scenario 1 per year (calculated using the binomial theorem and prescribed number of blasts per year)
– PoD|i: Probability of damage given that scenario 1 occurs
– PoDiY: Probability of damage for scenario 1 per year
– TPoDY: Total probability of damage per year.

LOM considerations:
– TPoDLOM: Total probability of one or more damage events over life of mine (calculated from PoDiY using the binomial theorem and prescribed number of years).

Other comments on the FTA spreadsheet:

– assumptions: 100 blasts per year, LOM is five years
– probabilities shown as 1.000 in the spreadsheet are always less than precisely 1.0, e.g. 0.999999 is rounded up to 1.000
– if the probability of any scenario occurring per blast is 0.1 or higher than the probability of one or more such scenarios occurring during 100 blasts (i.e. in one year) approaches 1.0
– in some cells a large number decimal places has been used to display the fact that there is a lower, mean, and upper value placed in the top, central and bottom cell, respectively
– all very pale grey cells are probabilities estimated by team members, all white cells are calculated probabilities based on these estimations, while black cells represent final values.

3.2 Case 2: Business risk model applied to blasting

In this case study, a business risk model is demonstrated. It is called the CSCC Risk Source Model and is used to identify risks related to the business Context, Strategy, Controls, and Changes

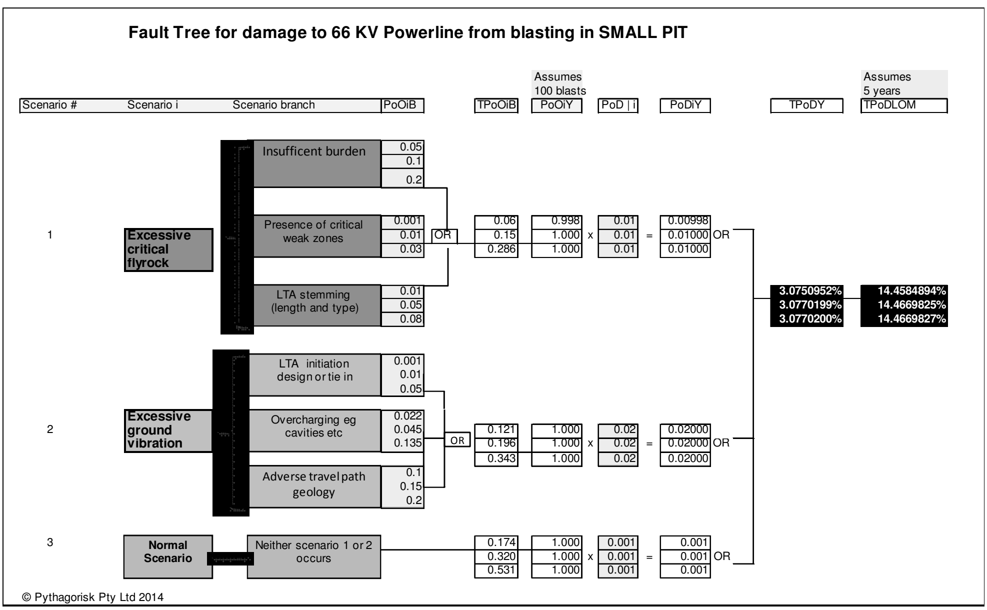


Figure 6. Fault tree analysis worksheet.

Table 7. CSCC Model for business risk.

Model Type	Risk Source	Nature of Risk	Risk Management Strategies
Context	Risk due to the business context and objectives	Inherent risks	Understand inherent business risks and develop appropriate strategies
Strategy	Risks due to strategies	Residual risks	Select and implement business processes and controls to suit business objectives and inherent risk profile
Controls	Risks due to inadequate or ineffective controls	Control risks	Identify and improve ineffective controls and/or introducing new controls
Change in context	Risks due to unexpected changes in context	New and/or modified inherent risks	Scan for trends and be ready for unexpected changes, undertake safe and stakeholder responsive operations

in context (CSCC). Table 7 shows the source, nature and appropriate strategy for each component of the model.

Organisations need to be in tune with contextual conditions and be alert to changing circumstances or they are at risk. Dynamic contexts provide opportunities (positive risks) and threats (negative risks) to organisations. The strategies and processes an organisation introduces to create value and manage risk are always subject to variability and uncertainty (plus/minus risks) and these need to be kept within the control limits.

3.3 Case 3: Risk generator tool for mine site explosives security

This brief case focuses on security risk identification and in particular on the development of a risk scenario generator. The aim of the risk identification workshop is to identify and characterise credible and non-trivial risk scenarios. Theft of explosives from a mine can be undertaken by three classes of people: authorised employees, non-authorised employees, and outside third parties. The characteristics of these three categories of people are presented next.

Characteristics of an authorised employee:

– has access to explosives over long period
– highly screened and trained
– limited number of them
– can be reached by communication and training programs.

Characteristics of a non-authorised employee:

– has limited periodic access to explosives
– not highly screened or trained
– known number of them
– may have relationship with authorised persons
– can be reached by communication and training programs.

Characteristics of third parties:

– has no legal access to explosives
– not screened
– unknown number of people
– may have relationship with authorised or non-authorised employees
– can't be communicated with directly.

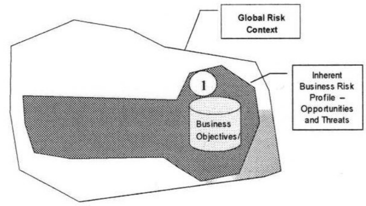
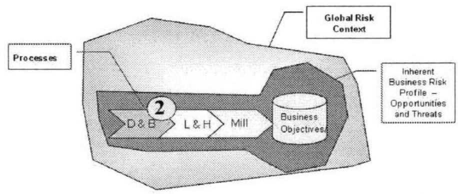
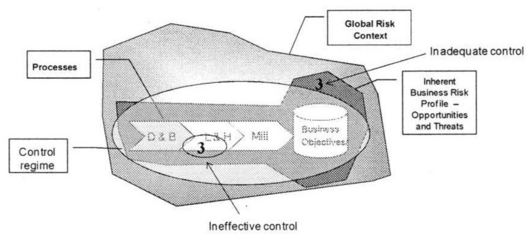
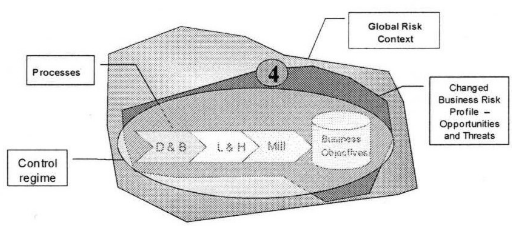
Table Risk type	Graphical depiction
RISK SOURCE TYPE 1 [B1]: *Inherent risks due to business context* - If blasting operations are to be used in mining or business activity there are a number of inherent risks in the following categories: safety, security, performance, and environmental.	
RISK SOURCE TYPE 2 [B2]: *Risks due to strategies* Strategies are developed and processes are introduced to cater for the context and to achieve business objectives. There is a risk that the strategies and processes adopted may be unsuitable or ineffective.	
RISK SOURCE TYPE 3 [B3]: *Risks due to controls* The control regime introduced to reduce the risk profile to acceptable level may be inadequate or ineffective for some risks. Other risks may be uncontrollable. These control deficiencies may become apparent during an audit.	
RISK SOURCE TYPE 4 [B4]: *Risks due to changes in context* Context changes could include: regulatory intervention that restrict blasting operations; reduce demand for services/ products; competitor or third party activities or natural disasters.	

Figure 7. Four diagrams showing the relationship between the global risk context, business objectives, and the risk type based on the CSCC model in a blasting context.

Table 8 presents a risk scenario generator which is based on the three categories of people; the life cycle stage, and the detection status.

A simple scenario generator presented in Table 8 can be used to generate 24 risk statements. This should be ample for a risk assessment of this nature. If however more detail is required, it is possible to be more specific about the classes (or individuals) of authorised employee (eg magazine keeper, authorised disposal expert, blasting supervisor, etc.) and to further breakdown the shotfiring activity into smaller tasks. A sample of risk statement is presented next:

Table 8. Scenario generator.

Stage	Authorised	Non Authorised	Third Party
Receival	A1, A2		
Storage		B8	C1, C2
Shotfiring	A3		
Disposal			
Detected	A2		C1
Undetected	A1, A3	B8	C2

Risk statement A1: Undetected theft of explosive by authorised employee during receival stage, leading to surprise supply of illegal explosives.

Risk statement A2: Detected theft of explosive by authorised employee during receival stage, leading to supply of illegal explosives.

Risk statement A3: Undetected theft of explosive by authorised employee during shotfiring activities leading to surprise supply of illegal explosives.

Risk statement B8: Undetected theft of explosive by employee during magazine storage stage, leading to supply of illegal explosives.

Risk statement C1: Detected theft (robbery) of explosive by third party during magazine storage stage, leading to supply of illegal explosives.

Risk statement C2: Undetected theft of explosive by third party during magazine storage stage, leading to supply of illegal explosives.

4 DISCUSSION AND CONCLUSIONS

Drilling and blasting operations are unique in at least three ways; high hazard, rapid design and implementation feedback is available, and occur early in the value chain. These features align well with the three faces of the risk continuum; hazard, variation/trade-off, and opportunity. In summary provided the pitfalls of risk frameworks discussed can be avoided, value can be created by:

– having a clear risk strategy – how you use risk thinking to achieve business objectives (section 2.1)
– using risk continuum – hazard, variation/ tradeoff, opportunity – thinking (2.2)
– developing and using an appropriate risk framework and governance structure (2.3)
– developing and using an enterprise wide risk glossary (2.4)
– aligning risk processes to the organisation's size, context, objectives and risk profile (2.5)
– using multi-level risk systems that enable full participation at the appropriate level (2.6)
– selecting the appropriate risk tools for each risk application (2.7)
– managing both internal and external interface risk (2.8)
– using integrating risk systems which enable effective decision making (2.9)
– having clearly defined; roles, responsibilities and governance (2.10)
– using facilitators to ensure risk workshop processes are effective and efficient (2.11)
– understanding and using risk communication and stakeholder consultation practices (2.12)
– having defined and fully accepted accountability for risks and risk treatment (2.13)
– ensuring all organisation’s risks are within its risk criteria (2.14)
– establishing and maintaining a risk aware culture (2.15)
– smarter design of risk controls and control effectiveness rating systems (2.16)
– act on the risk profile by taking action in priority order (2.17)
– using risk intelligence to optimise insurance coverage (2.18)
– having a current, correct and comprehensive understanding of its own risks (2.19)
– learning from success and failure and continually improving. (2.20)

The over-riding conclusion of this paper is that organisations that are effective in the way they use risk thinking have greater control of their own growth and sustainability and this is essential when conducting operations that use highly energetic explosives materials.

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