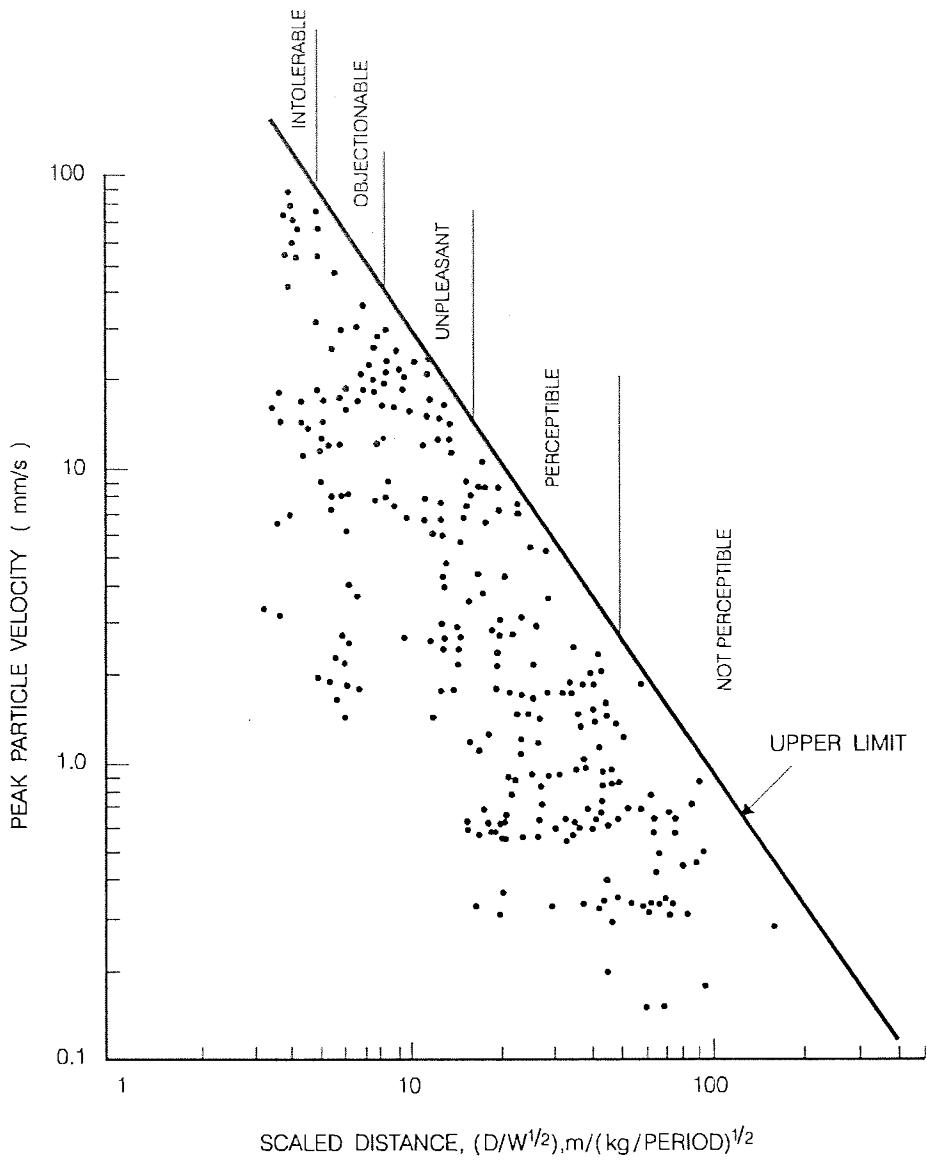

FIGURE 18: ANTICIPATED HUMAN RESPONSE TO BLAST VIBRATION AT DIFFERENT SCALED DISTANCES FROM PIT BLASTS.

3.4 Recommended Design Limits for Peak Particle Velocity

The outcome of the work on human response to blast vibrations is that, to minimise complaints, blast vibrations must be kept at levels considerably below those that cause the onset of damage.

Accordingly the final report of the Model Municipal Noise Control By-Law, (August 1978), in the Province of Ontario, Canada, stated that:

> **Blasting Operations**
>
> No person shall emit or cause or permit the emission of sound (concussion) or vibration from a blasting operation of a type mentioned in Publication NPC-119-Blasting, such that the peak pressure level or peak particle velocity at a point of reception located in a Quiet Zone or Residential Area, exceeds the applicable limit set out in Publication NPC-119-Blasting.

Publication NPC-119-Blasting states:

> Section 6: **Vibration - Cautionary Limit**
>
> Subject to Section 7, the peak particle velocity limit for vibration resulting from blasting operations in a mine or quarry is 1,00 cm/s.
>
> **Section 7: Vibration - Peak Particle Velocity Limit**
>
> If the person in charge of a blasting operation carries out routine monitoring of the vibration the peak particle velocity limit for vibration resulting from blasting operations in a mine or quarry is 1,25 cm/s.

The appropriate section from the Model Municipal Noise Control By-Law, Final Report, Ministry of Environment, Province of Ontario, August 1978, appears in *Appendix B*.

Since 1979, the U.S. Government has twice assessed their maximum peak particle velocity which was at 2 in/s (50,8 mm/s). It was first reduced to 1 in/s (25,4 mm/s), and more recently to 0,5 in/s (12,7 mm/s).

One difference that the Schoongezicht Mini-Pit has as compared with most situations elsewhere is that the house construction techniques in the immediate vicinity are not of high quality. Vibration levels that would present no concern to most properties potentially could produce problems in the neighbouring township. It is therefore recommended as regards the township area that the maximum peak particle velocity should be limited to 5 mm/s. A limit of 100 mm/s is recommended for use relative to structural damage remote from the general public such as for the prevention of damage to the nearby power lines and railway. A limit of 50 mm/s is recommended for use relative to the four steel pipelines.

It is therefore proposed that for the Schoongezicht Mini-Pit a maximum peak particle velocity limit of 5 mm/s be considered for Lynneville Village and the Schoongezicht Township, 10 mm/s be considered for design of blasts with respect to other residences and like structures, 50 mm/s for pipelines and a limit of 100 mm/s be used relative to structural damage remote from the general public such as for the prevention of damage to power lines.

3.5 Determination of the Recommended Explosives Weight per Delay

The most critical areas of the mini-pit as regards blast vibration control will be along the north and northeast sides of the mining area, the northwest near the pipelines and power line and the southeast beside the railway. Good control will certainly be required near the pipelines on the northwest side. At the same time, the degree of concern for the critical areas is also affected by the choice of mining method of which three have been proposed, these being:

(1) Strip the top soil and then drill and blast to the floor of 1 Seam;

(2) Drill and blast from the top of hards to the floor of 1 Seam;

(3) Mine the property in the conventional manner taking each level separately.

The choice of mining method changes the depth of the blastholes, and thus the potential charge length. In turn, if charge weights become large, deck loading with individual delaying of each deck may be necessary or the use of the 102 mm blasthole size rather than the 165 mm hole may be required. These choices revolve around the need to limit the weight of explosives fired per delay. As such, as regards blast vibration control, the chosen mining method, blasthole size, whether or not deck charges are employed, etc. is basically unimportant. What is important is that the design maximum explosives weight per delay is not exceeded. As regards this analysis, then, only the weight of explosives fired per delay will be considered, how it is chosen to use that explosive will be left to the discretion of the contractor in charge of the blasting operation.

As regards overburden cover, the shallowest area is in the northwest, and even in the northeast it is found that only 8 m is a typical depth. Regardless of the mining method, a maximum single column explosives weight per blasthole (and thus per delay) of 220 kg of emulsion in the 165 mm diameter size is the most that will be necessary. The scaled distance between the closest blast and the Schoongezicht Township fence line will therefore be no less than 39,4 $m/kg^{1/2}$. Review of *Figure 15* shows that such a value is expected to fulfill the recommended design limit for blast vibration peak particle velocity as regards the township.

As blasts become further from the township the overburden cover does tend to increase in depth. There may be areas of the pit which will therefore have a slightly lower scaled distance, although it is not likely. For example the very deepest cover at the south of the pit could be shot with an emulsion weight of close to 800 kg/hole to produce a similar vibration at the township as that of 220 kg/hole at the closest point. Such a weight is more than enough to blast the full cover using the 165 mm diameter blasthole. However, should any areas of concern be encountered in other sections of the property, a reduction in hole size would give the necessary control. Otherwise delay decks could be considered. It should therefore be possible to control blast vibrations to acceptable levels at the township as per the data presented in *Figure 15*.

Another point to note is that the geological conditions as regards sills, dykes and faults, etc. is not well known for the area, particularly underneath the township and village. Any adverse geological structure could potentially enhance vibration levels. For example a sill tends to limit the normal loss of blast energy directly down into the ground such that levels near the ground surface can be substantially higher than would normally be expected.

Therefore as the geological conditions at the Schoongezicht Mini-Pit are unknown, it was recommended that an Iso-Seismic Survey be conducted to fully investigate the influence of the geology on the blast vibration energy dispersion around the pit, particularly in the vicinity of the Schoongezicht Township. Such a survey is normally carried out by measuring blast vibration dispersion from small test blasts using approximately 125-150 micro-seismic blast vibration monitors. The result of the survey is an Iso-Seismic map showing the "contours" of vibration measured around the test blasts. These contours can then be used to accurately determine the explosives weight per delay that can be safely fired near the critical points of concern. Appropriate changes to the design scaled distances can be made as a result of this study. Accordingly a study was conducted, the results of which appear in *Appendix C*.

The first outcome of the Iso-Seismic Study was that the test data followed the relationship as described by the MREL upper limit line, albeit at lower levels. Certain of the test blasts produced calculated multi-period vibration levels estimated to be very similar to the MREL line. Others produced lower vibrations which will allow larger charge weights depending on the blast location.

The Iso-Seismic Survey results are also developed to produce vibration contours for two test blast sites assuming specific charge weights per delay. The charge weights used in the test locations, if they had been employed in multi-period blasts, would not have produced vibrations at higher levels than the recommended limit in any areas of the township or Lynneville Village.

However there are still two other areas of concern which must be addressed. The first of these is relative to the power line and pipelines in the northwest corner. Here the power line approaches to within 15 m of the pit while the pipelines are as close as 45 m at one point. Luckily the overburden is highly weathered in the area and is only some 4 m deep. It is unlikely that blasting will be required. If material is slightly hard, ripping can be employed in the critical areas. The use of the 102 mm hole for a section of the pit will also help ensure that no problems are experienced should blasting be employed. For example the 102 mm hole could contain full column charges of emulsion of as much as 50 kg/hole (~ 5 m of charge) at a distance of 55 m or more without a problem at the pipeline and similarly 35 m or more from the power line.

The other area of concern is the railway located at 50 m to the southeast of the property. *Table 2* presents the maximum explosives weight per delay which will fully protect the railway.

Minimum Distance Between the Blast and the Railway (m)	Maximum Explosives Weight per Delay (kg)
50	124
60	180
70	244
80	319
90	403
100	498

TABLE 2: RECOMMENDED MAXIMUM EXPLOSIVES WEIGHT PER DELAY FOR BLASTS FIRED AT CLOSE DISTANCES TO THE RAILWAY LINE.

Table 2 shows that blast vibration control for the railway will only affect blasts at relatively close distances and that the effect will be minor in most cases. Either delay decking in the larger hole, or the use of the 102 mm hole, will allow suitable blast designs to be employed.

A final recommendation as regards choice of blasthole size relates more to political concerns. The Iso-Seismic Survey demonstrates that the use of the 165 mm hole size will present no vibration problems for the majority of the mini-pit. But the fact is that the pit will be restarting after a long dormant period and it will be under close scrutiny. The final recommendation is therefore to consider starting up operations for the first blasts with the 102 mm hole size, even though the 165 mm hole is expected to prove acceptable, until the neigbouring residents become used to blasting again. This is because blasting in an economic manner will be discernable to some degree regardless of the techniques employed.

3.6 Recommended Blast Tie-ins

Single hole initiation is recommended for all blasts. While there are many ways this can be achieved, one proposed blast tie-in design uses a combination of 25 ms and 40 ms delays which gives a satisfactory result. It is therefore recommended that this standard design be maintained for all strip cut blasts whether overburden and coal are blasted together, or if shot separately. This blast tie-in design is illustrated in *Figure 19*.

The boxpit blasts will require some modification given that both sides of the shot will be bordered by solid ground. A suitable blast tie-in modification for this condition is presented in *Figure 20*. Again a combination of 25 ms and 42 ms delays are proposed to be employed.

Blasting should always be away from the informal settlement and other major structures and objects of concern.

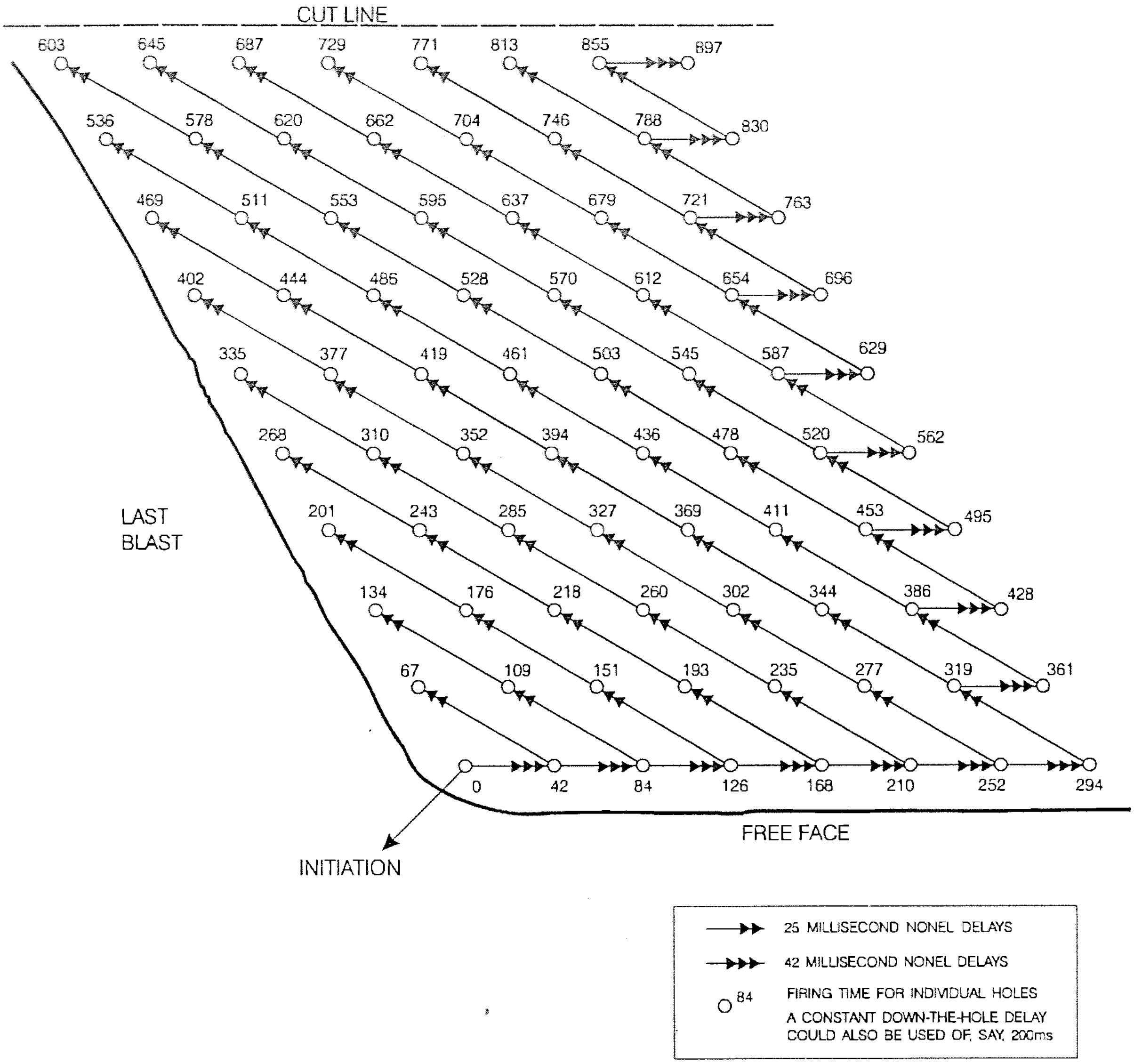

FIGURE 19: RECOMMENDED REPRESENTATIVE BLAST TIE-IN FOR ALL STRIP CUT BLASTS USING NONEL INITIATION AND NONEL SURFACE DELAYS.

3.7 Blast Vibration Monitoring

It is recommended that all blasts be monitored for blast vibration as well as air blast. Recommended permanent monitor locations for both blast vibration and air blast are as follows:

(i) At a secure position at one of the residences closest to the mini-pit in the Schoongezicht Township;

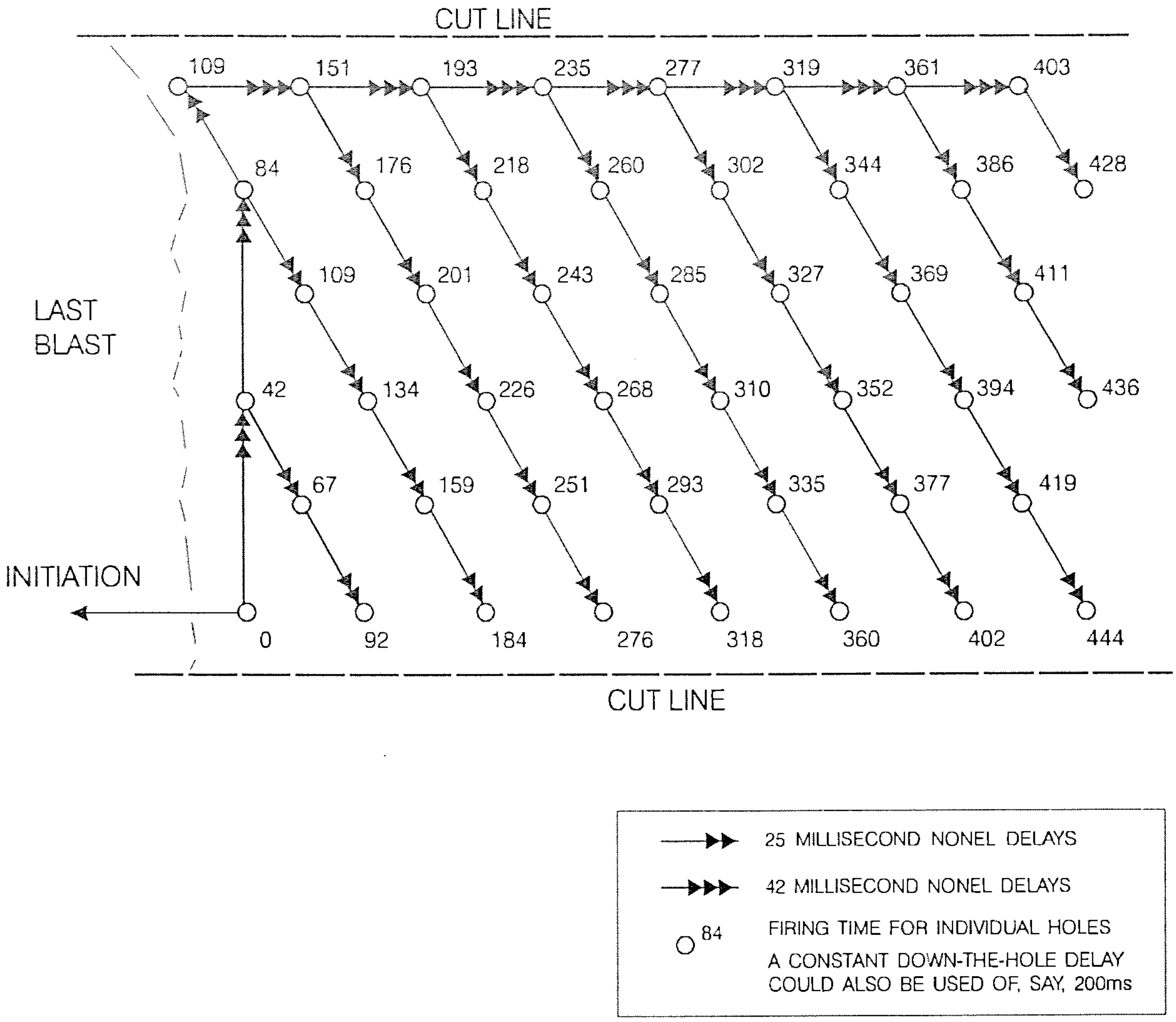

FIGURE 20: RECOMMENDED REPRESENTATIVE BLAST TIE-IN FOR ALL BOXPIT BLASTS USING NONEL INITIATION AND NONEL SURFACE DELAYS.

(ii) At a residence in Clewer, preferably on the mini-pit side of the village.

The planned mining sequence has been outlined in *Figure 2*. It will be seen that mining commences at the nearest point to Schoongezicht and Lynneville and works towards Clewer. The proposed permanent monitoring point data recorded for all blasts will continually provide further confirmation of the original blast designs, which will be based on the results from the Iso-Seismic Survey. At the same time, should unforeseen problems arise, the permanent monitoring stations will provide early warning of any changes, and will allow prompt blast design modifications to be made where necessary.

4.0 BLAST DESIGN PARAMETERS - NOISE AND AIR BLAST CONTROL

As introduction *Figure 21* presents the human and structural response to different sound pressure levels.

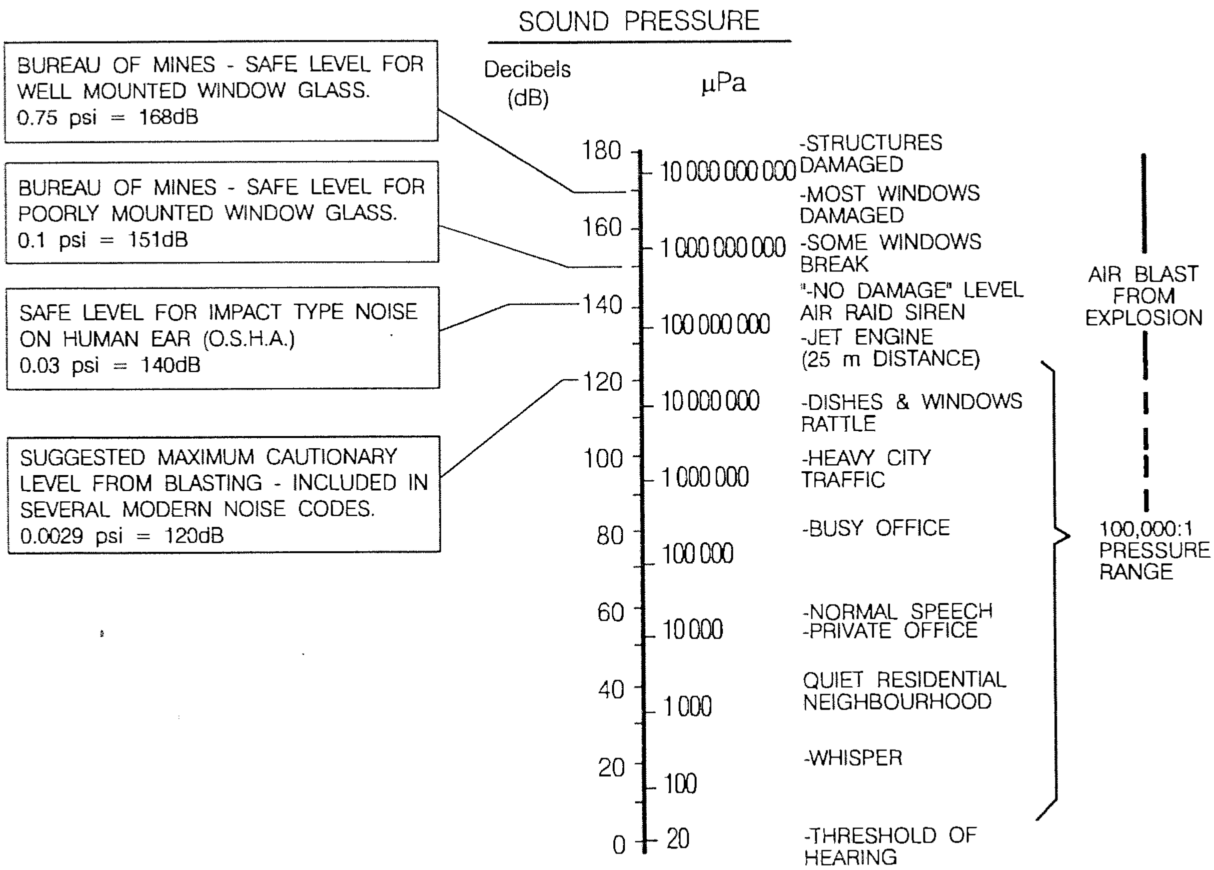

FIGURE 21: HUMAN AND STRUCTURAL RESPONSE TO SOUND PRESSURE LEVEL. (AFTER BRUEL & KJAER INSTRUMENTS, 1976)

As with blast vibrations, human response to blast noise and air blast is also very subjective. However, one occurrence that brings instant complaints is broken windows and with that in mind, *Figure 22* has been prepared giving the probability of window

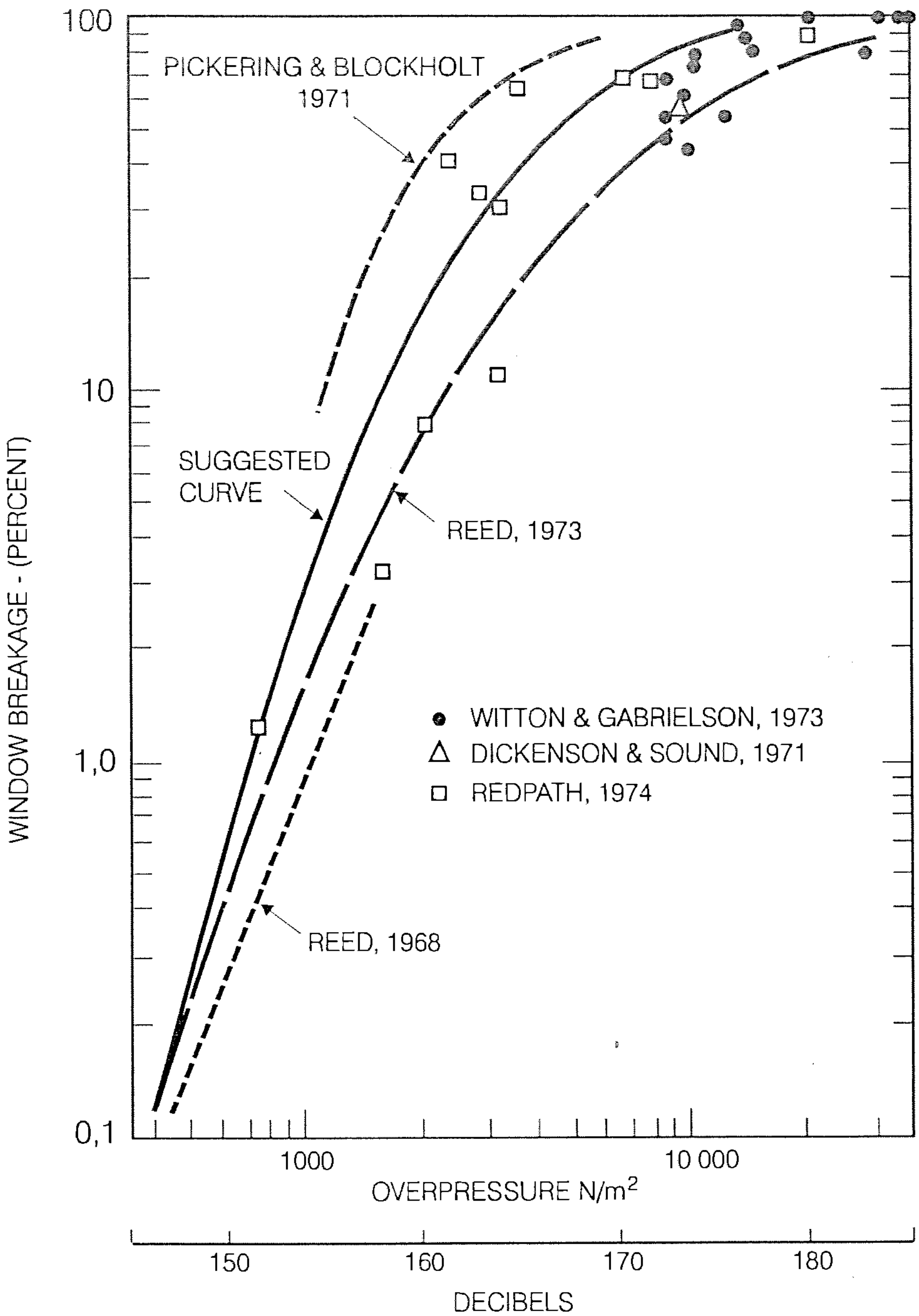

FIGURE 22: PROBABILITY OF WINDOW BREAKAGE AS A FUNCTION OF PEAK AIR BLAST OVERPRESSURE.

breakage as a function of peak air blast overpressure recorded by a number of investigators. Because of the random nature of the factors governing glass strength and blast overpressures, as well as different sizes and types of window, there is a considerable amount of scatter for the damage estimates. For a given degree of breakage, the corresponding overpressure may vary by a factor of two or more. Nevertheless, the curves can serve as a guide in assessing the hazard to windows in structures located near blasting operations.

4.1 Generation and Propagation of Air Blast Pressures

In-pit noise or air blast can be caused or aggravated by the following:

(i) Detonating cord trunk lines;

(ii) Lack of proper stemming material;

(iii) Inadequate stemming height;

(iv) Overdug or overloaded front row holes. Collars or burden near the crest too small due to back break;

(v) Delay sequence;

(vi) Atmospheric conditions such as temperature inversions or wind in the direction of concern;

(vii) Secondary blasting.

The first item can often be eliminated as a hazard by going to lower grain count detonating cord trunk lines or Nonel, covering with cuttings or using electrical blasting. This latter approach however can be more complicated. The use of surface Nonel is therefore recommended. Overdigging or overloading of the front row of holes can be eliminated by flagging for the shovel operator for parting or coal blasts and the stemming and stemming heights in the body of the blast increased. The blasts must be laid out so that a single hole is fired per delay period. Plaster shooting for secondary blasting is particularly hazardous with most of the explosive energy going into air blast. Pop holes produce much less air blast. *Figure 23* shows the values of peak air blast pressure encountered at different scaled distances from a shot point for normal

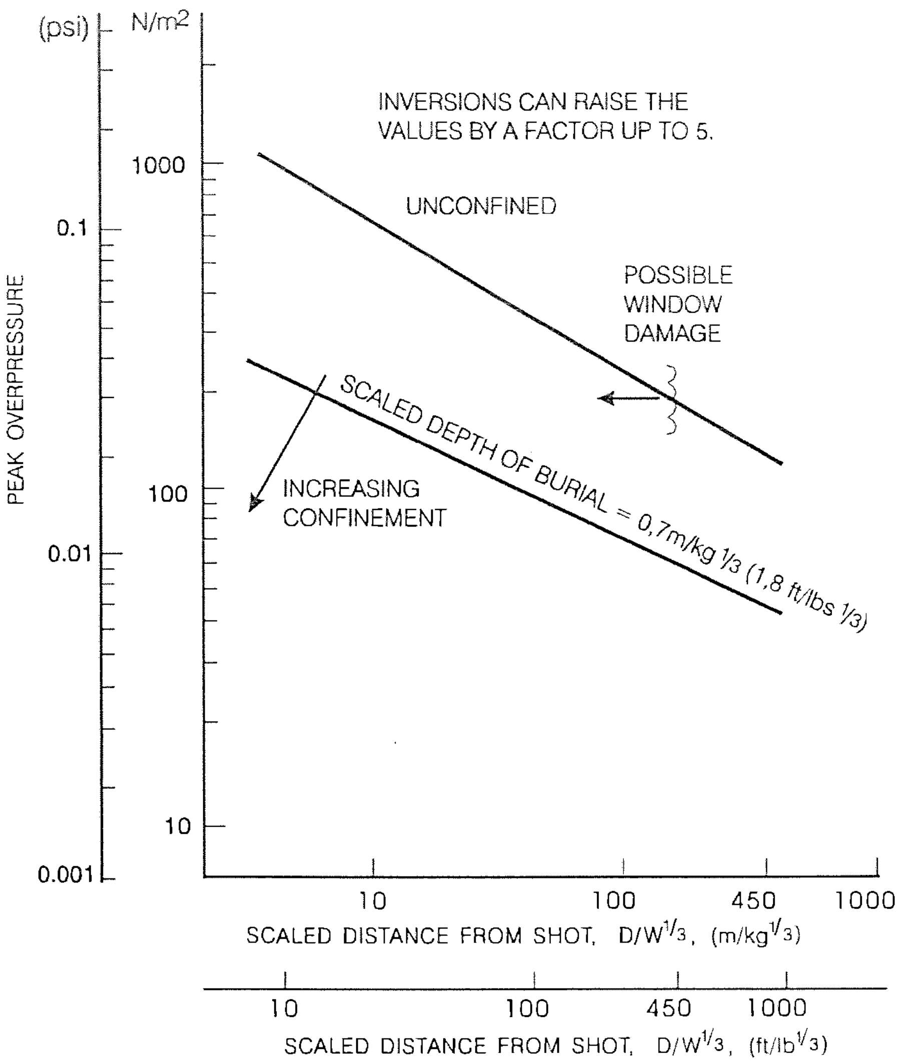

FIGURE 23: PEAK AIR BLAST PRESSURE GENERATED BY SPHERICAL CHARGES.

atmospheric conditions. The upper line is for unconfined charges, in this case then, charges placed on the ground surface. The lower line illustrates the reduction in overpressure experienced as the charges are buried in the ground. The scaled depth of burial at the Schoongezicht Mini-Pit will be recommended to be at least 2,5 $m/kg^{1/3}$ which should give very low noise. Climatic conditions are shown to have an influence of up to a factor of five times the values indicated on the graph. This type of plot should be used for measurements made from coal blasts where charges are essentially spherical and are at relatively shallow scaled depths of burial.

Delays can be used to isolate the effects of one charge from the next in secondary blasting. Arrange for an approximate minimum of 50 milliseconds to lapse between the arrival of the noise from the successive shots. If the closest one is fired first then the delay to be used can be arrived at by dividing the distance difference between the two shots by the sound speed, 335 m/s, and subtracting this from 50. A good rule of thumb might be to shoot the closest shot first with all others having delays between them of 50 milliseconds. Care should be taken to ensure that the blast wave from one shot does not dislodge the next. However, it is not anticipated that this type of blasting will ever be required at Schoongezicht.

If two blasts are to be fired it must be ensured that the arrival of the pressure wave at the point of concern from the second is suitably delayed from that of the last row of holes of the first blast. Probably the easiest way to do this is to fire the closest one first and to delay the second blast so that sound arrival at the point of interest from the second blast arrives no sooner than that from the last row of holes in the first blast plus a delay time of 50 milliseconds approximately. If there are 12, 25 ± 3 ms delays from the point of initiation of the first blast and the blasts are equidistant to the point of interest, then the second blast should be delayed a minimum of (12 x 28) + 50 ms or 350 milliseconds. Doubling this would be quite in order.

One way to further reduce air blast and noise is to construct a windrow of topsoil between the mining operation and any point of concern. Planting trees on the windrow will also help. Such a windrow will tend to deflect air blast, as well as noise of any type, upwards thus tending to minimise the portion that reaches any point of concern.

4.2 The Effect Of Atmospheric Conditions

The peak overpressure at a given point is influenced by atmospheric conditions particularly at long distances away from the blast. Wind and temperature altitude profiles have the major influence. The speed of sound in air is given by,

$$C = \frac{\sqrt{\gamma}P}{\rho} = \sqrt{\gamma}nRT$$

where

T = temperature

g = ratio of specific heats

P = pressue

r = air density

R = gas constant

n = number of moles

so that increases in temperature cause increases in sound speed. *Figure 24* shows typical atmospheric temperatures (Cook, 1958) conditions which can occur and the potential problems associated with temperature inversions or with an increasing temperature with altitude profile. These conditions, if they exist, can increase the peak overpressure by as much as a factor of five as previously stated.

The predominant wind directions are from the northwest and southeast, although other directions are also common. Air blast will naturally be minimised when the wind blows from the village towards the blast. When high winds blow in the opposite direction it is recommended that blasting not be performed. This will eliminate any air blast enhancement afforded by the wind, and it will similarly prevent the dispersion of any blast dust or noxious fumes towards the village.

4.3 Recommended Design Limit For Air Blast Overpressure

As was the case for blast vibration control, to minimise complaints from air blast the design limits must be kept at levels considerably below these that cause the onset of damage. For the Schoongezicht Mini-Pit, it is recommended that the Ontario regulations be accepted as the appropriate noise level. The final report of the Model Municipal Noise Control By-Law, (August, 1978) stated that:

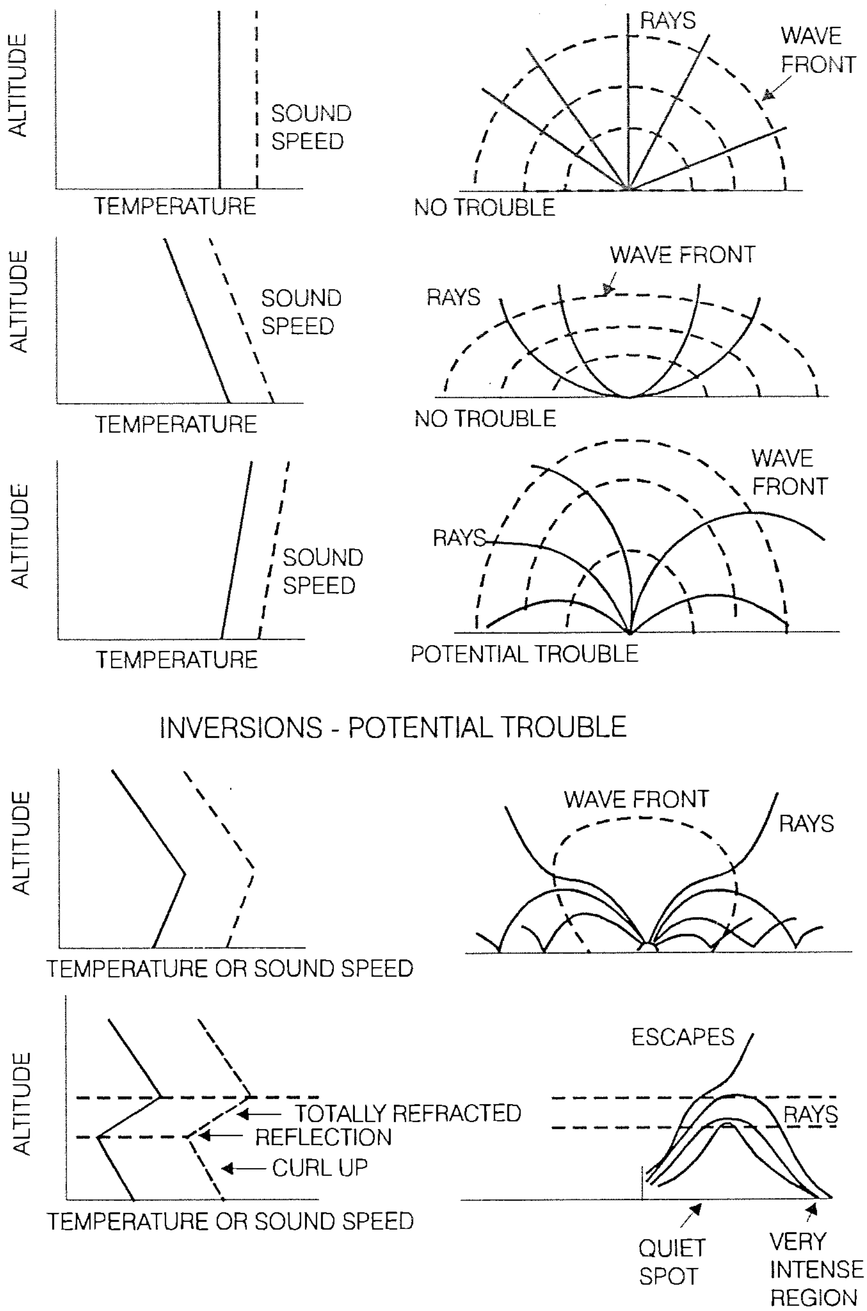

FIGURE 24: EFFECTS OF ALTITUDE TEMPERATURE PROFILES ON AIR BLAST PROPAGATION. (AFTER COOK, 1958)

Blasting Operations

No person shall emit or cause or permit the emission of sound (concussion) or vibration from a blasting operation of a type mentioned in Publication NPC-119-Blasting, such that the peak pressure level or peak particle velocity at a point of reception located in a Quiet Zone or Residential Area, exceeds the applicable limit set out in Publication NPC-119-Blasting.

Publication NPC-119 - Blasting states:

Section 4: Concussion - Cautionary Limit

Subject to Section 5 the peak pressure level limit for concussion resulting from blasting operations in a mine or quarry is 120 dB.

Section 5: **Concussion - Peak Pressure Level Limit.**

If the person in charge of a blasting operation carries out routine monitoring of the peak pressure level, the peak pressure level limit for concussion resulting from blasting operations in a mine or quarry is 128 dB.

As regards recommended measurement procedures, these are presented in *Appendix B* for both blast noise and vibration, being reproduced from the Ontario regulations as cited above. Air blast measurements should be taken at the same locations as recommended for blast vibration monitoring sites.

4.4 Summary of Major Air Blast Control Recommendations

Recommendations for the control of air blast include:

(i) Use Nonel initiation for both surface and in-hole blast initiation;

(ii) Cover Nonel detonators with at least 150 mm of drill cuttings;

(iii) Employ suitable stemming material for all blastholes of either sand or material having slightly larger sizing;

(iv) Prevent overdigging of the front row blastholes;

(v) Follow the recommendations as outlined relative to blast delaying practices and the firing of more than one blast at a time;

(vi) Do not blast under heavy overcast conditions, when there is the likelihood of temperature inversions, or when the winds are blowing in the direction of concern.

5.0 BLAST DESIGN PARAMETERS - FLYROCK CONTROL

To eliminate the problem of flyrock with respect to the informal settlement and other objects of concern, it is proposed that the collars for column explosives charges be designed using suitable scaled depths of burial for the top eight charge diameters of the column. The scaled depth approach takes care of different explosive types, blastholes sizes, etc., which are not readily catered for using other methods. The recommended design should be used for all blasts within 500 m of the areas requiring protection from flyrock. The method will now be reviewed.

The fragmentation of the blast surface, as well as quantity and distance of flyrock throw is controlled by the upper portion of the blasthole column. This can be inferred by imagining what effect the bottom one metre of charge in, say, a 165 mm hole has at the ground surface in, say, a 20 metre deep hole. The answer is very little, if any. In fact if that bottom one metre were detonated by itself, no ground surface disruption would be seen at all. If the second from the bottom one metre of hole is considered, the influence of this portion of charge on surface fragmentation would be a little more, but would still be very small. This procedure can be continued until it is seen that the very top portion of the explosive column will in fact have the most influence on the ground surface fragmentation and movement.

The next question is: How much of the top of the column should be included for design purposes? A column charge of length to diameter ratio of 8:1 acts as if it were a spherical charge. The top portion of the stress wave leaving a column charge also approximates the shape of a sphere. It is, therefore, reasonable to assume that the majority of the surface fragmentation is produced by the top of the column approximating a spherical charge, which would be equivalent to the top eight charge diameters in length. Using this charge, and regular cratering data, the upper portion of the blast can be designed. If the charge length is less than eight charge diameters in length, then all of the charge is the crater charge.

As introduction to this process *Figure 25* presents typical cratering terminology. *Figure 26* illustrates the effect of detonating a spherical charge of explosive of unit weight at different depths in the ground. For deep burials, nothing happens at the ground surface when the charge is detonated. As the charge is brought closer to the surface, doming occurs followed by the formation of a crater. At some depth a maximum volume of material will be fragmented. As the depth is further reduced, crater volume then begins to fall off. For fragmentation purposes, the maximum volume crater would be chosen for blast design whereas for close proximity blasting and flyrock control, the depth where flyrock would be eliminated would give the preferred collar.

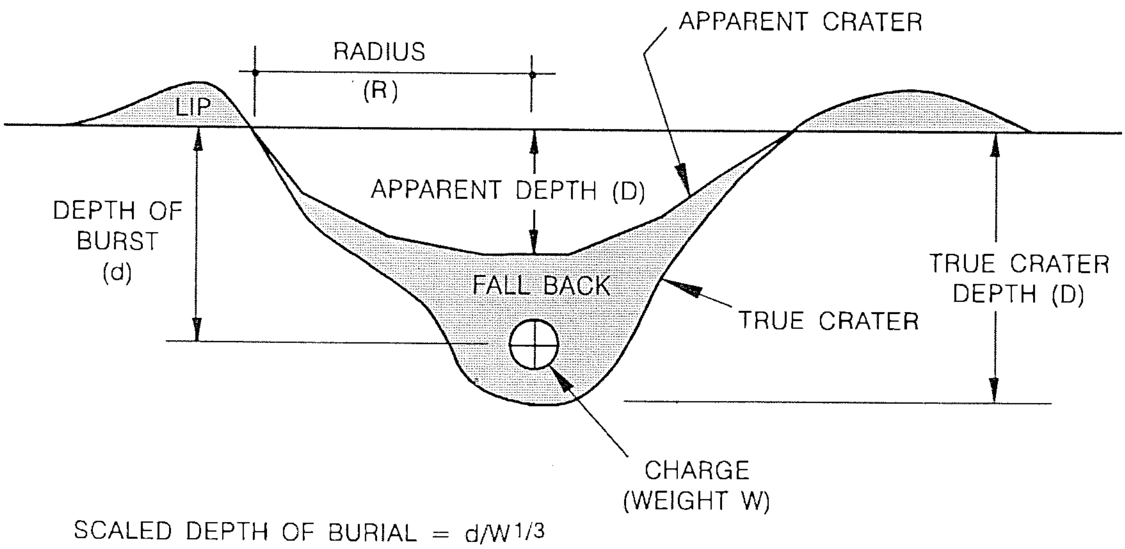

FIGURE 25: STANDARD CRATER TERMINOLOGY.

Figure 27 shows the effects of *Figure 26* in a quantitative and graphical form for spherical charges fired in brittle rock. As can be seen, all of the graphs are plotted against scaled depth of burial. In this way the relative effect of charge depth and size can be catered for and suitable designs can therefore be made. For spherical charges

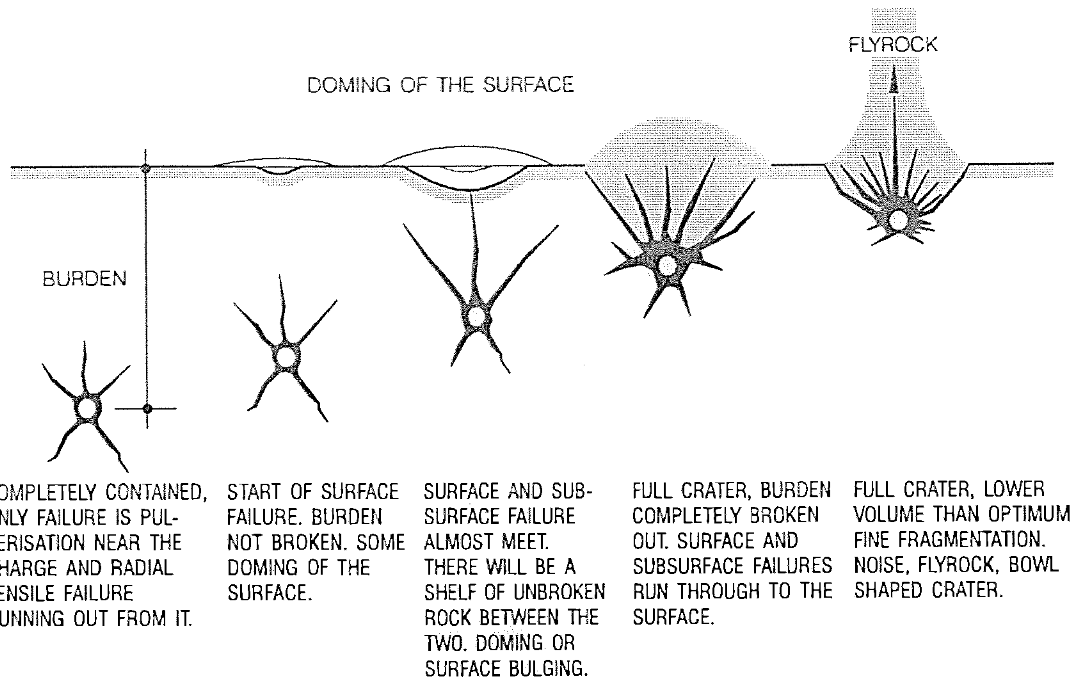

FIGURE 26: SCHEMATIC OF THE EFFECT OF DECREASING THE BURDEN ON CHARGES FIRED IN ROCK.

the scaled depth of burial is given by the actual depth to the centre of gravity of the charge measured in metres divided by the charge weight measured in kilograms raised to the one third power.

The upper three graphs in *Figure 27* present crater data for volume, radius and depth versus scaled depth of burial while the bottom graph presents flyrock travel. It should be noted that although the relationships are represented by single lines in fact the data for these types of test are commonly scattered and thus some results will fall both above and below these lines.

To design blasts to give complete containment of flyrock, *Figure 27* indicates that this occurs for scaled depth of burials of 1,1 $m/kg^{1/3}$ and greater. In view of the known scatter on these types of data, and given the proximity to the village and other very sensitive points, it is recommended that a design scaled depth of burial of 1,6 $m/kg^{1/3}$ be used for the initial cuts. Using this design there will be absolutely no chance of flyrock being of concern from these blasts.

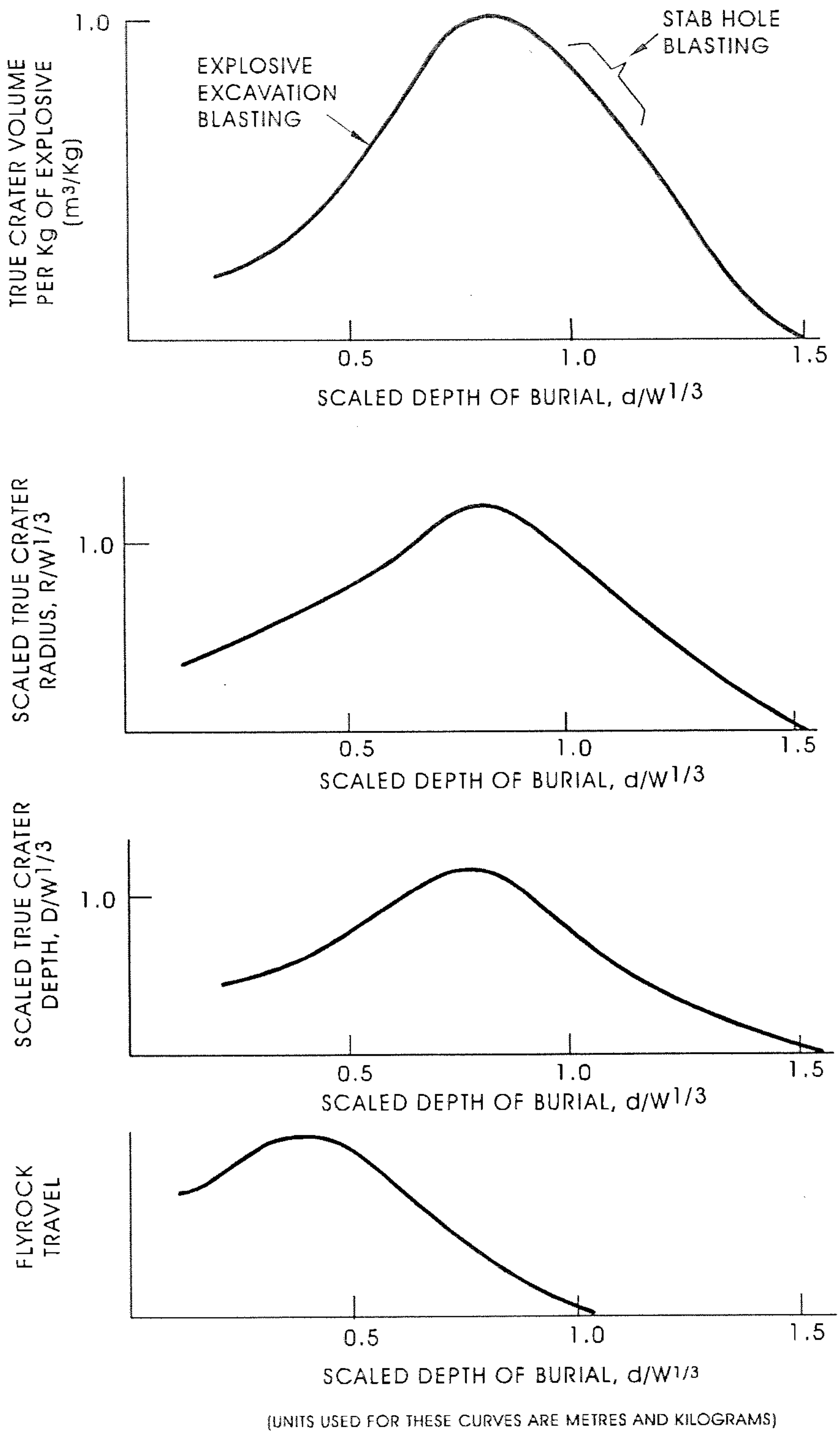

FIGURE 27: CRATERING RESULTS IN BRITTLE ROCK WITH SPHERICAL CHARGES.

The design specifies that initially the minimum blasthole collars for full explosive columns for charges equal to or greater than eight charge diameters in length for the 165 mm diameter blasthole will be no less than 4,00 m when using emulsion and 3,75 m when using AN/FO. This collar is naturally less for columns of explosive less than 1,3 m in length. For example, a 0,5 m explosive column requires a collar of 3,0 m.

5.1 Other Precautions Relative to Flyrock Control

Given the proximity of the mine to the informal settlement, it is strongly recommended that extra special precautions be taken when blasts are shot with respect to the possibility of unauthorised personnel entering the blasting area. It will be essential that:

(i) Suitable guards be placed to prevent access to the blast area via any traffic route;

(ii) A suitable procedure be developed to allow all local residents to be warned of the impending blasts;

(iii) It is suggested that a suitable guard location be selected to observe that no children stray from the settlement into the mining area once it has been cleared of all personnel, but prior to the blast actually being shot;

(iv) The blaster in charge of the shot should be in a position to communicate with all guards and should have a clear view of the workings just prior to shooting the blast;

(v) A suitable all clear procedure should be developed to inform local residents that the blasting operation has been completed.

Finally, appropriate precautions will be required relative to highway traffic when blasting near the Witbank-Pretoria N4 Freeway and the railway line.

6.0 BLAST DESIGN PARAMETERS - DUST AND NOXIOUS FUMES

It is recommended that dust and noxious fumes be controlled as follows:

(i) Use Nonel downlines through the collar stemming material which should be sand, or similar aggregate of only slightly larger sizing;

(ii) Blasts covered with excessive dust and other fines, particularly coal blasts, will require watering prior to shooting;

(iii) Ensure bulk explosives, if either AN/FO or emulsion, be of high quality, correctly fuelled, properly primed with at least a 150 g pentolite primer, and in the case of AN/FO, ensure that it is not used where or in a manner in which it may be subjected to water attack;

(iv) Do not blast when the prevailing wind is blowing towards the direction of concern.

7.0 BLAST DESIGN PARAMETERS - BLAST INITIATION RECOMMENDATIONS

Whenever it is necessary to blast with electric caps near high voltage power lines, special blasting procedures should be used. Because of the large quantity of electric energy carried by these lines careful attention must be given to ensuring that the power line does not present a hazard to electric blasting.

Choice of Detonator and Shot Exploder

AECI produce a high energy (Type 3) detonator for use near high tension lines, electric railways, etc. These detonators require approximately 375 times more energy for initiation than standard detonators. The minimum recommended firing current is 25A requiring the use of a high voltage Schaffler "Series 900" shot exploder in conjunction with properly insulated blasting cables. These units are recommended for consideration in this present situation.

Blasting Near High Voltage Power Lines

The recommended horizontal distances to the blasting caps from power lines of different voltage are as follows,

Power Line Kilovolts	Minimum Horizontal Distance to Blasting Caps (m)
70	20
130	30
220	38
400	58

The recommended procedures for minimising the factors by which a high voltage power line may represent a hazard to electric blasting are as follows:

1. Capacitive and Inductive Coupling

(i) Keep the blasting circuit wires close to the ground.

(ii) Eliminate large closed wire loops by using duplex or twisted pair wire.

(iii) Always try to run the firing line perpendicular to the power line direction.

(iv) Prior to any electric blasting, make pick-up test using a worst-case simulated circuit to determine that the effects of inductive and capacitive coupling are minimal.

Follow this up with periodic rechecks. The procedures for making these tests are described at the end of this section.

2. Stray Current

(i) Keep the blasting circuit isolated from earth by either insulating the splices with electrician's tape, or by keeping them off the ground.

(ii) Prior to any electric blasting make tests to determine the stray currents in the area are minimal. Follow this up with periodic checks. The procedure for making these tests is described at the end of this section.

3. Wires Thrown Over the Power Lines

(i) Do not run the firing line under the power line.

(ii) Anchor the blasting circuit to the ground.

(iii) Employ a positive means to open the firing line immediately after the blast is fired should there be any possibility of the firing line being thrown over the power line. A suitable positive opening means consists of a 250 mm length of detonating cord taped to the firing line which will cut the line if it is thrown in the air by the blast. The detonating cord should be initiated by an electric blasting (E.B.) detonator that is properly connected into the blasting circuit.

4. Electrical Storms

(i) Extend the area of concern for an electrical storm from within 1,6 to 3,2 kilometres of the blast site to within 8 to 16 kilometres.

(ii) If there are any electrical storms within this distance of the blast site, discontinue the loading operation and remove all personnel to a position of safety until the storm has passed over.

(iii) When retreating from the blast site, open all shunts on wired-up E.B. cap circuits making sure that the bare wire ends are insulated from contact with the earth. Leave individually shunted E.B. caps as they are.

(iv) Replace all shunts immediately upon return to the blast site after the storm has passed over.

The pick-up tests to detect excessive capacitive or inductive coupling or stray current should be made using a suitable electrical measuring instrument.

The tests that are to be made prior to any electric blasting should be performed using a simulated blasting circuit and measuring any extraneous electricity introduced into this circuit with the test meter. The tests can be made more severe by using a special circuit layout for each test that provides worst-case conditions. These layouts are as follows:

CAPACITIVE COUPLING

Suspend a 15 to 30 m length of wire between 1,2 and 1,5 metres in the air using wooden stakes. Connect one end of the wire to earth through a one ohm resistor. Connect the test meter across the one ohm resistor.

INDUCTIVE COUPLING

Lay out a rectangular loop of wire with the sides parallel to the power line direction about 30 m long and sides perpendicular to the power line direction about 15,2 m long. Connect a one ohm resistor between the two wire ends from the loop. Connect the test meter across the one ohm resistor.

STRAY CURRENT

Insert two metal stakes about 30 m apart in the ground under the power line such that a line connecting the stakes will be parallel to the power line direction. Wet around the stakes with water to assure good electrical contact. Connect a one ohm resistor to the stakes using a piece of extension wire on the ends of the resistor leads. Connect the test meter across the one ohm resistor.

If the power line is AC, inductive and capacitive coupling and stray current measurements can be made. Set the range selector on the test meter to the highest AC voltage range. If no reading or only an insignificant deflection is obtained, switch the selector to increasingly more sensitive voltage ranges. Continue this until either an appreciable reading is obtained or the most sensitive range is reached.

If the power line is DC, inductive and capacitive effects will not be present; only stray current measurements will be meaningful. Set the range selector on the test meter to the highest DC voltage range. If no reading or only insignificant deflection is obtained, switch the selector to increasingly more sensitive voltage ranges. Continue this until either an appreciable reading is obtained or until the most sensitive range is reached.

It is generally recommended that millivolts should be the maximum permissible reading. If higher readings are obtained do not attempt to blast using electric caps. Field experience has indicated that generally readings of a millivolt, or less, are encountered. It should be realized that proper laying out of the blasting circuit to minimise inductive and capacitive coupling and to prevent the entrance of stray current, should reduce any extraneous electricity to much lower values than indicated by these worst-case condition tests.

Once it has been ascertained that coupled energy and stray current are not excessive, rechecks can be made on either a permanent simulated blasting circuit, if this is possible, or by measuring the current introduced into the actual blasting circuit. When running tests on the actual blasting circuit, use only a Blasting VOM Meter or equivalent meter that is designed for connecting to live blasting circuits.

One other subject that should be discussed concerns procedures to follow after the blast. No responsible operator should leave the area after the blast until he has inspected for any hazardous conditions. If any are found, such as blasting circuit wires thrown over the power line or damaged power line equipment, barricade the area and post a guard. The barricade and guard ,should remain until the power company is notified and can send a crew to repair the damage. These repairs should be made only by experienced and properly equipped personnel.

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APPENDIX A

Letter to Mr. A.C. Johnson, Assistant Mine Manager
Landau Colliery from W.A. Crosby of November 21, 1996.

MREL
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November 21, 1996

Mine Manager
Landau Colliery
P. O. Box 78
CLEWER 1036
Republic of South Africa
Attention: Mr. A. C. Johnson
Assistant Mine Manager

Total: 3 pages

Dear Mr. Johnson:

Re: SCHOONGEZICHT MINI-PIT

It is my opinion that drilling and blasting operations can be performed at the Schoongezicht Mini-Pit both safely and with limited and acceptable environmental impact. This opinion assumes that blast designs conform to the recommendations that will be prepared as a result of the currently ongoing Iso-Seismic Survey being conducted in the Schoongezicht area. The survey results and final recommendations will be presented in the forthcoming report entitled "The Schoongezicht Opencast Mini-Pit, Blasting Within 500 m of Surface Structures" which will be prepared upon completion of the survey.

I consulted with Mr. D. Henderson, Manager, Bauer & Crosby (Pty) Ltd. and, based on preliminary results, the following initial recommendations can be made for use as the basis for the development of budget estimates for the mining operation. To ensure absolutely no environmental problems within the neighbouring communities or at isolated residences, it is recommended that the following guideline target values should be employed when preparing final blast designs.

BLAST VIBRATIONS

The target peak particle velocity is recommended to be 5,0 mm/s with an acceptable measured maximum value being 8,0 mm/s. It is anticipated that this level of vibration can be achieved by employing a minimum scaled distance of 32,0 m/kg$^{1/2}$ (calculated by dividing the distance between the blast and the point of concern measured in metres by the explosives weight per delay measured in kilograms raised to the one half power).

AIR BLAST

The target air blast value is recommended to be 115 dB with an acceptable measured maximum value being 120 dB. The necessary control is expected to be obtained by using a minimum full column collar dimension of 4,0 m for 165 mm diameter blastholes when charged with emulsion. The corresponding control for the 102 mm diameter blastholes would require a minimum collar of 2,5 m. Furthermore, all blast initiation, both on surface and in-hole, should utilise Nonel (ie. shock tube initiation) and any surface detonators should be covered with 150 mm of sand or suitable drill cuttings. Appropriate blasthole stemming material should also be employed, for example 8-10 mm sizing.

Blasting should not be conducted during adverse weather conditions such as low cloud or when the wind is blowing towards the neighbouring communities.

FLY ROCK

Fly rock will initially be controlled by utilising the minimum collar dimensions as already proposed. In addition, given the proximity of the mine to the neighbouring settlements, it is strongly recommended that extra special precautions be taken when blasts are shot with respect to the possibility of unauthorised personnel entering the blasting area. It will be essential that:

(i) Suitable guards be placed to prevent access to the blast area via any traffic route;

(ii) A suitable procedure be developed to allow all neighbouring residents to be warned of the impending blasts;

(iii) It is suggested that a suitable guard location be selected to observe that no children stray from the township into the mining area once it has been cleared of all personnel, but prior to the blast actually being shot;

(iv) The blaster in charge of the shot should be in a position to communicate with all guards and should have a clear view of the workings just prior to shooting the blast;

(v) A suitable all clear procedure should be developed to inform local residents that the blasting operation has been completed.

BLAST MONITORING

All blasts should be monitored for blast vibration and air blast using seismographs containing triaxial geophones.

In conclusion it is recommended that all of the aforementioned environmental factors be continually assessed as mining progresses towards surrounding settlements with a view to ensuring that no unidentified unusual geological conditions exist in the Schoongezicht Mini-Pit area. If such conditions are found, appropriate adjustments to the recommended guidelines must be made.

Yours truly,

W.A. Crosby, Ph.D., P.Eng.
President

cc. M.T. Brett

APPENDIX B

Recommended Procedure for Measurement of Sound

and Vibration Due To Blasting Operations

Reproduced from

Model Municipal Noise Control By-law

Recommended Concussion And Vibration Peak Particle Limits

Final Report

August 1978 Ministry of the Environment

Province of Ontario

Publication NPC-119

Blasting

1. Scope

   This Publication refers to limits on sound (concussion) and vibration due to blasting operations.

2. Technical Definitions

   The technical terms used in the Publication are defined in Publication NPC-101-Technical Definitions.

3. Measurement Procedures

   All measurements of peak pressure level and vibration velocity shall be made in accordance with the "Procedure for Measurement of Sound and Vibration due to Blasting Operations" set out in Publication NPC-103-Procedures, section 5.

4. Concussion - Cautionary Limit

   Subject to section 5 the peak pressure level limit for concussion resulting from blasting operations in a mine or quarry is 120 dB.

5. Concussion - Peak Pressure Level Limit

   If the person in charge of a blasting operation carries out routine monitoring of the peak pressure level, the peak pressure level limit for concussion resulting from blasting operations in a mine or quarry is 128 dB.

6. Vibration - Cautionary Limit

   Subject to section 7, the peak particle velocity limit for vibration resulting from blasting operations in a mine or quarry is 1,00 cm/s.

7. Vibration - Peak Particle Velocity Limit

   If the person in charge of a blasting operation carries out routine monitoring of the vibration the peak particle velocity limit for vibration resulting from blasting operations in a mine or quarry is 1,25 cm/s.

5. Procedure for Measurement of Sound and Vibration Due to Blasting Operations

(1) Application

This procedure applies to the measurement of sound (concussion) and vibration due to blasting operations.

(2) Sound

(a) Instrumentation

(i) Measuring Device

A Peak Pressure Level Detector shall be used.

(ii) Calibrator

An Acoustic Calibrator shall be used.

(iii) Windscreen

A windscreen shall be used in all outdoor measurements.

(b) Measurement Location

The measurement location shall be at a point of reception out-of-doors within 7 m of a building.

(c) Use of Instrumentation

(i) Battery Check

If the measuring device is battery powered, the condition of the battery shall be checked after the device has been allowed to warm up and stabilize and after each measurement has been made. The device shall not be used unless the battery condition is confirmed to be within the range recommended by the manufacturer for proper operation.

(ii) Calibration

The measuring device shall be calibrated after it has been allowed to warm up and stabilize and after each measurement has been made.

(iii) Meter Setting

The measuring device shall be set to read the peak pressure level using linear response and a 'hold' facility, if available.

(d) Instrument Configuration

(i) Reflective Surfaces

The microphone shall be located not less than 1 m above the ground, not less than 1 m from any sound reflective surface and not less than arm's length from the body of the person operating the device. Not more than one person, other than the operator of the meter, shall be within 7 m of the microphone and that person shall be behind the operator of the meter.

(ii) Microphone Orientation

The microphone shall be oriented such that the concussion wave to be measured is incident at an angle recommended by the microphone manufacturer for flattest frequency response in a free field.

(e) Readings

(i) Peak Particle Level

The value of peak pressure level reported shall be given to the nearest decibel.

(ii) Variation in Calibration

A measurement shall not be reported if the meter calibration after the measurement is more than 0.5 dB different from that before the measurement.

(iii) Battery deterioration

A measurement shall not be reported if the battery condition after the measurement is not within the range recommended by the manufacturer for proper operation.

(f) Weather Conditions

(i) Wind

Measurements shall not be reported unless the wind-induced sound pressure level is more than 10 dB below the measured peak pressure level. Reference should be made to Publication NPC-102 -Instrumentation.

(ii) Humidity

Measurements shall not be taken if the relative humidity is above the maximum for which the meter specification is guaranteed by the manufacturer (normally 90%).

(iii) Precipitation

Measurements shall not be taken during precipitation.

(iv) Temperature

Measurements shall not be taken when the air temperature is outside the range for which the meter specification is guaranteed by the manufacturer. (Normally only the lower temperature limit is significant.)

(3) Vibration

(a) Instrumentation

(i) Measuring Device

A Vibration Velocity detector shall be used.

(ii) Calibrator

An electrical reference signal of known voltage and frequency shall be used in the field for calibration of the Vibration Velocity Detector excluding the transducer. A reference vibration source shall be used for laboratory calibration of the complete Vibration Velocity Detector.

(b) Measurement Location

Vibration measurements shall be made at a point of reception inside a building below grade or less than 1 m above grade, preferably on a basement floor close to an outside corner.

(c) Use of Instrumentation

(i) Battery Check

If the measuring device is battery powered, the condition of the battery shall be checked after the device has been allowed to warm up and stabilize and after each measurement has been made. The device shall not be used unless the battery condition is confirmed to be within the range recommended by the manufacturer for proper operation.

(ii) Calibration

Field calibration shall be carried out before and after each measurement. Laboratory calibration of the complete Vibration Velocity Detector as used in the field, including the transducer, shall be carried out not less than once per calendar year and the results certified.

(d) Instrumentation Configuration

(i) Mounting

The transducer shall be affixed to a part of the structure so as to prevent movement of the transducer relative to the structure. The preferred structural element is the basement floor as indicated in clause (b).

(ii) Transducer Orientation

If three vector components of vibration velocity are recorded individually, it is preferable to orient the transducer such that the three axes of measurement are (a) vertical, (b) radial (along a horizontal line joining the location of the blast to the location of measurement) and, (c) transverse (along a horizontal line at right angles to the line joining the location of the blast to the location of measurement).

(e) Readings

(i) Peak Particle Velocity

The peak particle velocity in cm/s shall be reported.

(ii) Variation in Calibration

A measurement shall not be reported if calibration after the measurement is more than 5% different from that before the measurement.

(iii) Battery Deterioration

A measurement shall not be reported if the battery condition after the measurement is not within the range recommended by the manufacturer for proper operation.

(4) Documentation

The following represents the minimum information which shall be contained in a report of an investigation where the above procedure was used.

(a) Description of Area

(i) Location and description of the blasting operation.

(ii) Dimensioned sketch including photographs, if possible, of the location of the blasting operation, the nearest premises and the measurement location.

(iii) Description of the measurement location.

(iv) Physical and topographical description of the ground surface.

(v) Meteorological conditions at the time of the investigation, including approximate wind speed in km/h, wind direction, air temperature in degrees Celsius, approximate relative humidity, degree of cloud cover and whether or not a condition of thermal inversion prevailed.

(b) Instrumentation

All the equipment used for making sound and vibration measurements shall be listed, including:

(i) Type, model and serial number of Peak Pressure Level Detector;

(ii) Type, model and serial number of microphone;

(iii) Type, model and serial number of Acoustic Calibrator;

(iv) Windscreen;

(v) Extension cables and additional amplifiers, if used;

(vi) Type, Model and serial number of Vibration Velocity Detector;

(vii) Type, Model and serial number of transducers;

(viii) Type, model and serial number of vibration calibrator.

(c) Sound and Vibration Data

The measurement details shall be described, including:

(i) The location where measurements were taken, the time period involved and the orientation of instrumentation using a sketch, if necessary;

(ii) Details of all calculations;

(iii) The peak pressure level in dB and/or peak particle velocity in cm/s;

(iv) Comparison with applicable peak pressure limits and/or peak particle velocity limits.

APPENDIX C

Iso-Seismic Survey At Schoongezicht Opencast Mini-Pit

Solely Prepared as an Appendix for the Report

The Schoongezicht Opencast Mini-Pit

(Blasting Within 500m Of Surface Structures)

Table of Contents

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ISO-SEISMIC SURVEY AT SCHOONGEZICHT OPENCAST MINI-PIT

INTRODUCTION

Landau Colliery is planning to operate an opencast mini-pit at Schoongezicht commencing early in 1997. The mine is undertaking an environmental impact study in the area to determine the effects mining operations will have in the vicinity. The Witbank-Pretoria N4 Freeway and pipelines border the property on the north side as well as the Schoongezicht Township and Lynneville Village which are on the northeast side. A railway line borders the property on the southeast side. One part of the study involved determining the probable vibration levels experienced by the properties and structures bordering the mine. This was achieved by undertaking an Iso-Seismic Survey.

PURPOSE

The Iso-Seismic Survey has been carried out for three reasons: firstly to determine the vibration levels expected due to blasting operations using predetermined explosives weights; secondly the Iso-Seismic Survey allows identification of areas where blast vibrations have not uniformly attenuated, or indeed areas where vibrations would not be expected to be of sufficient magnitude to be detectable; and thirdly the survey is an exercise in public relations. It allows the mine to demonstrate to the local populace that vibration levels will be kept under control and that considerable effort is being spent to ensure this end is achieved.

METHODOLOGY

The Iso-Seismic Survey Concept

The concept behind the use of the Iso-Seismic Survey is to shoot a single test blast and to monitor the resulting vibration at numerous locations as a result of that single event. This approach allows the geological effects on the vibration to be automatically evaluated. A fixed amount of energy is released at the blast site. The energy dissipates through the ground, being enhanced or attenuated by the geological conditions, and the numerous blast monitors assess the amount of energy as experienced at each of the separate monitoring points. The beauty of the system is that it ensures a fixed energy release for all test results and the energy must travel through the specific geology between the blast and the monitoring sites. The disadvantage is the requirement that numerous blast monitoring units must be available to perform the survey.

Unfortunately there is only one suitable system available to conduct these surveys in the world at the present time and this system was not available at an appropriate time to conduct the Schoongezicht survey. Accordingly a modified concept was developed to provide a first order representation of the basic Iso-Seismic Survey system. A total of 11 Micro-Seismographs were obtained in order to maximise the amount of data obtained per blast. The concept was then to shoot individual shots as close together as possible so that the blast vibrations that were generated always passed through similar geological conditions. One problem is that it is not possible to produce equal energy release in each and every shot in any meaningful way because of variation in explosive performance, explosive charge weight, varying depths of burial, material type variations, etc. These problems are partially overcome by using a control vibration station common to all of the test blasts. Thus by knowing the distance between the test shot and the monitoring point, it is possible to estimate the relative amount of energy produced by each firing. In this way each blast can be correlated to the others such that a simulation of an Iso-Seismic Survey can be generated. This approach certainly does not produce a rigorous result but it can readily provide a first order estimate.

Another problem with multiple blasts and only a limited number of seismographs, should too low an explosive charge weight be used for the tests, is that many of the monitoring locations may not record any vibration at all. It is therefore necessary to conduct the tests with charge weights of somewhat larger size than would normally be used for a true Iso-Seismic Survey. This is not a problem with respect to potential damage to neighbouring buildings because the test shots are single events, and as such, produce no more than half the vibration level that a corresponding multiple-period shot of the same charge weight per delay. It does mean though, that the test results describe vibration levels higher than would normally be expected so that scaling is required when modifying the results for use in the final blast design.

A modified Iso-Seismic Survey was therefore conducted for the Schoongezicht area employing a total of ten individual test shots. These were fired at four blast test site areas to investigate the geological effects on blast vibration around the north and eastern part of the mine.

Blast Design

The Iso-Seismic Survey can be used to predict the expected values of vibration due to the mining operations in the Schoongezicht Mini-Pit. To ensure representative results, it was considered necessary to imitate expected conditions during production as far as possible in the tests. Hence, as noted above, similar to slightly larger charge weights per hole were chosen, hole diameters of 165 mm diameter were used (although in some cases existing exploration holes were employed) and these were drilled to the expected full depth. The hole depths were drilled to the top of coal although hole collapse before charging was a problem. A total of eight holes were drilled at two selected locations. *Figure C1* presents a plan view of the appropriate section of the Schoongezicht Mini-Pit illustrating four test blast locations, including two which employed previously drilled exploration holes. Each blast was a single blasthole. The blasthole coordinates for each site are presented in *Table C1*.

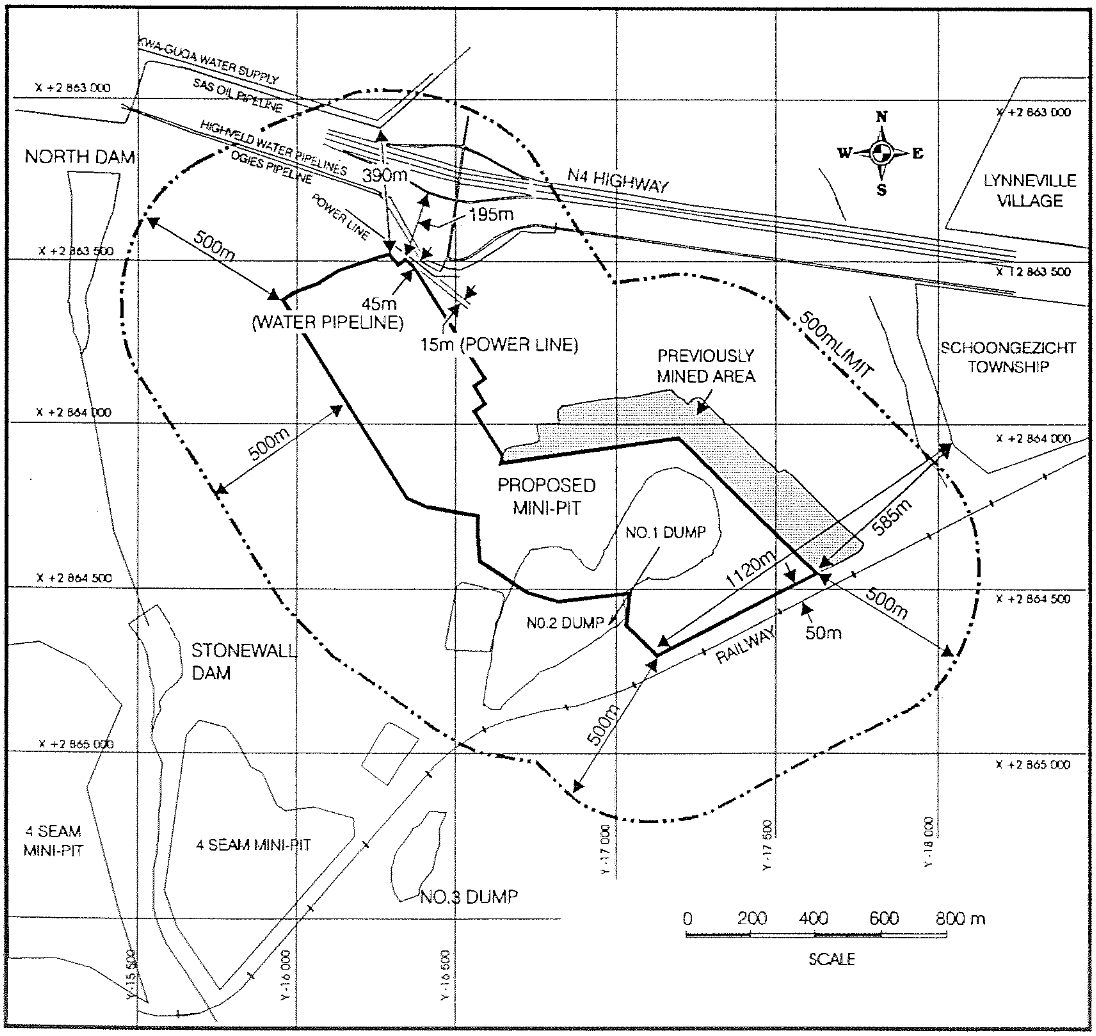

FIGURE C1: SCHOONGEZICHT MINE PLAN SHOWING THE TEST BLAST LOCATIONS AND THE DISTANCES TO THE CLOSEST STRUCTURES AND OTHER SIGNIFICANT OBJECTS.

Blast Site Location	Blast Number	Blasthole Y Coordinate	Blasthole X Coordinate
1	1	-17438	2864370
	2	-17456	2864371
	3	-17449	2864381
	4	-17437	2864382
2	1	-17564	2864486
	2	-17555	2864477
	3	-17545	2864483
	4	-17557	2864496
3	1	-16603	2864076
4	1	-16765	2864164

TABLE C1: BLASTHOLE COORDINATES FOR ALL 10 TEST BLASTS.

The basic plan was to shoot blasts containing a single charge weight similar to, or slightly larger than, the maximum charge weight expected to be used during production. It is known that in a blast where holes are fired individually, but within a few milliseconds of each other, an additive effect occurs such that the vibration level caused is approximately equivalent to double what would be expected from a single hole containing the same explosives weight fired on its own. Single hole test blasts were planned to be fired in these tests to ensure that the vibration and air overpressure levels experienced and flyrock would not cause damage or be excessive.

Blastholes were of varying depth, depending on the hole collapse between when they were drilled and when they were charged. All blastholes were charged with the collar not being less than 3,5 m.

Charging Method

BME HEF 100 emulsion was used in all holes primed using 400 g Pentolite boosters and initiated with Nonel shock tube. Each blasthole, constituting one blast each, was fired using an electric detonator.

Equipment Used

A total of 10 seismographs were used in the tests, these being all Micro-Seismographs. However only eight of these were available for any one test firing.

The Micro-Seismographs are versatile, being able to record levels of vibration of more than 100 mm/s. They are also capable of monitoring sound, having a built in microphone. The units are battery powered and are capable of recording up to twenty events each. As the units were moved between each blast, they were downloaded before every move, and therefore in this case the memory capacity of greater than one event was not required. The Micro-Seismograph units were set to trigger if vibration levels of 0,38 mm/s were exceeded. The vibration trigger levels are extremely low and any events missed would be of a negligible level. The air overpressure trigger levels were not used as the survey was primarily to determine vibration levels and it was necessary to avoid the memory of the unit being filled by false events generated by extraneous noises of which there were many in the blast area at the time of testing. As a result no units were triggered due to air overpressure, though air overpressure was recorded on several of the Micro-Seismographs.

Location of Units

A number of areas of concern were identified and a monitor layout pattern was designed to cover these locations. The areas identified were basically the north side of the mine and the railway line to the east and south. The majority of the units were located within or in front of the nearby township. The units located in the veld in front of the township were placed to cover the area next to numbered stakes positioned the previous day, these stakes being surveyed in by mine personnel. The grid pattern was extended to other areas as required. The monitoring locations are shown in *Figure C2*. It should be noted that some difficulty was experienced maintaining the numbered

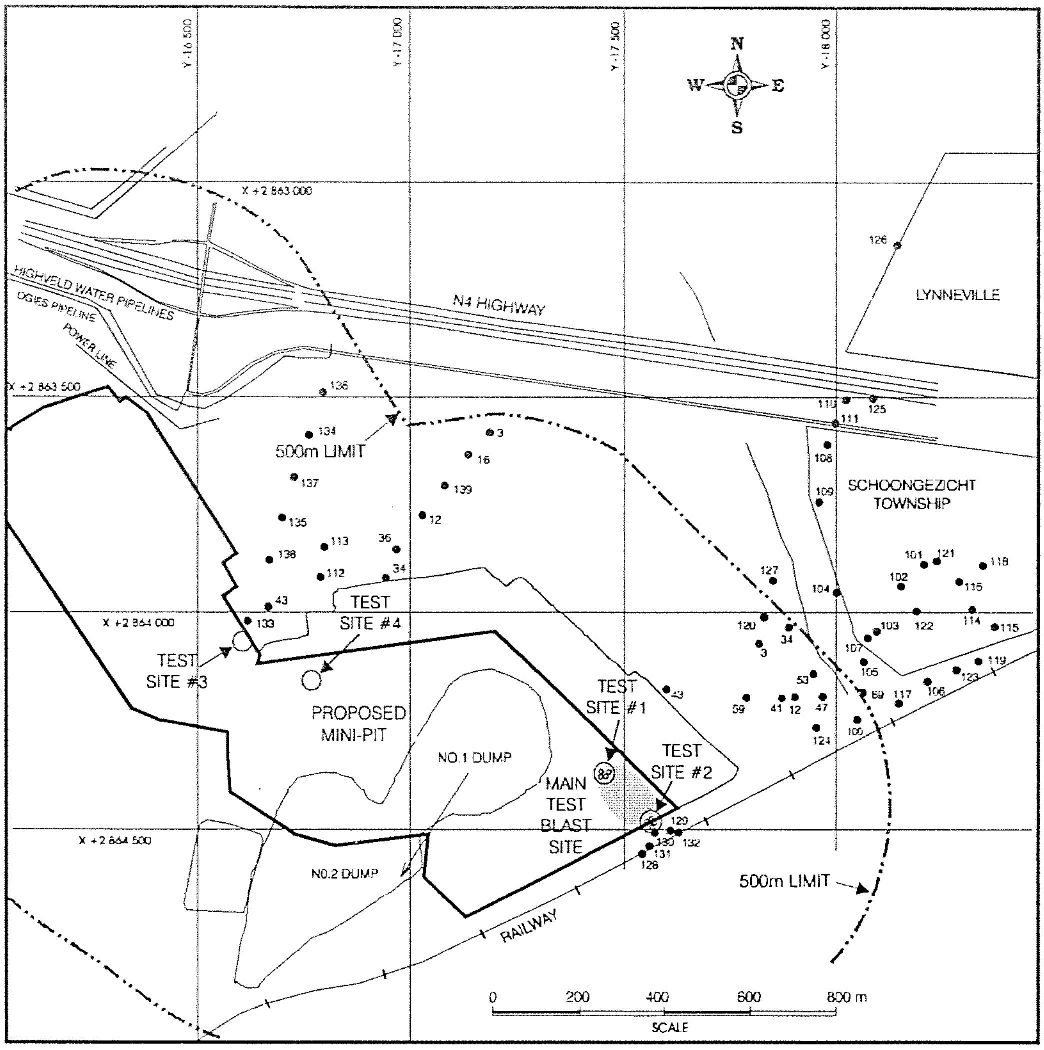

FIGURE C2: TEST BLAST AND TEST MONITOR LOCATIONS.

stakes in the field as many of them went missing after they had been originally placed, sometimes before surveying and sometimes after. Accordingly a number of additional monitoring points had to be introduced, as required, on the day of the blasts.

RESULTS AND DISCUSSIONS

The results obtained have been broken down into areas of concern to allow specific locations to be focused on. All the results given are peak particle vibration levels which equate to half the free surface vibration levels recorded by the monitors. The vibration results are presented in *Tables C2* through *C11*.

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17438	2864370	250	-	-	-	-	-
Bridge	100	-18034	2864252	250	607,6	38,4	3,10	1,55	135
4671	101	-18189	2863900	250	885,9	56,0	<0,76	<0,38	-
4670	102	-18134	2863949	250	813,4	51,4	<0,76	<0,38	-
4533	103	-18079	2864052	250	715,5	45,3	2,00	1,00	119
4669	51	-17953	2864003	250	632,4	40,0	4,10	2,05	116
4672	34	-17889	2864038	250	560,0	35,4	2,80	1,40	117
4530	104	-17988	2863964	250	683,6	43,2	2,80	1,40	122
4532	3	-17809	2864081	250	470,3	29,7	2,50	1,25	121

TABLE C2: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 1, FIRED ON NOVEMBER 20, 1996 AT 10:12 (TEST BLAST SITE #1).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17456	2864371	306	-	-	-	-	-
Bridge	100	-18034	2864252	306	590,1	33,7	4,80	2,40	124
4670	105	-18050	2864122	306	644,1	36,8	2,54	1,27	112
4671	106	-18198	2864167	306	769,5	44,0	<0,76	<0,38	-
4672	43	-17619	2864192	306	242,1	13,8	12,50	6,25	114
4530	59	-17785	2864206	306	368,1	21,0	11,70	5,85	121
4532	41	-17862	2864204	306	439,0	25,1	4,80	2,40	119
4533	107	-18059	2864067	306	675,3	38,6	2,80	1,40	117
4669	47	-17950	2864207	306	520,5	29,8	6,10	2,05	116

TABLE C3: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 2, FIRED ON NOVEMBER 20, 1996 AT 11:09 (TEST BLAST SITE #1).

At present no maximum vibration or air overpressure levels are legally stipulated in South Africa. However, the Witbank Inspectorate of Mines have recently specified maximum allowable limits of 120 dB and 25 mm/s for a mini-pit in the Clewer area. The 25 mm/s applies to vibration with a dominant frequency of greater than 10 Hz, in the event of the dominant frequency being less than 10 Hz, the maximum limit would be 12,5 mm/s. *Note: no specification was made to these levels being free surface values or in peak particle vibrations.* The recommendation as regards maximum

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17449	2864381	220	-	-	-	-	-
Bridge	100	-18034	2864252	220	599,1	40,4	2,03	1,02	114
4533	108	-17966	2863631	220	910,9	61,4	<0,76	<0,38	-
4671	109	-17945	2863757	220	797,1	53,7	<0,76	<0,38	-
4672	110	-18007	2863528	220	1019,3	68,7	<0,76	<0,38	-
4530	111	-17982	2863580	220	961,5	64,8	<0,76	<0,38	-
4532	112	-16786	2863928	220	803,0	54,1	1,80	0,90	117
4669	113	-16797	2863861	220	834,0	56,2	2,50	1,25	110

TABLE C4: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 3, FIRED ON NOVEMBER 20, 1996 AT 12:49 (TEST BLAST SITE #1).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17437	2864382	220	-	-	-	-	-
Bridge	100	-18034	2864252	220	611,0	41,2	2,03	1,02	114
4533	114	-18298	2864002	220	941,1	63,5	<0,76	<0,38	-
4669	115	-18349	2864041	220	973,7	65,6	<0,76	<0,38	-
4530	116	-18268	2863938	220	942,2	63,5	<0,76	<0,38	-
4671	117	-18131	2864217	220	713,3	48,1	2,70	1,35	117
4672	118	-18322	2863902	220	1006,8	67,9	<0,76	<0,38	-
4532	119	-18312	2864119	220	913,7	61,6	<0,76	<0,38	-
4670	120	-17819	2864020	220	526,3	35,5	2,70	1,35	112

TABLE C5: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 4, FIRED ON NOVEMBER 20, 1996 AT 13:44 (TEST BLAST SITE #1).

vibration limits near the Schoongezicht Mini-Pit will be noted to be only 5 mm/s and so the levels experienced in such areas as the neighbouring township to the northeast of the pit will be considerably lower than those accepted at other mines in the area.

Each test blast was essentially monitored in one area directly away from the shot. Therefore each blast result describes the geology in that particular direction.

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17564	2864486	114	-	-	-	-	-
Bridge	100	-18034	2864252	114	525,0	49,2	1,52	0,76	135
4669	121	-18217	2863891	114	883,4	82,7	<0,76	<0,38	-
4742	122	-18171	2864007	114	773,2	72,4	1,02	0,51	110
4743	103	-18079	2864052	114	673,5	63,1	1,78	0,89	112
4670	20	-17965	2864119	114	543,6	50,9	2,80	1,40	110
4304	53	-17934	2864150	114	499,8	46,8	2,80	1,40	110
4052	12	-17891	2864199	114	435,1	40,7	2,04	1,02	112

TABLE C6: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 1, FIRED ON DECEMBER 18, 1996 AT 10:42 (TEST BLAST SITE #2).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17555	2864477	203	-	-	-	-	-
Bridge	100	-18034	2864252	203	529,2	37,1	2,54	1,27	116
4669	117	-18131	2864217	203	632,0	44,4	1,27	0,63	112
4742	122	-18171	2864007	203	774,8	54,4	1,27	0,63	110
4670	123	-18261	2864140	203	782,3	54,9	1,02	0,51	112
4743	115	-18349	2864041	203	905,8	63,6	<0,76	<0,38	-
4304	69	-18036	2864194	203	558,1	39,2	4,06	2,03	114
4052	124	-17939	2864272	203	435,3	30,6	2,54	1,27	118

TABLE C7: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 2, FIRED ON DECEMBER 18, 1996 AT 11:14 (TEST BLAST SITE #2).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17545	2864483	220	-	-	-	-	-
Bridge	100	-18034	2864252	220	540,8	36,5	1,52	0,76	117
4669	125	-18074	2863525	220	1094,4	73,8	1,02	0,51	112
4742	122	-18171	2864007	220	786,4	53,0	1,27	0,64	114
4743	126	-18128	2863719	220	961,0	64,8	<0,76	<0,38	-
4670	110	-18007	2863528	220	1060,9	71,5	1,02	0,51	112
4304	127	-17839	2863936	220	621,0	41,9	1,02	0,51	112
4052	120	-17819	2864020	220	538,0	36,3	2,54	1,27	116

TABLE C8: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 3, FIRED ON DECEMBER 18, 1996 AT 11:40 (TEST BLAST SITE #2).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-17557	2864496	144	-	-	-	-	-
Bridge	100	-18034	2864252	144	535,8	44,6	1,50	0,75	-
4669	128	-17535	2864554	144	60,5	5,0	42,90	21,45	140
4670	129	-17602	2864503	144	49,2	4,1	57,90	28,95	140
4742	130	-17564	2864507	144	12,0	1,0	69,10	34,55	140
4743	131	-17550	2864539	144	49,2	4,0	54,00	27,50	139
4304	132	-17621	2864509	144	60,5	5,0	41,70	20,85	139

TABLE C9: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 4, FIRED ON DECEMBER 19, 1996 AT 12:35 (TEST BLAST SITE #2).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-16603	2864076	300	-	-	-	-	-
2285	43	-16667	2863995	300	103,2	6,0	25,70	12,85	126
4743	133	-16619	2864029	300	50,0	2,9	86,00	43,00	130
4669	134	-16763	2863601	300	500,0	28,9	3,05	1,52	114
4670	135	-16698	2863791	300	300,0	17,3	8,40	4,20	118
4742	136	-16795	2863505	300	600,0	34,6	2,50	1,25	112
4304	137	-16730	2863697	300	400,0	23,1	4,80	2,40	110
4052	138	-16667	2863887	300	200,0	11,5	16,30	8,15	124

TABLE C10: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 1, FIRED ON DECEMBER 19, 1996 AT 11:34 (TEST BLAST SITE #3).

Monitor Number	Point Number	Y Coordinate	X Coordinate	Charge Weight (kg)	Distance (m)	Scaled Distance ($m/kg^{1/2}$)	Peak Free Surface Velocity (mm/s)	Peak Particle Velocity (mm/s)	Air Blast (dB)
Blasthole Location		-16765	2864164	150	-	-	-	-	-
4052	16	-17133	2863647	150	634,6	51,8	<0,76	<0,38	-
4669	34	-16943	2863929	150	294,8	24,1	2,80	1,40	116
4670	12	-17029	2863787	150	460,2	37,6	2,80	1,40	110
4743	3	-17182	2863595	150	705,4	57,6	2,03	1,01	106
2285	43	-16667	2863995	150	195,4	16,0	5,30	2,65	117
4304	36	-16966	2863860	150	364,4	29,8	2,80	1,40	114
4742	139	-17081	2863717	150	547,4	44,7	2,80	1,40	116

TABLE C11: BLAST VIBRATION PEAK PARTICLE VELOCITY AND AIR BLAST RESULTS FOR TEST BLAST # 1, FIRED ON DECEMBER 19, 1996 AT 12:01 (TEST BLAST SITE #4).

Accordingly the data from each shot have been plotted separately so that they can be used individually as required. *Figures C3* through *C12* present peak particle velocity versus scale distance graphs which are suitable for use in blast design. Superimposed on the graphs is an upper limit line for all of the appropriate single event test data. An estimated upper limit line for multi-period blasts is also included, the estimate being double the single event level. Finally the MREL upper limit line has been added so that a comparison can be made with data supplied in Dr. Crosby's report entitled "The Schoongezicht Opencast Mini-Pit - Blasting Within 500 m Of Surface Structures" of January 1997. Care should be taken that individual designs use the correct graph corresponding to geology through which blast vibrations will propagate to the particular point of concern. Also it must be remembered that these graphs are for single hole events. Multi-period blasts can be expected to produce approximately twice the single event level of vibration, as shown by the estimated upper limit line for multi-period blasts. Finally it will be noted that the anticipated multi-period blast vibration, as calculated for some shots, is very similar to the MREL upper limit line. Also all of the data from every blast essentially follows the same slope as the equation which describes the MREL upper limit line itself.

In order to prepare an estimate of the shape of the blast vibration around each blast site, it is first necessary to normalise the vibration data. This is done using the common blast monitoring site used for the first two sets of blasts, in this case Monitoring Site "Bridge". One blast is taken as the standard and the other blasts are compared with it. In this case the first blast site was normalised to the third and fourth blast shot weight of 220 kg while the second blast site was normalised to the third blast fired on December 18th which also had a shot weight of 220 kg. The normalised data are presented in *Tables C12* and *C13*.

Figure C13 illustrates the shape of the blast vibration around the single event initiation blasts at Test Sites #1 and #2, these viewed from the northeast of the mini-pit. It had

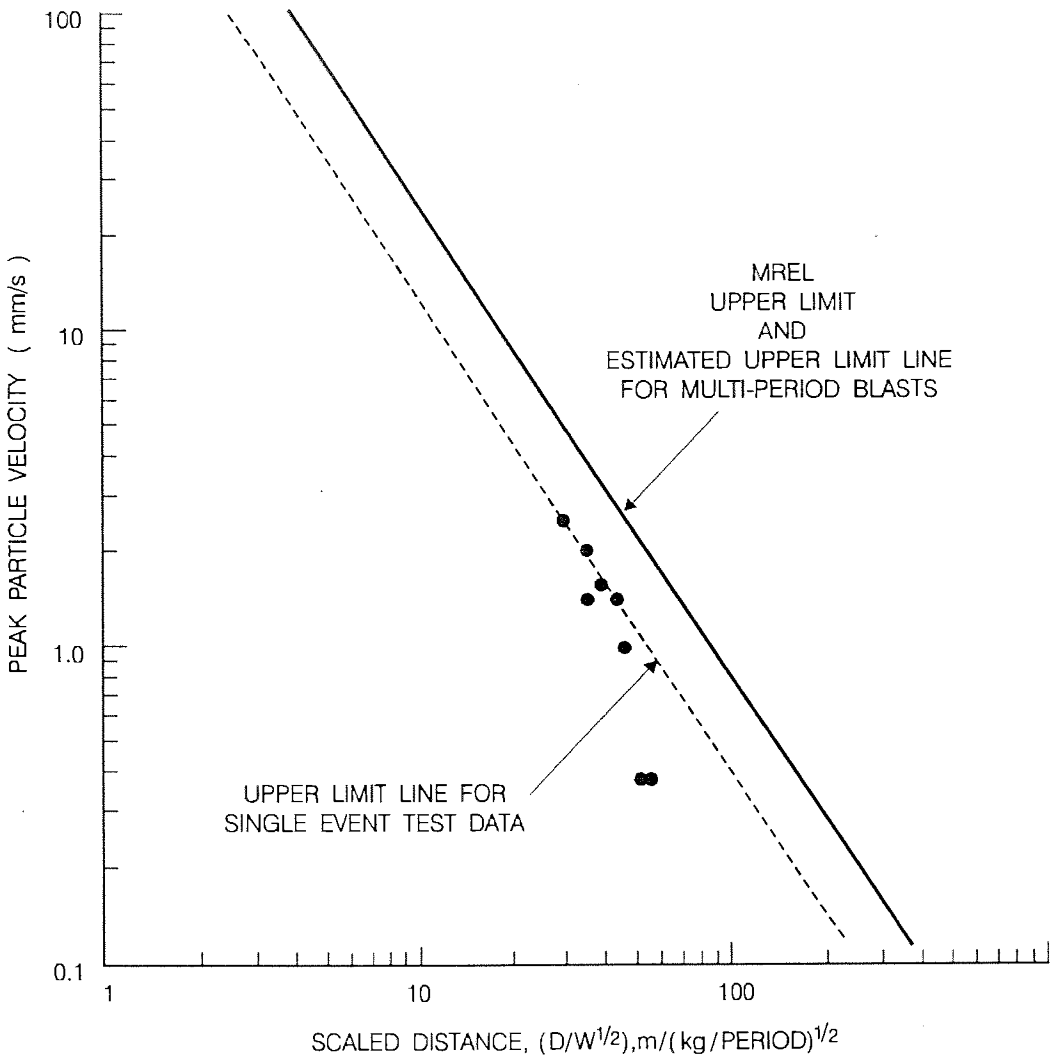

FIGURE C3: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FIRST BLAST SHOT ON NOVEMBER 20, 1996 AT TEST SITE #1.

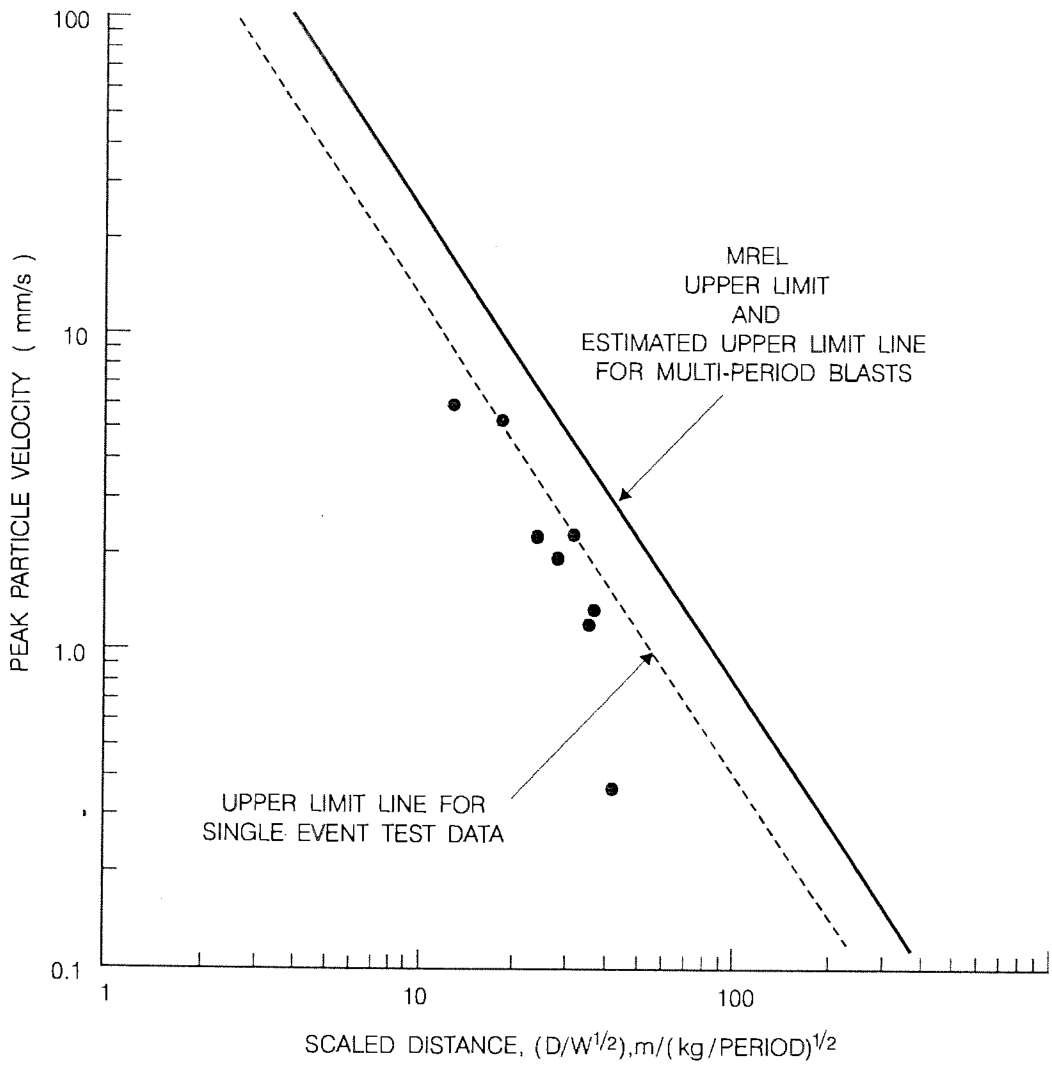

FIGURE C4: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE SECOND BLAST SHOT ON NOVEMBER 20, 1996 AT TEST SITE #1.

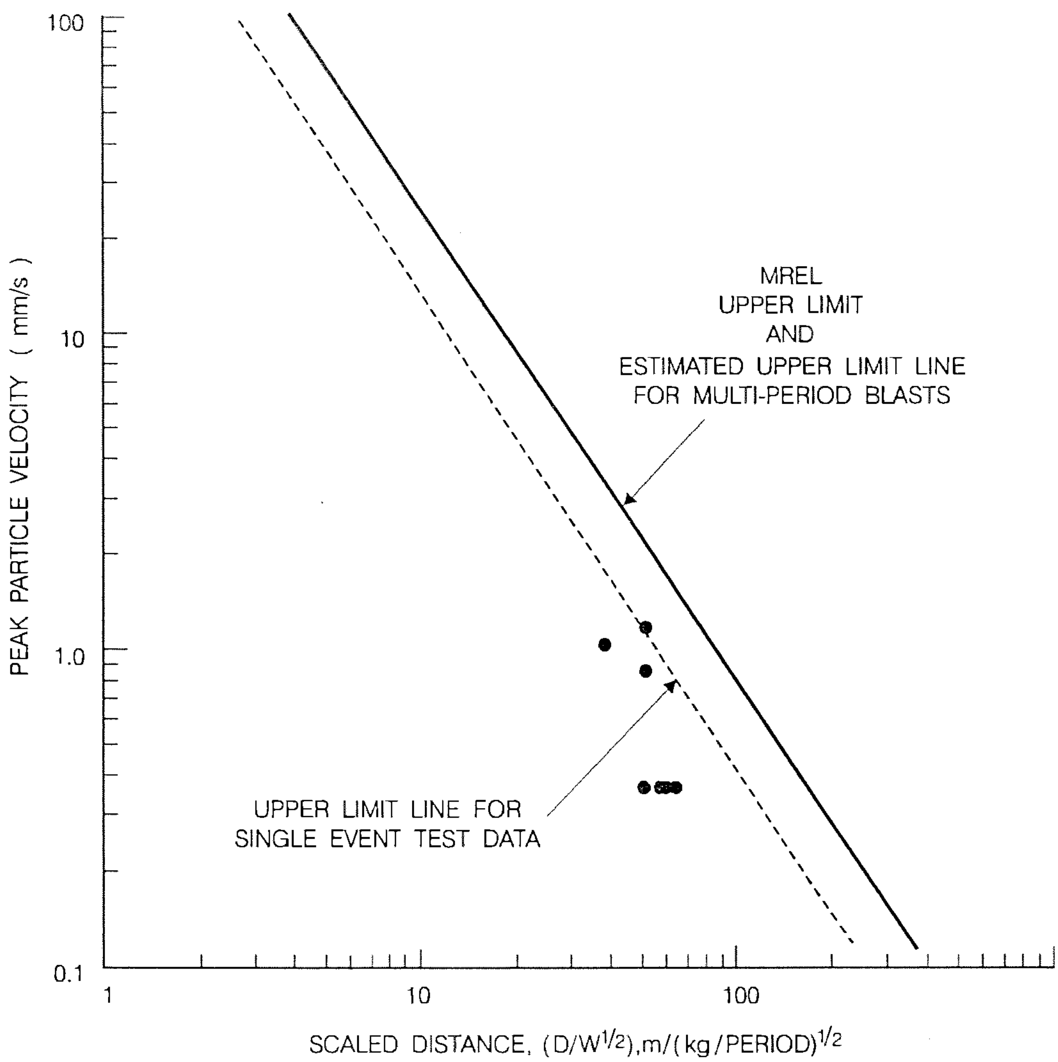

FIGURE C5: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE THIRD BLAST SHOT ON NOVEMBER 20, 1996 AT TEST SITE #1.

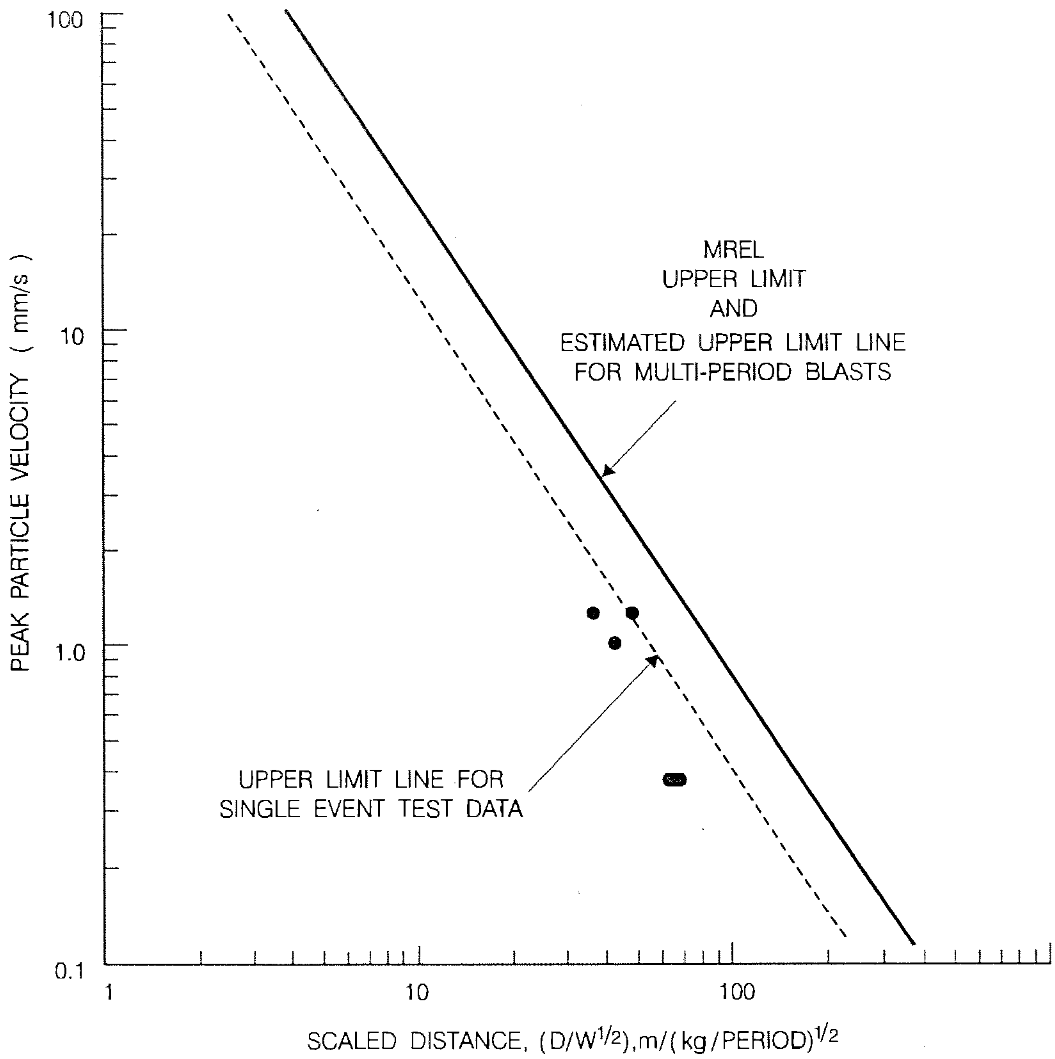

FIGURE C6: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FOURTH BLAST SHOT ON NOVEMBER 20, 1996 AT TEST SITE #1.

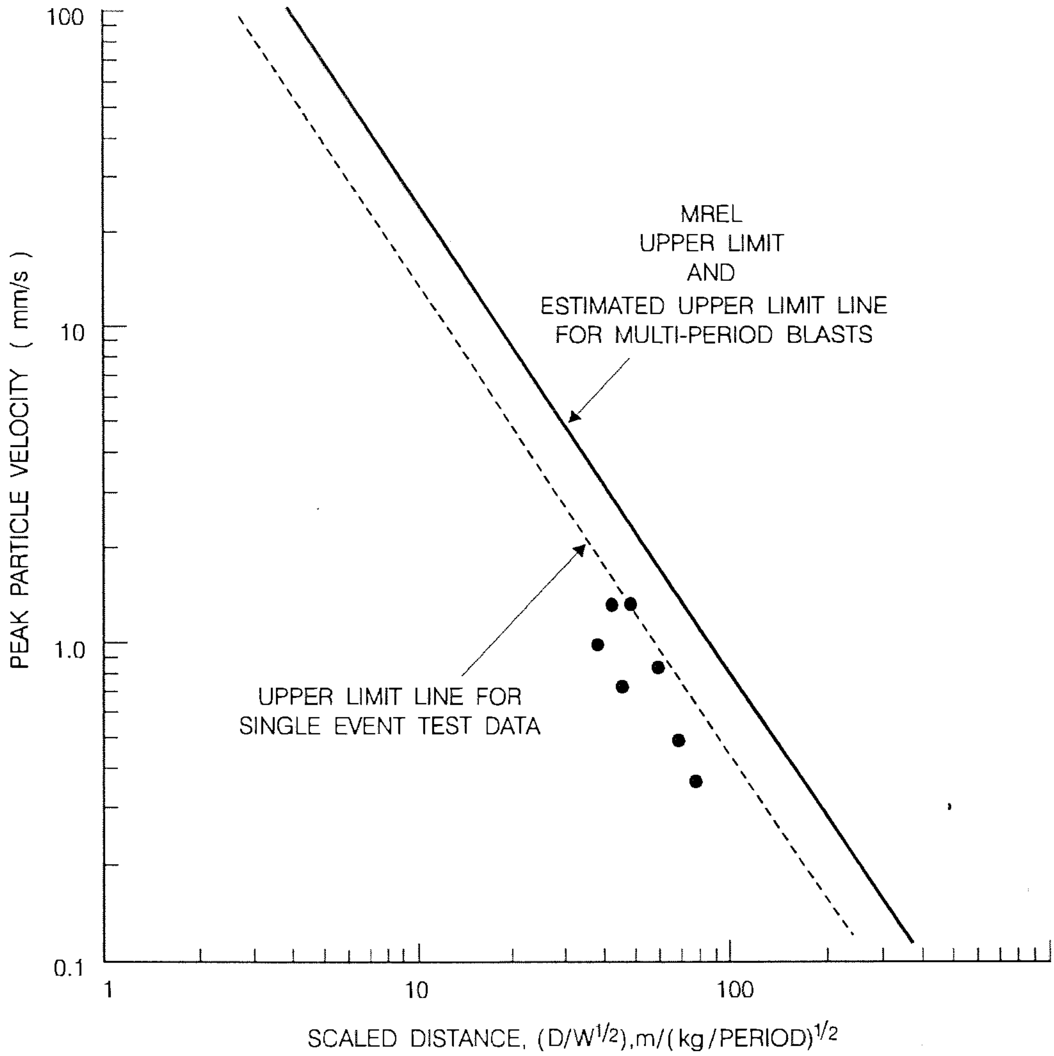

FIGURE C7: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FIRST BLAST SHOT ON DECEMBER 18, 1996 AT TEST SITE #2.

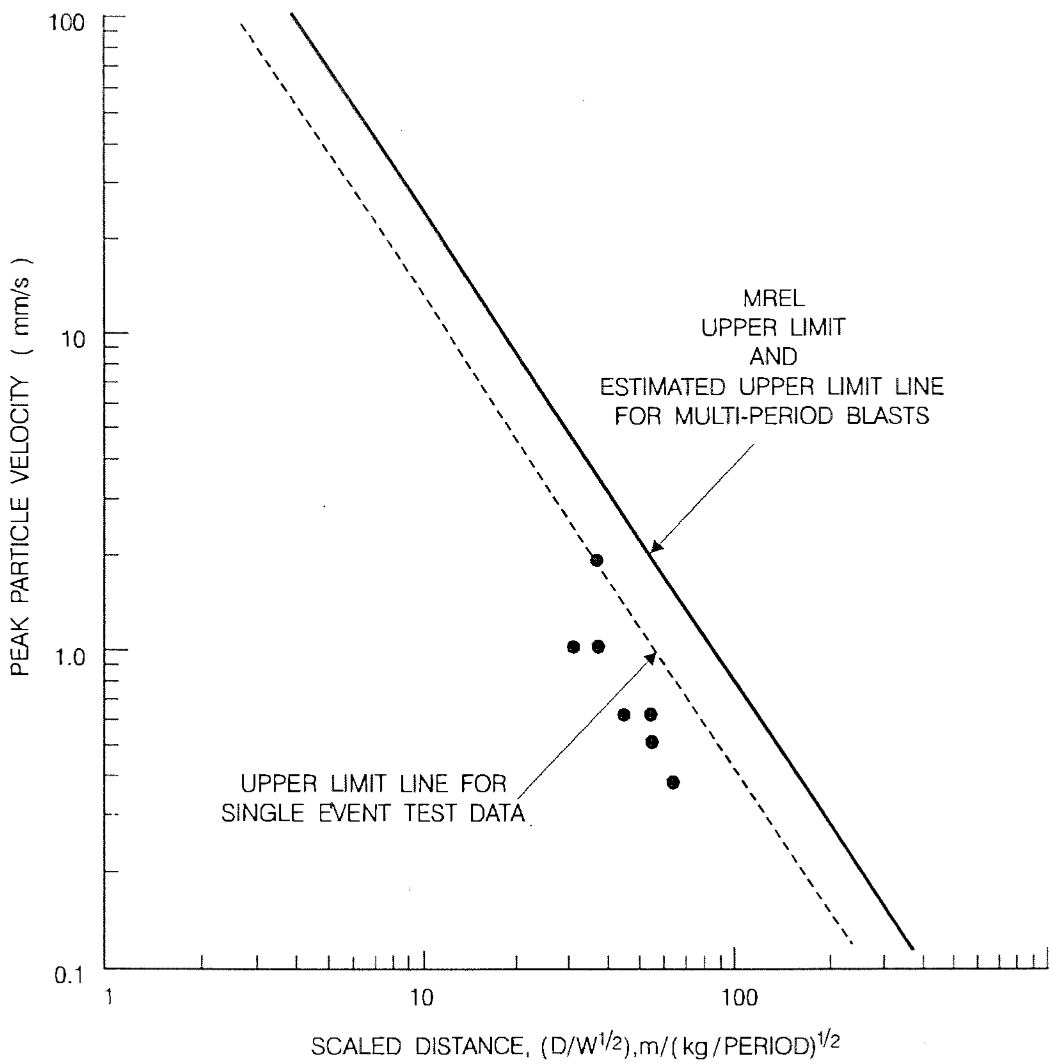

FIGURE C8: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE SECOND BLAST SHOT ON DECEMBER 18, 1996 AT TEST SITE #2.

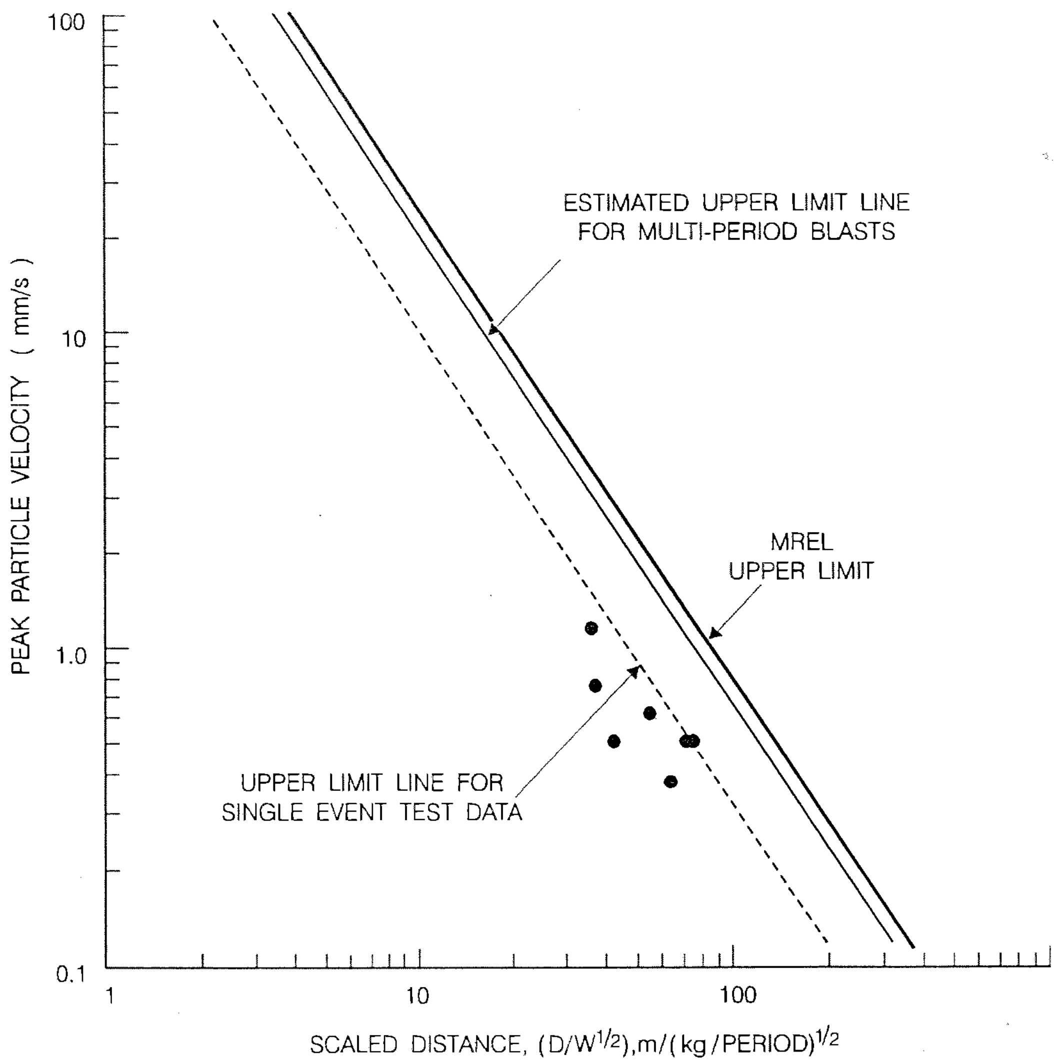

FIGURE C9: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE THIRD BLAST SHOT ON DECEMBER 18, 1996 AT TEST SITE #2.

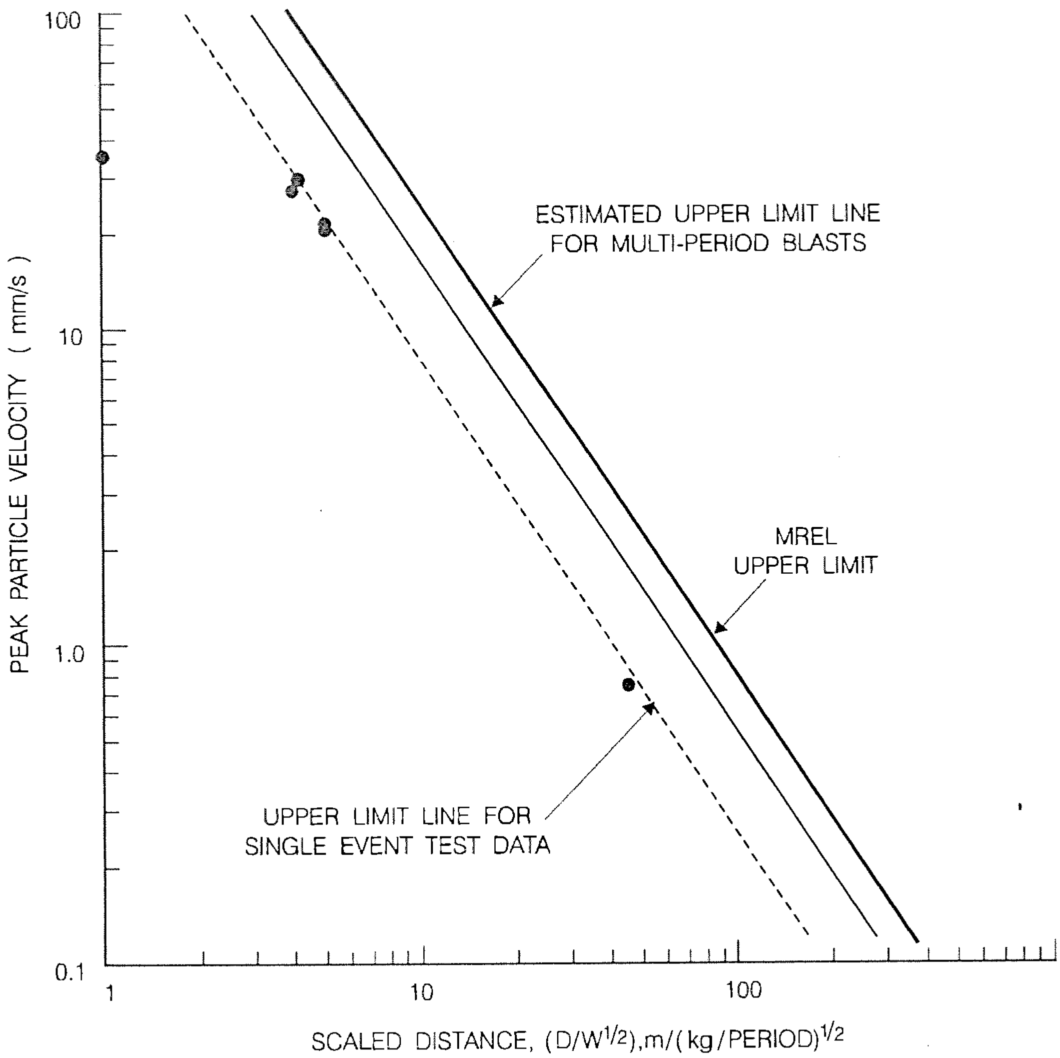

FIGURE C10: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FOURTH BLAST SHOT ON DECEMBER 19, 1996 AT TEST SITE #2.

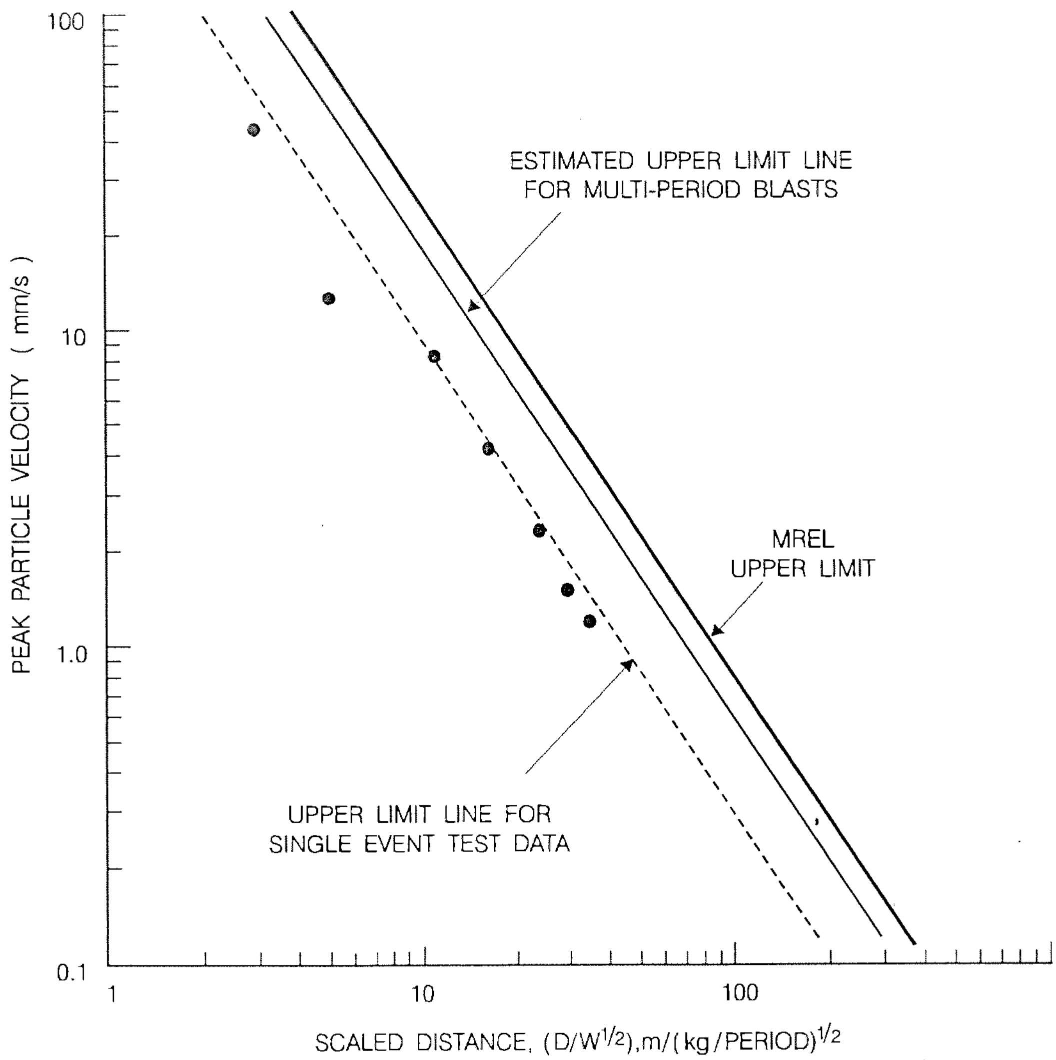

FIGURE C11: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FIRST BLAST SHOT ON DECEMBER 19, 1996 AT TEST SITE #3.

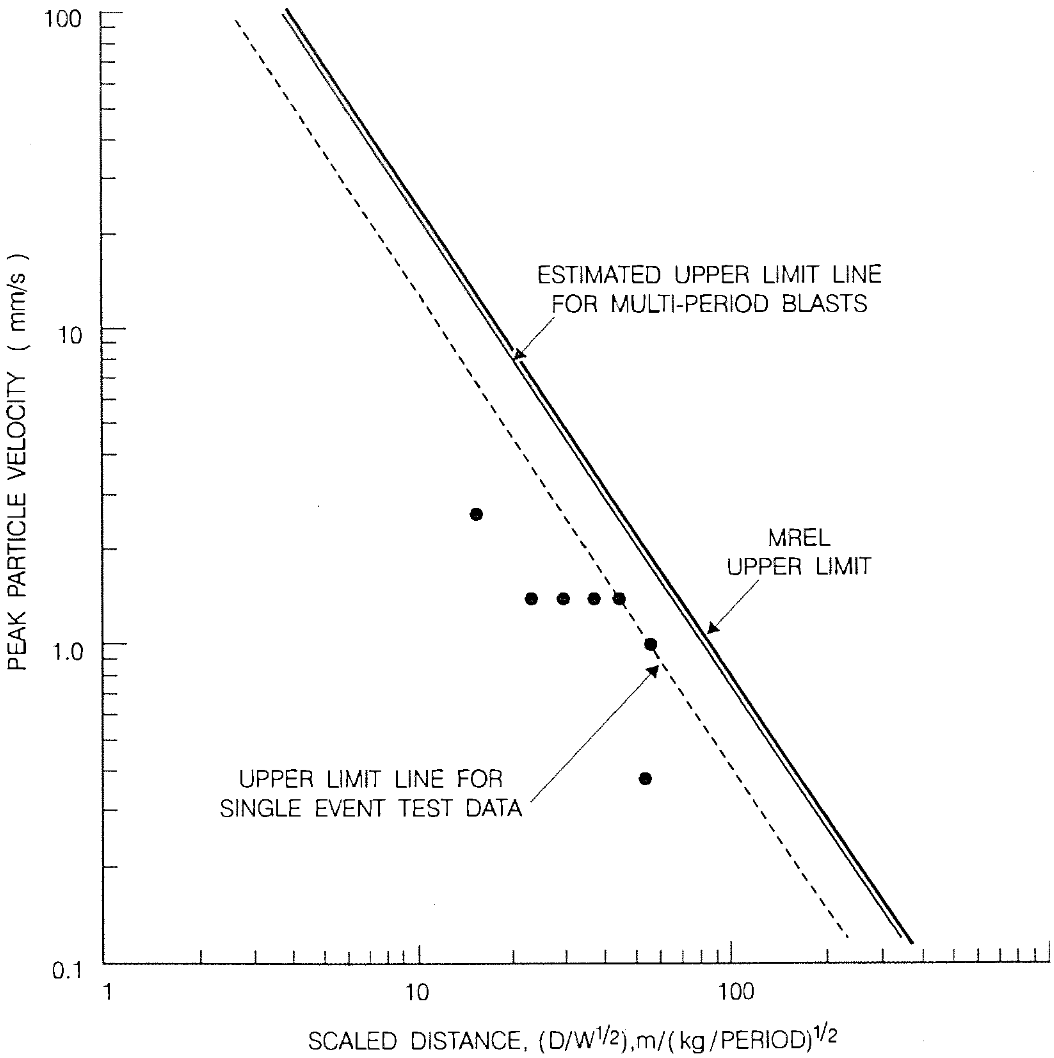

FIGURE C12: GRAPH OF PEAK PARTICLE VELOCITY VERSUS SCALED DISTANCE AS PRODUCED BY THE FIRST BLAST SHOT ON DECEMBER 19, 1996 AT TEST SITE #4.

Monitor Number	Point Number	Peak Particle Velocity As Measured For A Single Event (mm/s)	Normalised Peak Particle Velocity As Calculated For a 220 kg Single Hole Blast (mm/s)	Estimated Normalised Peak Particle Velocity As Calculated For a 220 kg Multiple Hole Blast (mm/s)
Bridge	100	1,02	1,02	2,03
4671	101	<0,38	<0,27	<0,54
4670	102	<0,38	<0,27	<0,54
4533	103	1,00	0,71	1,41
4669	51	2,05	1,45	2,90
4672	34	1,40	0,99	1,98
4530	104	1,40	0,99	1,98
4532	3	1,25	0,88	1,77
4670	105	1,27	2,31	4,61
4671	106	<0,38	<0,69	<1,38
4672	43	6,25	11,35	22,70
4530	59	5,85	10,62	21,24
4532	41	2,40	4,36	8,72
4533	107	1,40	2,54	5,08
4669	47	2,05	3,72	7,44
4533	108	<0,38	<0,38	<0,76
4671	109	<0,38	<0,38	<0,76
4672	110	<0,38	<0,38	<0,76
4530	111	<0,38	<0,38	<0,76
4532	112	0,90	0,90	1,80
4669	113	1,25	1,25	2,50
4533	114	<0,38	<0,38	<0,76
4669	115	<0,38	<0,38	<0,76
4530	116	<0,38	<0,38	<0,76
4671	117	1,35	1,35	2,70
4672	118	<0,38	<0,38	<0,76
4532	119	<0,38	<0,38	<0,76
4670	120	1,35	1,35	2,70

TABLE C12 : ESTIMATED NORMALISED PEAK PARTICLE VELOCITY AS CALCULATED FOR A 220 kg MULTIPLE HOLE BLAST AT BLAST SITE #1.

Monitor Number	Point Number	Peak Particle Velocity As Measured For A Single Event (mm/s)	Normalised Peak Particle Velocity As Calculated For a 220 kg Single Hole Blast (mm/s)	Estimated Normalised Peak Particle Velocity As Calculated For a 220 kg Multiple Hole Blast (mm/s)
Bridge	100	0,76	0,76	1,52
4669	121	<0,38	<0,25	<0,49
4642	122	0,51	0,33	0,66
4743	103	0,89	0,58	1,16
4670	20	1,40	0,91	1,82
4304	53	1,40	0,91	1,82
4052	12	1,02	0,66	1,33
4669	117	0,63	0,37	0,73
4742	122	0,63	0,37	0,73
4670	123	0,51	0,30	0,59
4743	115	<0,38	<0,22	<0,44
4304	69	0,53	0,31	0,62
4052	124	1,27	0,74	1,48
4669	125	0,51	0,51	1,02
4742	122	0,64	0,64	1,27
4743	126	<0,38	<0,38	<0,76
4670	110	0,51	0,51	1,02
4304	127	0,51	0,51	1,02
4052	120	1,27	1,27	2,54
4669	128	21,45	16,24	32,48
4670	129	28,95	21,92	43,83
4742	130	34,55	26,16	52,31
4743	131	27,50	20,82	41,64
4304	132	20,85	15,78	31,57

TABLE C13: ESTIMATED NORMALISED PEAK PARTICLE VELOCITY AS CALCULATED FOR A 220 kg MULTIPLE HOLE BLAST AT BLAST SITE #2.

initially been planned to prepare two such shapes, one for each blast site. However as the blast sites were relatively so close together, it was found there was little to distinguish between the two as a result of any changes in geology. Therefore only a single blast vibration shape is presented.

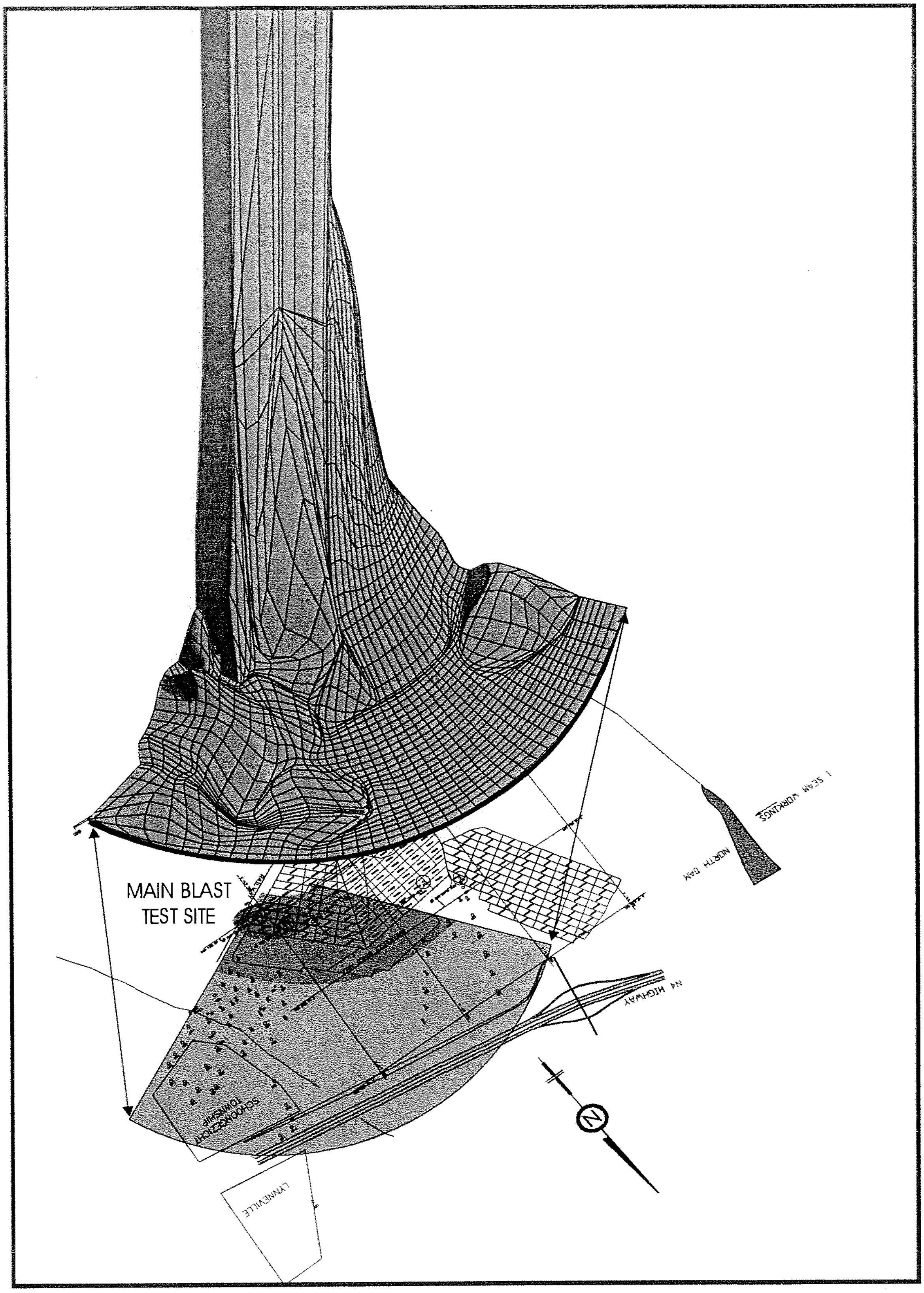

FIGURE C13: SINGLE EVENT BLAST VIBRATION ENVELOPE PRODUCED AROUND TEST BLAST SITES #1 AND #2 OBSERVED FROM A NORTHEAST DIRECTION.

Figure C14 presents the blast vibration contours for estimated multi-period blasts using 220 kg of HEF 100 emulsion per delay in the vicinity of Blast Test Site #1 and/or #2. These contours have been developed as a composite derived from the individual blasts. The contour of principal concern is the 5 mm/s which is the recommended design level, although a measured peak particle velocity of 8 mm/s is deemed acceptable.

The main area of concern is the Schoongezicht Township to the northeast of the proposed mini-pit. *Figures C13* and *C14* indicate that should multi-period blasts be fired using the test weight of explosive in either shot then vibration levels within the township will not exceed the recommended values when the shots are fired at the extreme northerly edge of the pit with the exception of a tiny isolated area near the township border adjacent to the mine property. Essentially a small "island" of vibration just above 5 mm/s was identified at this location, (see *Figure C14*). As such this should not give a problem but it does indicate where a problem may develop should care not be taken with the control of explosive weight per delay.

The Iso-Seismic Survey indicates that in the shallowest cover there should be no problem with blast vibrations relative to the railway. As the cover increases a potential problem could exist but this will be readily controlled using the recommendations as made by Dr. Crosby in his main report.

Frequency of Vibration

All the monitors used were capable of detecting and providing the dominant frequency of the individual channels or of the highest reading channel. However where vibration levels are very low, it becomes difficult to determine the frequency of vibration. Frequencies are primarily important where vibration levels are in the range where damage may be caused and hence low frequency vibrations should be avoided as they

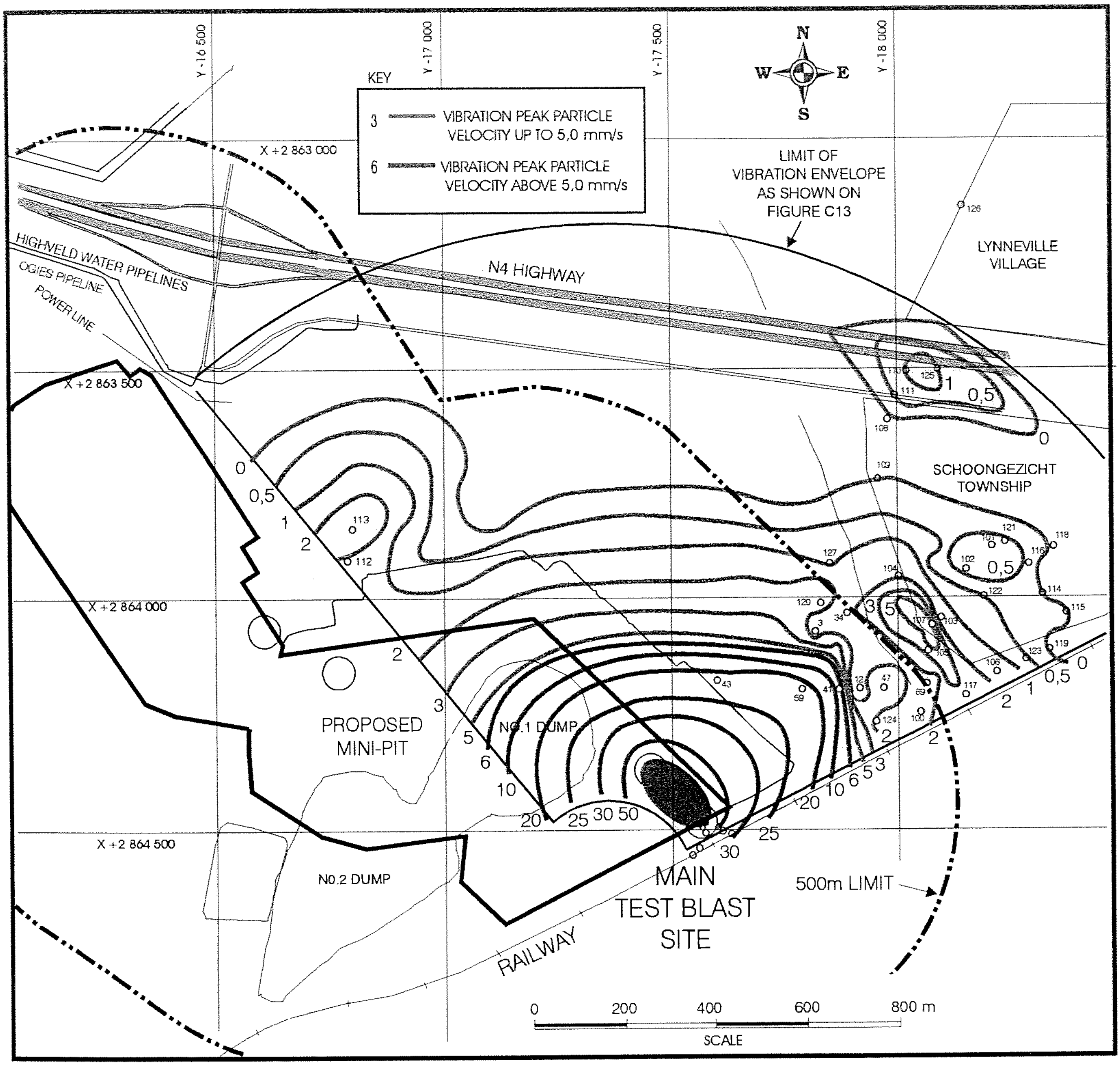

FIGURE C14: BLAST VIBRATION CONTOURS FOR MULTI-PERIOD BLASTS USING 220 kg OF EMULSION EXPLOSIVE PER DELAY FOR TEST SITE #1 AND/OR #2.

may cause resonance in structures if vibration levels are high enough. In this instance the blast is being designed to reduce vibration levels to a point much too low to cause damage and to some extent frequency is therefore irrelevant.

The frequency of vibrations of the monitors reading in excess of 4 mm/s have been examined. At lower vibration levels frequency is less important and the monitors are unable to detect a true dominant frequency at very low vibration levels. It was found that the frequencies almost exclusively fell within the range of 8-15 Hz. Records taken close to the blast did reach values of 30-60 Hz and sometimes higher.

Air Blast Results

The Iso-Seismic Survey is used to determine the rate of attenuation of vibration as it is known that this will remain constant in a given area being reliant primarily on geology. Air blast is reliant on meteorological conditions to a very high degree hence this phenomenon will be extremely variable in the short term.

The air blast records for all seismographs will be found in *Tables C2* through *C11*. In general the blasts all provided acceptable levels of air blast albeit some were bordering on the recommended 120 dB level, and indeed some were even above it. However it will be noted that the majority of the high values were recorded at extremely low scaled distances, very close compared with any readings that would normally be required for blast compliance purposes. Furthermore, some of the blastholes were charged with collars as short as 3,5 m, (as opposed to the recommendation of 4,0 m), although which holes had the shortest collars was not recorded. However it is fully anticipated with the recommended practices being followed that it will prove a relatively straightforward matter to maintain air blast levels within the recommended limit.