Technical Note 03

Measurement of Ground Vibrations and Airblast

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1 SCOPE

This technical note considers ground vibrations and airblast and the instrumentation used for their monitoring. It recommends procedures and safe vibration and airblast levels that should be used in Department construction activities.

2 NATURE OF GROUND VIBRATIONS AND AIRBLAST

Vibrations are ground movements that result from one of the following:

- The sudden application and release of pressure in blasting operations.
- The repetitive application of a force as in pile driving.
- The application of a centrifugal force resulting from the rotation of an eccentric weight such as in the case of vibrating rollers.
- The use of heavy construction equipment, for example, bulldozers and scrapers.
- Traffic vibration resulting from the variation of contact forces between vehicle wheels and the road surface, and engine vibration.

The vibrations are transmitted by body waves (compression and Shear) and surface waves known as Rayleigh or Love waves. They can be short lived such as from blasting or can continue over longer periods such as from pile driving or from vibrating rollers.
Airblasts are the air pressure waves generated by explosions. The high frequency portion of the pressure wave is audible and is the sound that accompanies a blast; the lower frequency portion is not audible but excites structures.

3 WHY DO WE MEASURE VIBRATIONS AND AIRBLAST?

Ground vibration may result in permanent damage to property and cause substantial nuisance to the local population. The damage to property can be caused directly by ground wave movements or indirectly via potentially unstable soil or rock conditions in the vicinity of the construction site (e.g. soil liquefaction, slope failure). Airblast is not considered to be a significant factor in causing damage to structures but can be a major factor in human response type complaints.

4 MEASUREMENT OF DAMAGE POTENTIAL

The level of ground vibration can be determined by the measurement of the velocity, displacement or acceleration of a "particle" at the site. Research has led most authorities to adopt particle velocity as the best criterion for relating ground vibration to building damage.

The relationship between velocity, acceleration and displacement is given by the following equations:

$$A = \frac{V}{2\pi f}$$

$$a = 2\pi f V$$

a = acceleration mm/s2

A = displacement (amplitude) mm

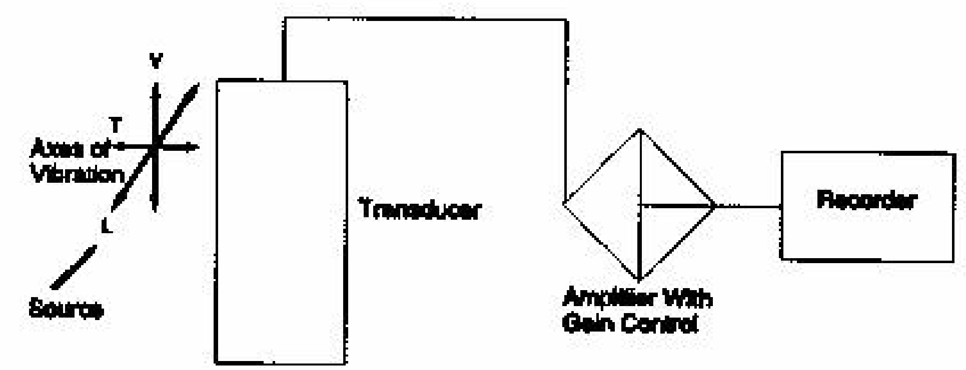
V = particle velocity mm/s

F = frequency Hz

5 INSTRUMENTATION

There are several instrumentation systems on the market that can be applied to the problems of vibration recording. The general system of vibration measurement is shown in Figure 1

Figure1 –Generalised System of Vibration Measurement



The Vibration Measurement system consists of three basic components:

- A package of a 3D geophone or transducer
- An amplifier with gain control, and
- A recorder system

The package of a 3D geophone is comprised of three mutually perpendicular geophones or transducers. The geophone or transducer is a device for converting ground motion to a varying voltage.

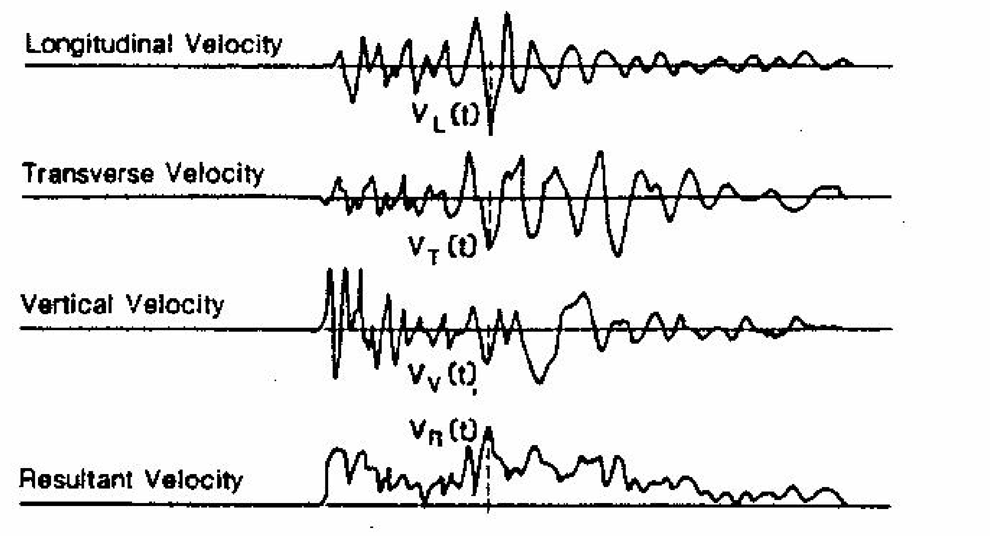
The voltage is generally very small (a few millivolts) and so requires amplification to allow processing. The resultant larger output voltage, which reflects the original ground motion, can then be displayed via the recording system.

The recording system may be a galvanometer camera system with a photographic or a direct writing paper recorder or an oscilloscope screen, both of which display voltage output and therefore particle velocity as a function of time. Another type of recording system utilises metering and digital recording devices which display the peak output from each geophone or the peak resultant output over a given period of time.

The 3D geophone system, designated L-T-V, orients the actual direction of vibratory motion in space. The transverse or T axis is normal to L axis. The vertical or V axis is normal to both the L and T axes. This results in two horizontal and one vertical direction.

The first three graphs in Figure 2 are typical of a record produced from a vibration seismograph with a 3D geophone. The resultant velocity graph is the graph that would be produced from the vector sum of the three components.

Figure 2 – A sample of a Blast Vibration Seismogram



The resultant particle velocity at a given instant can be obtained by the vector sum from three mutually perpendicular geophones, i.e. resultant particle velocity at a given time (t):

$$V_R(t) = \sqrt{V_T(t)^2 + V_L(t)^2 + V_V(t)^2}$$

The maximum resultant particle velocity Vr (max) characterizes the vibration severity and is called the peak particle velocity (PPV).

Like ground vibrations airblast pressure waves can be described with time histories where the amplitude is air pressure instead of particle velocity. The "linear" weighting scale is used with the airblast level normally recorded in decibels.

Instruments used for the measurement of particle velocity and air blast overpressure within the Department are held at **Geotechnical Services**, Brisbane. They can be operated either manually or left unattended to be triggered by either resultant ground vibration or air overpressure events.

Immediate output of resultant ground vibration and air overpressure levels and waveforms is available.

For normal monitoring Departmental equipment is appropriate. However, in special circumstances outside consultants and specialised equipment could be necessary.

6 SAFE GROUND VIBRATION AND AIR BLAST LEVELS

The Department's policy in reducing ground vibrations and airblast levels is just as much directed towards minimising distress to people as avoiding damage to buildings. Since humans respond to levels of ground vibrations and airblast considerably lower than those necessary to induce structure damage, the limits recommended for Departmental construction projects are quite conservative.

As mentioned in Section 4, particle velocity is used as a parameter for damage assessment. The limits recommended depend on the vibration source as defined below:

i. Blasting: The recommended acceptable levels of ground vibration from blasting are those in the current Australian Standard AS2187-983 (Reference 1). These are shown in Table 1

Table 1 – acceptable levels of ground vibration from blasting

Type of building or structure		Particle Velocity (V_R max) mm/sec
1	Historical buildings and monuments, and buildings of special value or significance	2
2	Houses and low-rise residential buildings: commercial buildings not included in item 3 below	10
3	Commercial and Industrial buildings or structures of reinforced concrete or steel construction	25

Notes:

1. This table does not cover high-rise buildings, buildings with long span floors, specialist structures such as reservoirs, dams and hospitals and buildings housing scientific equipment sensitive to vibration. These require special considerations which may necessitate the taking of additional measurements on the structure itself, to detect magnification of ground vibrations which might occur within the structure. Particular attention should be given to the response of suspended floors.
2. In a specific instance, where substantiated by careful investigation, a value of peak particle velocity other than that recommended in the table may be used.
3. The peak particle velocities in the table have been selected taking no consideration of human discomfort and the effect on sensitive equipment within the building. In particular, the limits recommended for buildings types 2 and 3 may cause complaints.

ii. Pile Drivers, Vibrating Rollers, Traffic: Ground vibrations caused by these sources are of a continuous nature usually lasting for extended time periods. Because of this it is proposed that vibration limits should be set at lower levels than from blasting. A peak particle velocity (VRmax) limit of 5 mm/sec is therefore recommended.
Tynan (Reference 2) has produced a handy user guide applicable to vibrating rollers which approximates the recommended limit. It is shown in Table 2.

Table 2 – user guide applicable to vibrating rollers

Roller Class		Example – Weight Range and Centrifugal Force (CF)	Restriction: Distance to Nearest building
1	Very light	Maintenance & patching rollers, less than <1.25t (CF 1-2t)	Generally not restricted for normal road use (0ft, 3m)*
2	Light	1-2t (CF 2-5t)	Generally not restricted for normal road use (15 ft, 5 m) (30 ft, 10 m)
3	Light – Medium	2-4t (CF5-10t)	5 ft, 5 m (30 ft, 10 m)
4	Medium Heavy	4-6t (CF 10-20t)	Not advised for city and suburban streets 30 ft 0 m (65 ft, 20 m)
5	Heavy	7- t (CF20-30t)	Restricted. Not advised fr built-up areas. 65 ft, 20 m (130 ft, 40 m)
6	Very Heavy	2t and over (CF over 30t)	Restricted, major construction rural areas away from structures and buildings

* Values in brackets are those suggested to keep claims and complaints to an acceptably low level. For complaints to be stopped completely in residential areas, these values would possibly be needed to be increased still further.

iii. Airblast: The control of blasting procedures to limit ground vibration levels to those outlines in Table 1 should automatically limit airblast overpressures to safe levels with respect to building damage. The current Australian Standard has no recommended limits for airblast but a new Australian Standard now in preparation (Draft) proposes the maximum levels shown in Table 3 below.

Table 3 – maximum airblast levels

Time of explosion	Max. airblast level to minimise the risk of human discomfort dB (linear)	Max. airblast level to minimise the risk of structural damage to residential and industrial buildings dB (linear)
Mon-Sat 9.00am – 5.00pm	120*	133
Mon-Sat 5.00pm – 9.00am	115*	133
Sundays & Public Holidays	115*	133

* Ten percent of explosions may exceed this level up to an additional 5dB

The limits in i., ii., and iii. above may need to be lowered in individual circumstances, such as close proximity to historical buildings, hospitals etc., or in the presence of sensitive machinery.

It should also be stressed that, although maintaining ground vibrations below, a particular level does not provide immunity against claims, it reduces the degree of liability for damage likely to be attributed to ground vibration.

7 RECOMMENDED PROCEDURES

In the planning stage of any major road or bridge construction projects, the planning flow diagram shown as Figure 3 should be followed.

Figure 3 – vibration hazard – planning flow diagram

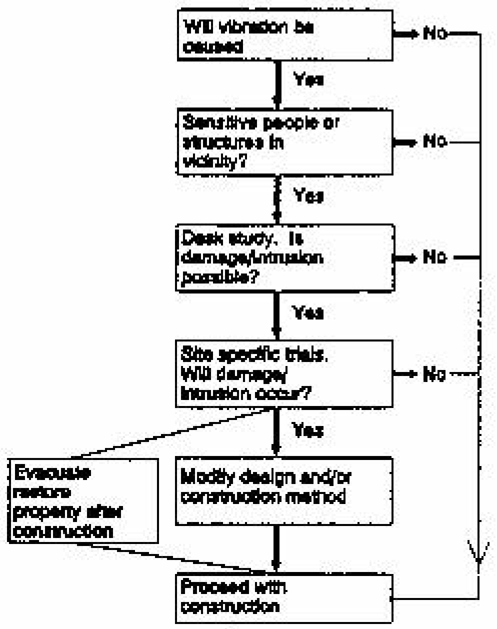


FIGURE 3
Vibration Hazard - Planning Flow Diagram

If a need for vibration monitoring is perceived then either a Divisional Construction Services Unit or Geotechnical Services unit should be contracted.

The control procedures that may be necessary include:

i. Locality Survey: Survey the area surrounding the site for buildings and services (both surface and underground) which require protection. Remember that nuisance from air vibration may extend a considerable distance from a blast location.

ii. Building Survey: Decide on the type of building survey required for buildings in the area. This will vary with the vibration level anticipated, the condition of buildings in the area, and human relations factors such as:
   - are people in the area used to blasting etc?
   - are they sympathetic or antagonistic towards the project?

iii. A building survey may vary from casual external observation by the foreman to a full structural survey by an independent building specialist. This would include detailed photography both inside and out.
   Human Relations: Provide adequate notice to people in the area before carrying out any blasting or pile driving operation.

iv. Monitoring: This enables vibration levels to be controlled within the specification and allows modifications to the construction procedures as required.

8 REFERENCES

1. Standards Association of Australia (SAA). Explosives Code AS2187-983 Part, Use of Explosives.

2. Tynan A.E. (1973). Ground Vibrations, Australian Road Research Board Special Report.