Proceedings of the Institute of Acoustics

HUMAN RESPONSE TO BLAST INDUCED GROUND VIBRATION - THE EXPERIENCES OF A LOCAL AUTHORITY ENVIRONMENTAL HEALTH OFFICER

J.M. Nelson

Environmental Protection and Leisure Services, Dumbarton District Council

1. Introduction

As an environmental health officer with Dumbarton District Council I have been involved in the field of acoustics for some twenty years, though from the local authority standpoint of endeavouring to resolve the public's problems in terms of statutory nuisance legislation.

I have been involved with two hardrock quarries and large scale engineering works in the form of road building on Loch Lomondside and the construction of shore based facilities to support the Trident nuclear submarine fleet. Many of you will probably be unaware of the fact that Dumbarton District has been home to the UKs Polaris nuclear submarine fleet and a major NATO armaments depot for some twenty years or so.

All of these operations require the extraction of huge quantities of rock by means of explosives and this results in the generation of ground vibration, air-overpressure and various other environmental impacts as a consequence.

The purpose of this paper is not to discuss either investigation methods or assessment criteria. Rather it is to use my own experiences to illustrate the problems of vibration nuisance as perceived by the public, factors influencing their response to it, techniques which may be employed to minimise the generation of vibration and suggest ways of minimising its impact on the community.

At this point I must include the caveat that all views expressed are my own and are not necessarily those of Dumbarton District Council.

2. Nuisance

Since one of the primary functions of an environmental health officer is the prevention or abatement of statutory nuisance, I shall first address the term *nuisance*. The conventional view of nuisance is of anything which causes material discomfort or inconvenience to a person, or amount to an unwarrantable interference materially affecting the use and enjoyment of a person's property.

The term nuisance is not in fact defined in legislation, however a definition may be found in the case of *Walter v. Selfe* [13] which took place in the English courts in 1851. In that judgement nuisance was held to be :-

an inconvenience materially interfering with the ordinary comfort, physically, of human existence, not merely according to elegant or dainty modes of living, but according to plain and sober and simple notions among the English people.

Nuisance is dealt with in Scotland under the Control of Pollution Act 1974 and in England and Wales under the Environmental Protection Act 1990. In both cases vibration is included within the definition of noise. Construction activities are dealt with under the Control of Pollution Act 1974 in all three countries.

The most common means by which an environmental health officer deals with nuisance is by summary action. In this case legislation requires that.....*where a local authority is satisfied that noise amounting to a statutory nuisance exists, or is likely to occur or recur*.....then it.....*shall serve a notice (an abatement notice).*

There is however another method open to the environmental health officer in order to deal with incidents of severe or widespread nuisance and that is to seek interdict in Scotland or injunction in England and Wales.

There is one further method by which nuisance may be tackled, though in this case by members of the public rather than the local authority. The acts state that.....*A Sheriff or magistrate's court.....may act under a summary application or complaint* [made by the occupier of any premises] *on the ground that.....he is aggrieved by noise* [or vibration] *amounting to a nuisance.*

Noise and vibration from construction sites can also be dealt with and the local authority may serve notice to prevent or restrict unreasonable activites. However a contractor may apply for consent prior to works commencing if he so chooses.

3. Human Perception of Vibration

The Collins English Dictionary defines *annoy* as... *to irritate or displease*...and...*to harass with repeated attacks.*

Although this is not a legal definition it is one which I believe illustrates two very important points. Firstly we are not dealing here with the readily understood and objective criteria of building damage, but with the much more esoteric and very subjective criteria of human annoyance. Secondly the concept of intermittency and repetition is recognised.

When I first dealt with the quarrying and construction industries, and even the mandarins of the Scottish Office, all talk was of structural damage thresholds. The effects of vibrations causing disturbance or annoyance to local residents tended to be passed over with a dismissive gesture of the hand. This despite the fact that research carried out as long ago as the 1930s indicated that human perception of vibration was very acute [12].

The human body is extremely sensitive to vibration and the threshold of perception, expressed as peak velocity in the vertical axis, has been identified as 0.3 mm/s for continuous vibration [5, 12] and 1.5 mm/s in the case of transient vibration [11]. A continuous velocity of 2.5 mm/s has been considered sufficient to cause annoyance [5, 12].

My early experiences with quarrying seem to have coincided with a greater awareness on the part of the public of the nuisance from vibration and air overpressure associated with blasting activities. In the case of vibration the public view any single incident, large or small, with concern, not from the

point of view of disturbance, but from a highly subjective assessment of the perceived damage to their homes.

Conventional nuisance criteria do not seem to apply in the case of blasting. It is a highly emotive issue and on more than one occasion I have had elderly people compare quarry blasting with the blitz on Clydeside during the Second World War. These comments have not arisen from people whom one might consider to be highly strung, but from ordinary sensible members of the public displaying a genuine fear, however irrational some of us may consider it, about blasting activities. This may seem somewhat far fetched to those of us with a more objective turn of mind but it happens nonetheless.

The terms disturbance, annoyance and inconvenience do not seem to enter into the vocabulary of the vast majority of those who complain about blasting. Indeed I can think of no single occasion when the complainer confined himself to what I would call nuisance. Their concern is for the structural safety of their property every time they feel - or hear - a blast. For this reason the conventional notions of nuisance can be all too easily overlooked and the environmental health officer can find himself in a rather unusual role. He carries out a monitoring exercise, not with any great expectation of gathering evidence of nuisance, but more as a source of reassurance.

In my experience the public view any vibration as bad vibration, particularly when it is associated with other forms of environmental impact or pollution.

4. Blasting Techniques

In mineral extraction operations, bulk blasting techniques involving large charges of relatively low grade explosives are used. The requirement here is not only for good breakout to remove the rock from the face, but also to fragment it to a size suitable for loading into the primary crusher.

Although quarries tend to be remote from habitation and therefore gain the benefit of distance from sensitive properties, this is not always the case.

In contrast, road construction work requires much more controlled blasting involving much smaller charges of higher grade explosives, though often detonated very close to buildings [10, 11].

The technique used in road cuttings comprises pre-splitting and then bulking-out [10]. The pre-splitting technique requires detonation in very confined rock in order to create fracturing within the rock but without breakout or fragmentation taking place. Thus quite high levels of ground vibration occur. Bulking-out is a conventional blasting technique similar to that used in quarrying, though more care must be taken. Levels of vibration from this method are generally lower than those from pre-splitting.

In general terms the greater the energy expended in breaking out the rock and fragmenting it, the lower the resulting ground vibration will be, therefore the better the blast from the industry point of view, the lesser the sensory impact from the public's point of view [9, 11].

Probably the single most important factor in the generation of vibration is the weight of explosives detonated. By incorporating short delays into the initiation system the maximum instantaneous charge is reduced and since this is related to the magnitude of vibration then that too is reduced [1, 6].

In the case of pre-splitting for highway rock excavation the method used to reduce ground vibration is to decouple the charge from the side of the hole [10, 11].

5. Vibration Levels

In quarrying, levels of 1.0 to 1.5 millimetres per second peak particle velocity are typical. The highest level I have recorded was 6 mm/sec and the next highest 3 mm/sec. Complaints are usually lodged if the magnitude exceeds 1.0 mm/sec - not much higher than the threshold of perception - and if 2-3 mm/s is reached then complainants become vociferous.

In road construction, velocities of 3 to 6 mm/s are commonplace. The highest level I have recorded on any road contract is a peak particle velocity of 20 mm/s. This was at a distance of 48 metres from a blast at which the maximum instantaneous charge of explosives was only 6.75 kilos.

These figures relate to measurements carried out on the structure of buildings, either on doorsteps or window sills. However in order to assess levels of vibration at the point of entry to the human body an allowance must be made for the transfer function between the measurement point and the body entry point [2].

6. Factors Influencing the Perception of Vibration

Large quarry blasts do not necessarily take place every day, far less several times each day. However this type of operation is usually a long term undertaking and hence its environmental impact will persist for many years. Thus whilst the frequency of blasting may not be great, the fact that it may continue for many years has a great influence on the willingness of affected residents to tolerate this type of activity.

As demand for rock rises and falls so production follows suit and when an increase in the number of blasts follows a lull of several months or more then public concern is reawakened.

Road construction on the other hand requires frequent blasting, perhaps several shots per day. However such operations are of course much shorter lived than quarrying activity and for this reason higher levels of vibration may be tolerated to some degree.

In my experience complaints arise not only as a result of ground vibration, but also due to loud noise, windows rattling, ornaments moving, mirrors falling off walls, cracked WC pedestals etc.. Such incidents trigger an alarm in the minds of the public who then associate them with large scale ground movement. It is therefore very important to question complainers closely and ascertain just exactly what they have in fact experienced.

Probably the single greatest influence on the public's perception of ground vibration is the airborne pressure wave. When explosives are detonated, both ground waves (vibration) and airborne waves (air-blast or air-overpressure) are generated. Whilst a portion of these waves are within the audible range, the lower frequencies (concussion) can rattle loose fitting windows and also cause a phenomenon known as *the diaphragm effect* whereby the airwave impacting on a structure may cause excitation of suspended floors or stud partitions [1].

HUMAN RESPONSE TO BLAST INDUCED GROUND VIBRATION

The perception of vibration can be influenced by a number of factors and in general these tend to relate to the attitude of the contractor and the way in which the quarrying or road construction operation is carried out.

A sudden loud noise associated with a blast often causes startle and if this is combined with window rattle as a result of air-blast then the occupier usually associates it with ground movement and assumes that his house is being shaken. This results in an increase in the level of complaint even though the degree of ground vibration may be minimal [3, 4].

Other activities which have an impact on the environment may heighten awareness of the issue therefore consideration should be given to the impact of all activities. Dust from the stemming of shot holes, drilling rigs or traffic movement can focus attention on the quarry as can the smoke from coating plant. Noise from heavy vehicles or from compressors supplying drilling rigs can draw attention to the quarry's unattractive and unwanted activities.

There are of course other obvious ways of avoiding adverse public reaction, though these tend to relate more to road construction activities than quarrying.. Ensure that sufficient land is acquired in order that the works can be carried out safely and control fly-rock. Damage as a result of this tends to negate all other public relations efforts!

Earthmoving plant also causes vibration and heavy plant such as this may operate near houses for a much longer period than blasting operations. Such plant may also give rise to safety issues either from their sheer size or from mud deposited on roads. Works causing disturbance to field drainage can result in excess surface water being shed by hillsides and flooding being caused.

Blasting during the night is a very sensitive issue. It should be avoided if at all possible since it can be more trouble than it is worth in terms of strained public relations, adverse publicity and the exceedingly tight conditions likely to be imposed by the local environmental health officer in response to public concern.

A number of different issues arose in the case of the Clyde Submarine Base compared with those illustrated by the Loch Lomond road works. Some of these issues though external to the actual construction works themselves nevertheless coloured opinions before the first sod was lifted or spade turned.

Local and national politics influenced attitudes, both for and against the project, as did the anti nuclear debate. The NIMBY (Not In My Back Yard) syndrome was encountered periodically and a proportion of residents expressed resentment at the UK's nuclear deterrent being located in their neck of the woods. This combined with concerns over peacetime radiation risks and wartime vulnerability contributed to a perception of imposition by government from afar.

The Clyde Submarine Base is the biggest single employer in the district with over 4,000 civilians working there. Many families rely on the base for their income therefore there is much greater tolerance of disturbance from the activities carried on there than there is for example in relation to quarrying activities with their much smaller employment opportunities

In every case visual impact is a daily reminder of the unwelcome intrusion of such operations.

7. Implications of Low Vibration Levels on Contract Length

Vibration levels are generally much higher in road construction works, although such contracts are of relatively short duration when compared with surface mineral extraction. Higher levels may therefore be tolerated - within reason.

There is however the practical difficulty of balancing the lower level of vibration wished for by the public, against the extended time period thereby required to carry out the contract. There certainly is a benefit in completing the work as quickly as possible - though not at any price and finding this balance is extremely difficult. In my experience people will tolerate higher levels of vibration arising from construction activities provided that the experience lasts no more than perhaps two or three weeks and provided of course that it is not excessive.

If levels are likely to exceed say 6 mm/s then there will be complaints. If levels of some 10 or 12 mm/s are experienced then there will undoubtedly be very considerable adverse reaction from the public. It is at this level that it might be prudent for the contractor to invite occupiers along to the local hotel for a cup of tea while blasting is taking place. But under no circumstances must damage from either ground vibration or fly rock result.

If either does happen then all the goodwill which might otherwise have been gained will be lost and litigation will undoubtedly ensue. In any event, if occupiers experience such levels on even one occasion then it is extremely unlikely that they will ever leave their home again during such activities for fear of the contractor inflicting damage to their property.

I believe therefore that, provided public consultation takes place, the best course of action in terms of public response and tolerance may be to reduce the contract period - but with adequate safeguards in relation to damage and of course safety.

8. Methods of Reducing the Impact of Blasting on the Community

Having briefly described blasting techniques and methods available to reduce its impact on the community, let me offer an example of what can be done to alleviate the public's concern and anxiety brought on in part by the sensitivity of the human body.

A very considerable public campaign gradually grew against one of the quarries in the district until it reached not only local newspapers but also local radio. Only at this point did the quarrying company consider their public relations. It then held public meetings and every complainer was visited on an individual basis. In addition regular monitoring was carried out by the blasting contractor and the explosives manufacturer and "tell-tales" affixed to selected properties.

Gradually the public began to realise that their concerns were being addressed, just as the quarry operator began to realise how many aspects of the quarrying activities were considered unacceptable by local residents - an eye opener for both sides!

From that day to this, periodic monitoring has been carried out, initially by the blasting contractor, but later by my own department, to check on vibration levels and compare them with blasting records. By doing this the quarry management and the environmental health officer are able to build up a

picture of the method and maximum charge weights likely to be acceptable in terms of the ground vibration (and overpressure) generated.

This is not intended to replace a vibration survey and scaled distance assessment by the quarry operator and/or blasting contractor. It is however a very useful tool in assisting the environmental health officer and quarry operator in understanding the problem and minimising complaints.

More recently, a down the hole detonation technique has been introduced with the effect of minimising noise from surface detonation lines and dust columns from stemming, both of which had been attracting adverse comment from members of the public. Once again these factors were associated with a fear of ground vibration damaging their homes.

9. Conclusions

In the case of noise the criteria of nuisance is usually only met if the offending noise occurs regularly. In the case of vibration however the public view any single incident, large or small, with concern, not from the point of view of disturbance, but from a highly subjective assessment of the perceived damage to their homes. What then can be done to inform the public about such operations and allay their fears?

All too often the wrong attitude prevails and industry makes no attempt to inform local residents of their plans. Hopefully this attitude is changing and a more positive and constructive approach is now being adopted.

Good public relations are essential, therefore before the first turf is lifted at least one public meeting should be held. Such a forum allows an exchange of views. The client/contractor can explain what is proposed, why it is to be done in a particular way and what is to be done to reduce its impact on the community. Local residents are in turn able to convey their concerns directly to the contractor. In this way both sides gain an understanding of each other's position and both can benefit from this information.

The public should be given a point of contact so that they may either obtain advice and information or register dissatisfaction. In order to reduce the startle factor blasting should be carried out at regular times and the public informed of these times. In addition audible warnings should be given immediately prior to blasting.

The hours of blasting should be restricted to weekday daytime working hours when residents might be expected to be going about their daily activities. Night time blasting should be avoided if at all possible since this is a particularly sensitive period and public reaction will reflect this.

Survey selected vulnerable properties, fit "tell-tales" before work commences and resurvey periodically thereafter.

Ensure that no damage occurs - from any source.

Look at the overall impact of the operation and control every aspect of it. This includes blasting effects, traffic movement, road conditions, noise, dust, flooding etc..

We have come a long way in the last 20 years. The quarrying and construction industries have come to recognise that building damage criteria is not an adequate standard to foist on the public. I have to say however that in my experience the quarrying industry has generally accepted their responsibility more readily than the construction industry.

Environmental health officers are in daily contact with the public and are therefore familiar with local feelings and expectations. They can help industry with advice based on local knowledge and experience. It is far from inevitable that the two parties are on opposite sides of the fence.

10. References

1. M. BALL, 'Vibrations from blasting - Problems and Solutions', Paper presented at a study course held in Nottingham in December 1976, reprinted from Quarry Management and Products.
2. BRITISH STANDARD BS 6472 : 1992 'Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)', BSI, London.
3. K.A BROADHURST & T.J. WILTON, 'Blast Induced Ground Vibration and Air Overpressure - Terminology, Standards and Control', Rock Environmental Limited, Derby.
4. K.A BROADHURST & T.J. WILTON, 'Blasting Vibration and Noise - a Comprehensive Review', Rock Environmental Limited, Derby.
5. BUILDING RESEARCH STATION, 'Digest 117 - Vibrations in buildings - 1', HMSO, 1970.
6. D.P. BURNHAM & J.C. CLARK, 'Developments in Blasting Practice', Quarry Management and Products, February 1982.
7. CONTROL OF POLLUTION ACT 1974.
8. ENVIRONMENTAL PROTECTION ACT 1990.
9. B.J. GREENLAND & J.D. KNOWLES, 'Environmental Considerations of quarry Blasting', The Quarry Managers' Journal : Institute of Quarrying Transactions, October 1970.
10. G.D. MATHESON, 'Transport and Road Research Laboratory Report 1094 - Presplit blasting for highway rock excavation', TRRL, Livingston, 1983.
11. B.M. NEW, 'Transport and Road Research Laboratory Report 53 - Ground vibration caused by civil engineering works', TRRL, Crowthorne, 1986.
12. R.J. STEFFENS, 'Building Research Establishment Report - Structural vibration and damage', HMSO, 1974.
13. *Walter v. Selfe* (1851), 4 De G. and Sm. 315