Document control:

Originated by:	Recommended by:	Approved by:	Revision	01	Next review date:
Global HSE Steering	Global HSE Steering	Board of Directors			June , 2009
Date: May, 2004	Date: April, 2007	Date: Dec. 6, 2007	Global HSE Steering		Staff Contact: Rosenbusch

Minimum Offset Guidelines For Land Seismic Sources

CONTENTS

INTRODUCTION

These guidelines have been produced at the request of the IAGC HSE Sub-Committee to replace the minimum offset distance tables which were contained in previous editions of the IAGC HSE Manual.

The guidelines do not state or recommend distances; instead they describe recommended techniques and standards to be followed. The standards are based on particle velocity.

There is a vast array of minimum offset information in existence and in use around the world. These guidelines are intended to be a new global industry standard.

This document also discusses the related subjects of air-blast and human factors and mentions use of explosives near fishing zones. It does not discuss effects on animals.

While compliance with these guidelines will ensure no damage, this will not ensure any complaints or legal proceedings. If an operation is following their own best practice monitoring, not these guidelines, it does not imply that they are at fault.

OBJECTIVE

These guidelines are intended for acceptance by authorities worldwide as the best practice standard to which seismic contractors should comply.

Demonstration of compliance by the seismic contractor should contribute to the avoidance of legal proceedings and in any litigation assist to prove that the seismic contractor performed with due diligence to industry standard with no issue of negligence.

It is intended that the guidelines will be included in contract specifications

SCOPE

The guidelines are applicable to all land seismic sources.

APPLICATION

Clearly in remote areas of limited infrastructure there will be no requirement to apply these guidelines. The scale of any study or active particle velocity monitoring will be dependent upon both the degree of infrastructure and the applicable jurisdiction.

It is preferable that the physical locations subject to these guidelines be discussed and wherever possible referred in the seismic acquisition contract. This should note the scale of application required [pre-start velocity study / active monitoring].

The effects of the seismic source may be described in the environmental impact assessment and/or project risk assessment. The offset control standards and techniques may be described in the project environmental plan or project HSE plan. This is the preferred mode of assessing and documenting this aspect.

METHODOLOGY

There are four interrelated parameters that may be used in order to define ground vibration magnitude at any location. These are:

- Particle Displacement – the distance that a particle moves before returning to its original position, normally measured in millimetres [mm].
- Particle Velocity – the rate at which particle displacement changes, normally measured in millimetres per second [mm/s]. Peak particle velocity is normally measured.
- Particle acceleration – the rate at which the particle velocity changes, measured in millimetres per second squared [mms^{-2}].
- Frequency – the number of oscillations per second that a particle undergoes measured in Hertz [Hz].

In all standards the preferred parameter of measurement is peak particle velocity [ppv]. The measurement of particles by vibration waves is usually measured in 3 mutual perpendicular directions, as particles will be oscillating in 3 dimensions. These are:

- Longitudinal [sometimes termed radial] – backwards and forwards particle motion in the same direction that the vibration wave is travelling.
- Vertical – up and down movement perpendicular to the direction the vibration wave is travelling.
- Transverse – left and right particle movement perpendicular to the direction the vibration wave is travelling.

Unless specified in the applicable local standard, data should be recorded outside of property or structures at ground surface immediately at the closest façade to the source location. Measurements should not be taken remotely from the structure or at a given distance from the source.

Magnification effects may occur with levels from 0.5 to 2.0 most likely within low rise residential type structures. The actual magnification will depend on many factors but primarily the frequency content, the duration of the incoming vibration and the natural frequencies of the building or structure. In terms of damage, magnification effects are well known and allowed for in the relevant standards.

The frequency content of source vibration is a significant factor in determining magnification levels and both human and structural response to vibration. This is reflected in the standards.

The geology of the intervening ground will largely determine the manner in which the vibration is transmitted and the characteristics including frequency content and magnitude at any given distance. The more competent and less weathered the rock mass then the greater is the propagation velocity. As velocities vary both within one rock type and between types can be significant, site specific measurements are important.

Water wells and aquifers exhibit a constrained response when subject to ground vibration, they move in concert with the geologic material that surrounds them and in general this geologic material surrounding the well must be disrupted to cause damage to water well. Furthermore, the ground motion velocity greatly attenuates with depth. The largest effect on vibration attenuation with depth is the geometric relationship with the charge. In most cases, except where the direct ray path is significant shorter, measurement of ppv at the well head will be satisfactory.

In the past, formulae were often used which related ppv to distance and charge size, possibly with the inclusion of a geological factor. These are no longer recommended.

Wherever possible the local particle velocity standard should be applied, such as the US Bureau of Mines [USBM], DIN 4150 etc. A listing and references to available standards are included in the appendices.

When operating in regions where there is no regulatory standard then the decision on which standard will be applied to the seismic contract should be made by and in consultation with the client and government agencies. In case of conflicting standards then the most stringent should be applied.

As the standards require varied particle measurement methods, it is essential that the seismic contractor establishes and follows a precise procedure.

The methodology to be used may include pre-survey condition inspections, pre-survey studies, active or passive monitoring and post-acquisition inspection. The procedure established will obviously be dependant on the methodology utilised, for example preparation of offset distance tables from a pre-survey study, or direct control of vibrator force levels from real-time active vibrometric monitoring.

Sensitive sites, such as world heritage sites may require additional controls. Such sites must be identified and controls agreed with the stakeholders before acquisition.

If previous study or data information is to be used then seasonal and any other variances must be considered and this documented in the acquisition contract or project plan.
It may be necessary for the contractor to later demonstrate and verify due diligence to the procedure.

MEASUREMENT TYPES

Pre-Survey Condition Inspections

Prior to a survey the operator may choose to photograph or video the condition of the points of concern potentially affected by a survey. Care should be taken to show time and date of inspection. Still photographs or video of streets and adjacent structures provide a base line for comparison of conditions.

Pre-Survey Studies

One level of protection for the seismic contractor and client is to perform a ground motion attenuation study. A statistically valid study will demonstrate safe approach distances to points of concern based on the applicable regulatory standard (USBM, DIN 4150, etc.). This type of study measures ground motion at a range of distances and performs a least-squares linear regression of the data to determine safe approach distances to the points of concern. Special care must be taken to assure an appropriate number of valid data points are taken for a statistically valid analysis.

Pre-Survey studies are site specific and often it is necessary to conduct separate studies in varying conditions on the same project. Typically these areas vary from low wetland to high, dry mesa or ridge-top conditions.

Unexpectedly high vibration levels often occur when a structure is at a different elevation (notably when higher) than that of the SP/VP.

Such studies may be relatively costly as they may require a full set of vibrators for a number of days in the differing terrain types. Analysis of existing data sets may be useful.

Active Monitoring

The highest level of liability protection for the seismic contractor and client is to actively monitor ground motion at the closest points of concern while the survey is being conducted. Ground vibration monitoring should demonstrate compliance with applicable regulatory standards. Safe approach distances should be determined on a site specific basis using the methodology described in the above "Pre-Survey Studies" section. Active monitoring should include measurement of ground motion, air overpressure where applicable, and accurate field notes.

Post Acquisition Inspection

Post acquisition inspections are often termed damage claims. Post acquisition inspection will be necessary if the owner of the property is alleging damage. A sampling post acquisition inspection is considered good practice to verify that the methodology, assumptions and processes have been effective.

Documentation of Results

All monitoring documents, inspection photographs, video tapes, diagrams and field notes should be incorporated into an organized report that is signed by the individual(s) conducting the work. Calibration certificates may be included.

PHOTOGRAPHS

Digital photographs, recorded pre and post-seismic acquisition, are a tool which can provide inexpensive and irrefutable evidence. Photographs must be date stamped and as with all other techniques must be recorded as part of a well-designed and controlled procedure. Care must be taken to recognize limitations restricting inspections due to adverse weather and seasonal variations.

AIRBLAST

Airblast, commonly known as "air overpressure" or "concussion", is an impulsive airborne shock wave generated by an explosive blast as a result of rock fragmentation and movement, as well as escaping gasses. Airblast varies widely in generation, propagation, and effects on humans and structures. Abnormal levels of airblast sometimes occur far from a blast source, and so they can involve a much larger area than is usually associated with ground-borne vibrations. Weather conditions can cause anomalous airblast propagation through focusing caused by temperature inversions, overcast conditions, and intensification from wind. Similarly, terrain can cause intensification through focusing. The level and character of an airblast are also strongly affected by the degree of explosive confinement afforded by the burden, stemming, and geologic conditions. The use of surface detonating cord (especially uncovered) may also have a significant effect on airblast and especially annoyance.

The general airblast can be characterized as an impulsive noise primarily in the infrasonic range. Most of the energy in an airblast is inaudible, because its frequency content is below the range of human hearing (20 Hz to 20 kHz). Because the airblast is generally below the range of hearing, a resident is unable to differentiate between the airblast and ground motion effects.

Airblast can be separated into high (> 6 Hz) and low (< 2 Hz) frequency types. "Both types are dominated by low-frequency energy (below 2 Hz), but the former has a secondary band of frequencies (over 6 Hz), which is less than 15 dB below the low-frequency energy level. The higher frequency type airblast is more troublesome because of its energy in the resonant frequency range of structures. The high frequency airblast is generated by the gas releases. A general swelling of the shot area generates the low frequency airblast.

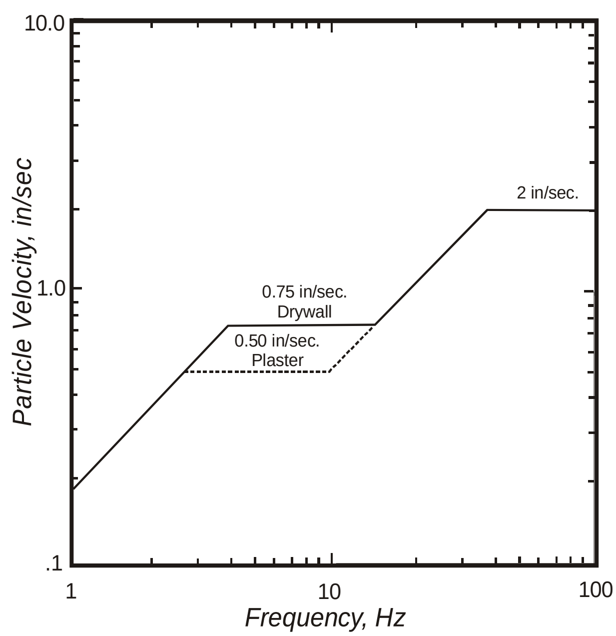
Glass is the element in a typical home most sensitive to airblast damage. Structural damage due to airblast (such as plaster cracking) is extremely rare and is always accompanied by extensive window breakage. Imagined damage from airblast is common because of the perceptible nature of the event.

STANDARDS

The U.S. Bureau of Mines [USBM] and the Office of Surface Mining [OSMRE] recommend a safe vibration level of 0.5 in/sec [12 mms^{-1}]. This is a conservative level that is safe for the most fragile of construction materials, plaster. USBM Report of Investigations 8507, Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting states that residential structures are most prone to damage as a result of vibration energy within the frequency range of 4-12 Hz and the 0.5 in/sec is recommended to preclude “threshold” damage to plaster on older structures. Maximum of 0.75 in/sec [18 mms^{-1}] is recommended for the protection of modern drywall interior construction.

Above 12 Hz the allowable vibration increases as the frequency increases up to 40 Hz. Above 40 Hz, a constant 2.0 in/sec [50 mms^{-1}] is recommended to protect the interior walls and ceilings of structures, regardless of construction material.

A graphic representation of the USBM recommended criteria is shown below [1 in/sec=25mms^{-1}].



Pipeline studies undertaken by USBM have indicated that a ppv of 125 mms^{-1} measured at the surface is a safe-level criterion for grade B or better steel pipelines. The same criterion is recommended for SDR 26 or better PVC pipe. Also, no adjustment is necessary for pipeline age, assuming the protective coating is intact, unless the pipeline is known to be at risk from previous damage or other causes.
The same safe-level criterion of 125 mms^{-1} also appears applicable to vertical steel-cased wells.

British Standard BS 7385 Part 1 1990 discusses the measurement of vibration in buildings and in general terms. BS 7385 Part 2 is a definitive standard in terms of relevant vibration damage criteria for the prevention of structural damage, against which the likelihood of building damage can be assessed.

Guide values are provided for damage with respect to 3 damage classifications:

- Cosmetic or threshold damage – the formation of hairline cracks or the growth of existing cracks in plaster, drywall surfaces or mortar joints. At a frequency of 4Hz the guide value is 15mms^{-1} ppv, increasing to 20mms^{-1} at 15 Hz and 50mms^{-1} at 40 Hz and above.
- Minor damage – the formation of large cracks or loosening and falling of plaster on drywall surfaces or cracks through bricks/concrete blocks. Minor damage is possible at vibration magnitudes that are greater than twice those given for the possible onset of cosmetic damage.
- Major or structural damage – damage to structural elements of a building. Structural damage is possible at vibration magnitudes that are greater than four times those given for the possible onset of cosmetic damage.

Transient Vibration Guide Values for Cosmetic Damage – BS 7385			
Line	**Type of Building**	**Peak Component Particle Velocity in Frequency Range of Predominant Pulse**	
		4 Hz to 15 Hz	**15 Hz and Above**
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Un-reinforced or light framed structures Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

Engineered structures such as industrial and heavy commercial buildings and underground constructions are able to sustain higher levels of vibration than residential type properties by virtue of their more robust design.

BS 6472 1992 Evaluates human exposure to vibration in buildings.

Appendix C gives guidance on satisfactory levels for human exposure to vibration from blasting. For blast induced vibration, it recommends the satisfactory vibration levels for human exposure should not be exceeded by more than 10% of the blasts and that no blast should give rise to vibration which exceeds the same level by more than 50%. For blast vibration up to three blasts per day, the human exposure vibration level is 8.5 mm/s (peak particle velocity) for occupants of residential buildings during daytime. Normally, night-time blasting is not permitted but, when it is, the nominated acceptable level is 2.8 mm/s.

DIN Standard 4150 is used almost exclusively in Europe.

This standard is also used extensively in the Middle East and CIS states in the absence of local standards.
This standard contains instructions for the determination and estimation of the effects on structures including buried pipe work (part 3), and persons in buildings (part 2) caused by vibrations.
Specific instructions are given for the measurement of vibrations and instruments used to perform it shall meet the requirements specified in DIN45669 standard.

Guidelines values for vibration velocity to be used when evaluating the effects of short-term vibration on structures					
Line	**Type of structure**	**Guideline values for velocity in mm/s**			
		1 Hz to 10 Hz	**10 Hz to 50 Hz**	**50 Hz to 100 Hz***	**Vibration at horizontal plane of highest floor at all frequencies**
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15
3	Structures that, because	3	3 to 8	8 to	8

	of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g.: listed buildings under preservation order)			10	
* at frequencies above 100 Hz, the values given in this column may be used as minimum values					

The Australian Standards Explosives Code AS 2187.2-1993 recommends criteria as the following table:

Recommended Peak Particle Velocity - AS 2187.2	
Type of Building or Structure	**Peak Particle Velocity**
Houses and low-rise residential buildings; commercial buildings not included below	10 mm/s
Commercial and industrial buildings or structures of reinforced concrete or steel construction	25 mm/s

The standard goes on to say that the likelihood of damage in residential areas starts to increase at ground vibration levels above 10 mm/s (peak particle velocity). Structures which may be particularly susceptible to ground vibration should be examined on an individual basis. Peak particle velocity may not be the appropriate criterion for determination of damage. In the absence of a particular site-specific study which may determine the appropriate damage criterion, then peak particle velocity is suggested as the damage criterion and a maximum level of 5 mm/s is recommended for blast design purposes, as experience has shown that damage is unlikely to occur at ground vibration levels below this level.
The New Zealand standard NZS 4403 1976, Code of Practice for Storage, handling and use of explosives may be referenced.

Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters may be referenced. The detonation of explosives in or near water produces compressive shock waves characterized by a rapid rise to a high peak pressure followed by a rapid decay to below ambient hydrostatic pressure. The latter pressure deficit causes most impacts on fish.

Studies show that an overpressure in excess of 100 kPa will result in these effects. The degree of damage is related to the explosive type, charge size and pattern together with the offset distance water depth and fish species, age and size.

This standard does not attempt to relate ppv to overpressure value.

HUMAN FACTORS

Human response to blast or vibroseis induced ground vibration is a relatively complex phenomenon and is dependant on a range of factors of which the actual vibration magnitude is only one and not necessarily the most important. It is well recognised that the human body is very sensitive to the onset of vibration and while this may vary significantly between individuals, a person will generally become aware at levels or around 1.5mms^{-1} ppv and under some circumstances as low as 0.5 mms^{-1}.

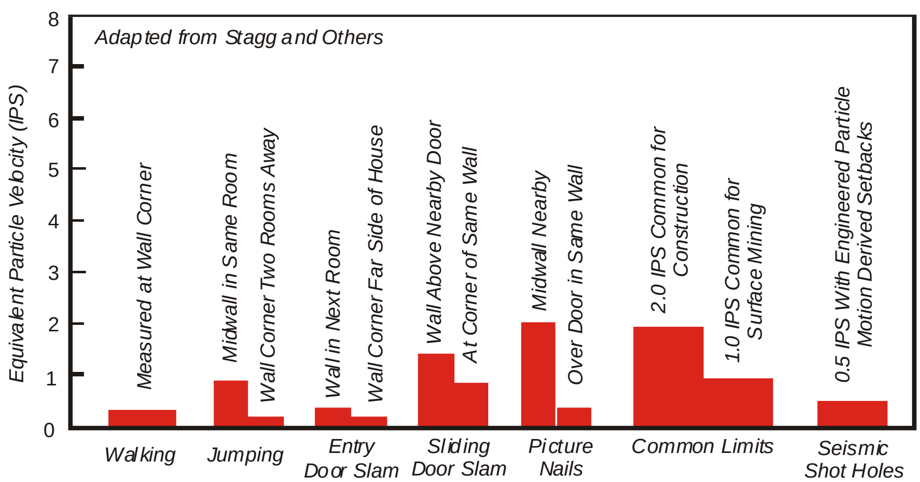
Once a received vibration is greater than an individual's perception threshold then it is possible for concern to be expressed about the source. Such concern usually relates to the vibration's potential for causing damage to the complainant's property.

The degree of concern and whether it leads to complaints is governed by many factors perhaps the most obvious is the vibration itself, in terms of magnitude, duration and frequency. As the vibration magnitude at which complaints arise varies so greatly from site to site, no common complaint threshold exists. This is partly a reflection that individuals are very poor at distinguishing between vibrations of differing magnitudes.

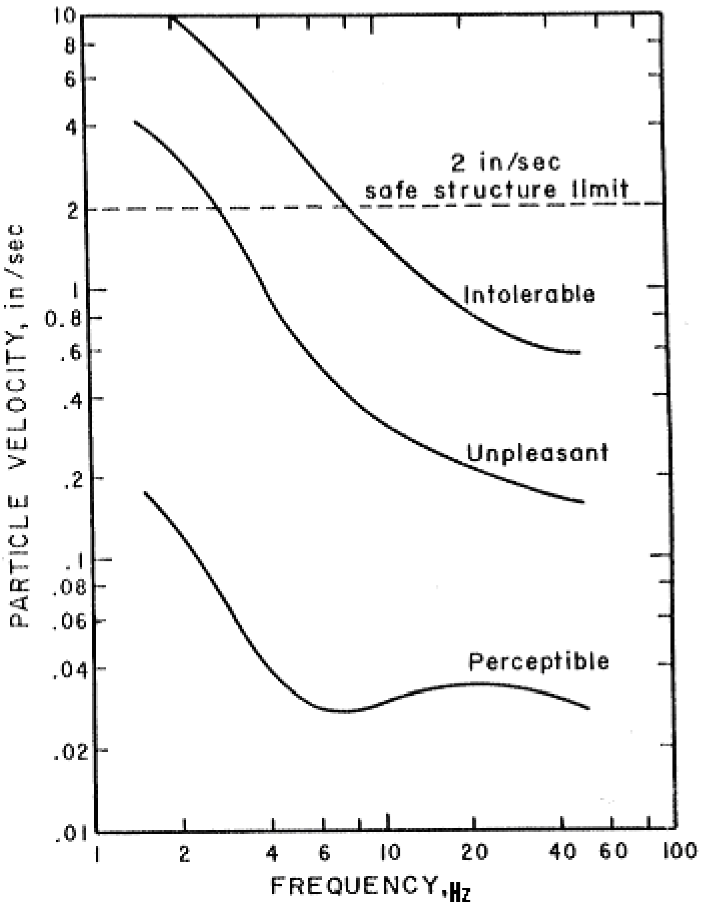
BS 6472 indicates Vibration Dose Values [VDVs] at which complaints are probable. VDVs may be derived from the ppv but are not discussed in this standard.

The following table provides a useful comparison [1 IPS – 25 mms^{-1}]

Vibrations Levels of Everyday Activities



The following table indicates the subjective response of the human body to vibratory motion [1 in/sec = 25mms^{-1}].



In conclusion, while human perception of vibrations may coincide more or less with the DIN standard for ancient, historic buildings in poor condition, sound modern buildings are probably quite capable of withstanding ppv levels of 50 mms^{-1}, a level intolerable to human beings.

This has two implications; for sound buildings, if people are not really alarmed by vibration levels these are probably well below damage threshold. For higher vibration levels, people management [perception] will need much attention, well before safe ppv levels for sound buildings are exceeded.

COMPETENCE

Irrespective of which method is used, the contractor will be required to utilize and verify competency in following these guidelines.

The competency will include planning, establishing and following procedure, selection of competent personnel and selection of correct and calibrated equipment.

It must be decided if the work will be conducted "in-house" or contracted to a specialist vibrometric expert. Selection of the most suitable and competent vibrometric expert is critical.

A vibrometric expert may be utilized for the complete works or may be contracted only for methodology planning and procedure establishment.

INSTRUMENTATION

Selection

Ground vibration monitoring should meet all regulatory criteria. In the case of shot hole seismic exploration ground motion should be measured in the frequency band of 2 – 250 Hertz and air overpressure should be measured in the frequency band of 2-250 Hertz. Excellent recommendations for explosives monitoring are established by the International Society of Explosives Engineers (www.isee.org).

Particle velocity is the parameter that is the best predictor of potential structural damage from ground motion in the 2-250 Hertz frequency band. Instrumentation that accurately measures ground vibration in the above mentioned frequency band can provide particle velocities, and with processing accelerations and/or displacements.

Monitoring and measurement is normally of ground motion only. Air overpressure is not normally monitored. In urban environments it may be advantageous to measure sound to assure compliance with local noise regulation.

Calibration

Instrumentation should be calibrated to meet all regulations and manufacturers recommendations. It is typical to require annual calibration traceable to a National standard. Daily sensor check of the instrumentation is recommended to confirm calibration.

Operation

Operation of monitoring equipment should be attempted only by a qualified, trained, geotechnical professional. Third party monitoring provides the greatest degree of liability protection because it is conducted by a trained party with specific expertise. In addition to applicable operation of the measurement device, accurate field notes describing the location of each individual reading is essential.

APPENDICES

Appendix 1 **USBM Standard**
http://www.msha.gov/TRAINING/LIBRARY/BureauofMines.htm
http://www.msha.gov/

Appendix 2 **DIN 4150 Standard**
http://www.din.de

Appendix 3 **BS Standard**
http://www.bsi-global.com

Appendix 4 **NZ Standard**
http://www.standards.co.nz

Appendix 5 **IN Standard**
http://www.iso.org

Appendix 6 **Australian Standard**
http://www.standards.org.au

Appendix 7 Partial Listing of Vibrometric Companies

Ameridian Technologies, Inc.
12507 Chessington
Houston, TX 77031
USA
+1 713 557-7261
http://www.ameridiantechnologies.com/

Apave Parisienne
Laboratories Saint-Ouen,
97-103 Boulevard Victor Hugo
93 400 Saint-Ouen
France
+33 1 40 545955
http://www.apave.com/

DMT GmbH
Am Technologiepark 1
45307 Essen
Germany
+49 (0)201 172-01
http://www.dmt.de/

Matheson Mining Consultants, Inc.
2801 Youngfield Street, Suite 171
Golden, CO 80401
USA
+1 888-456-4538
www.mathesonmining.com

Vibronics, Inc.
P. O. Box 5488
Evansville, IN 47630
USA
+1 812 853-2300
www.vibronics.com

Vibra-Tech Inc.
109 E. 1st Street
P. O. Box 577
Hazleton, PA 18201
USA
+1 800 233-6181
www.vibra-tech-inc.com

Appendix 8 Partial Listing of Instrumentation Companies

Instantel, Inc.
309 Leggett Drive
Ottawa, Ontario
Canada K2K 3A3
(800) 267-9111 Toll Free
www.instantel.com

White Industrial Seismology, Inc.
1206 Shifferdecker P. O. Box 1206
Joplin, MO 64802
(800) 641-4538
www.whiteseis.com