

Ground vibrations during impact rolling

Derek Avalle

Broons Hire (SA) Pty Ltd, Sydney, Australia

Keywords: impact roller, vibrations, dynamic compaction, ground improvement

ABSTRACT

The dynamic effect of a towed non-circular impact module has been used for many decades to induce deep compaction on a wide variety of sites and soil conditions. The “square” impact roller is towed at a speed of 10-12km/h, and the solid four-sided module imparts substantial impact energy into the ground. Ground improvement using the impact roller can offer considerable cost and time savings for sites with poorly compacted fill or weak soils. However, consultants, contractors, property owners and regulators are sometimes confronted with a dilemma as to whether such ground improvement techniques may constitute a hazard to nearby sensitive structures or buried services. Ground vibrations that are generated by the impact roller have been independently measured on numerous sites in south-eastern Australia and assessed for the purposes of each project on the basis of available guidance.

Vibration monitoring results from these sites have been collated and are presented on a composite graph of peak particle velocity versus distance from the impact module. A simple form of near-upper bound relationship is evident between the peak particle velocity, as a measure of ground vibrations, and the distance from the vibration source. Additional aspects of material types, directional effect and energy transfer are the subject of further research efforts. As an interim measure, this simple relationship is suggested for use in the initial appraisal of the potential risks to nearby structures and buried services due to impact rolling.

1 INTRODUCTION

The use of impact rolling for ground improvement, or rolling dynamic compaction as it is also known, commenced in Australia in 1985. Originally developed in South Africa (Clegg & Berrangé 1971), the impact roller found early application in the construction and mining sectors. Operating on the principle of a non-circular drum or module rotating about a corner and falling to impact the ground, these rollers travel at a relatively high speed. The four-sided or “square” impact roller has a single solid 8t to 12t module and incorporates a unique system that utilises the horizontal acceleration of the drum during its toppling motion to maximise the energy imparted into the ground. The effective depth of compactive effort is significantly larger than with conventional circular drum rollers due to the relatively high energy (Pinard 1999). This energy translates into ground vibrations as the impact wave traverses the surface and subsurface materials, a factor that can be of concern for various receptors, such as people, historical structures, residential dwellings, commercial buildings and buried infrastructure, amongst others.

2 THE “SQUARE” IMPACT ROLLER IN AUSTRALIA

Utilising impact techniques to densify the ground goes back at least to ancient Roman and Chinese times. Drop weight machines designed in the Middle Ages look similar to mid-20th Century dynamic compaction cranes, employing a free-falling mass. In the mid-1970s a system was patented, with a torsion bar springing system (Clifford, 1976 and 1978), which evolved into the four-sided towed impact roller. In the mid-1980s, Broons Hire (SA) Pty Ltd was the first to introduce these impact rollers into Australia, where they have since been manufactured and progressively improved. Figure 1 illustrates the “square” impact roller and the shape of its four-sided module.

The impact roller was initially developed for civil engineering applications to increase the in situ density of weak road subgrades at depth. Its potential benefits in these applications were soon realised. The impact roller has also found on-going use for deep fill compaction applications, in the mining sector and agriculture, and more recently, in large scale land reclamation and ground

improvement projects. Impact rolling has been found to be suitable for a wide variety of materials and moisture contents. The impact roller's ability to improve the density gradient across a site, developing a more uniform soil "raft", lends itself to a multitude of different applications (Avalle 2004). Questions about vibrations due to impact rolling and their potential adverse effects are frequently asked prior to decisions on ground improvement options. However, the occurrence of significant problems relating to vibrations caused by the impact roller are rare. This may be due to:

- increasing the stand-off area to minimise the risk of complaints, and
- frequent measurement of ground vibrations during compaction.

Measurement of ground vibration during impact rolling, has become common as part of construction risk management.

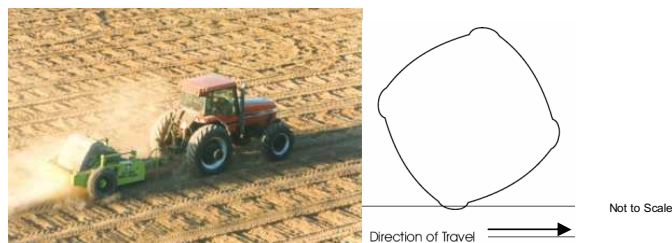


Figure 1: The “square” Impact Roller and its cross-sectional shape.

3 CONSTRUCTION VIBRATIONS

The vibrations associated with civil engineering construction projects that can affect people and buildings generally result from pile drivers, rock breakers, vibrating rollers, dynamic compaction and impact rollers, road profiling, blasting, trucks and heavy vehicles, etc. The vibration is transmitted through the ground, although airborne noise may add to the effect of the vibration. Construction vibrations can cause adverse effects that range from annoyance to people, cosmetic damage (e.g. plaster cracks), through to physical structural distress.

The vibration travels through the ground as an elastic wave which results in small surface deflections. Early research focused on the velocity of the surface particle movement, which was found to correlate with the appearance of cosmetic cracking (Dowding 2000). The surface velocity is measured by a geophone, which, as it is vibrated by the motion, produces a small electric current that is proportional to the velocity. The peak particle velocity is the maximum rate of change with respect to time of the particle displacement and is generally expressed in mm/s.

Ground vibrations attenuate or decay due to two phenomena: geometric spreading and cyclical (or hysteric or material) damping (Dowding 2000). The geometric spreading of Raleigh (or surface) waves, along with the energy the wave loses as it is required to overcome friction, combine to reduce the peak particle velocity as the distance from the source increases. However, Raleigh waves travel only on a surface and thus spread their energy in a cylindrical form rather than the spherical surface of body waves, which accounts for the predominance of Raleigh waves for construction motions.

4 “SAFE” LEVELS OF VIBRATION

Human perceptibility commences at about 0.1-0.5mm/s, but people can become annoyed by vibrations even lower than that, and many people can tolerate vibrations up to 5-10mm/s. However, the duration and frequency are also factors in this complex topic. In essence, humans are far more sensitive than structures (by at least an order of magnitude) and a vibration will generally become unacceptable to humans before that vibration reaches levels of potential structural distress.

In the absence of a standard in Australia that provides guidance on limiting construction vibration to prevent structural damage, reference is frequently made to British and German standards (BS 7385-

2: 1993 and DIN 4150-3: 1999, respectively). These standards provide guidance values for short term vibration velocity, as summarised in Table 1.

Table 1 British and German guidance values for peak particle velocity

BS 7385-2:1993		Transient vibration guide values for cosmetic damage		
1	Industrial/commercial buildings	50mm/s (at 4Hz and above)		
2	Residential/light buildings	15-20mm/s (4Hz to 15Hz)	20-50mm/s (15Hz to 40Hz +)	
DIN 4150-3:1999		Guideline values for vibration velocity when evaluating short-term vibration		
1	Industrial/commercial buildings	20mm/s (1Hz to 10 Hz)	20-40mm/s (10Hz to 50Hz)	40-50mm/s (50Hz to 100Hz)
2	Dwellings	5mm/s (1Hz to 10 Hz)	5-15mm/s (10Hz to 50Hz)	15-20mm/s (50Hz to 100Hz)
3	Sensitive structures (e.g. historic)	3mm/s (1Hz to 10 Hz)	3-8mm/s (10Hz to 50Hz)	8-10mm/s (50Hz to 100Hz)

5 CASE STUDY SITES AND TEST RESULTS

Data from 25 sites in Victoria, New South Wales and South Australia have been collated for analysis. The prevailing ground conditions at these sites have been grouped into four main categories based on primary geotechnical characteristics (i.e. clay, sand, mixed fill and waste), as listed in Table 2, which also identifies secondary characteristics of the subsurface materials at each site.

Table 2: Geotechnical characteristics at case study sites

Site Number	Main geotechnical characteristic	Secondary geotechnical characteristics
01	Clay	Gravel and clay fill
02	Mixed fill	Soil and building rubble, etc
03	Clay	Clay fill over clay
04	Clay	Fill
05	Sand	Sand fill and natural sand
06	Clay	Natural clay
07	Mixed fill	Soil and building rubble, etc
08	Clay	Clay fill
09	Clay	Clay fill over clay
10	Clay	Clay and gravel fill
11	Clay	Clay fill
12	Clay	Clay fill with boulders
13	Mixed fill	Soil and building rubble, etc
14	Clay	Clay fill and clay over weathered rock
15	Waste	Refuse, with capping
16	Clay	Natural clay
17	Clay	Clay fill and clay
18	Mixed fill	Mixed soils over saturated fine-grained soils
19	Sand	Sand fill and sand
20	Clay	Clay fill and clay
21	Mixed fill	Soil and building rubble, etc
22	Mixed fill	Soil and building rubble, etc
23	Mixed fill	Soil and building rubble, etc
24	Mixed fill	Soil and building rubble, etc
25	Mixed fill	Soil and building rubble, etc

Vibration monitoring at these sites varied from being specifically related to the monitoring of vibrations at the boundary or at sensitive structures, through to intensely undertaken trials, which has resulted in a large dataset, as shown in Figure 2. The results are plotted on a log-log scale to facilitate interpretation.

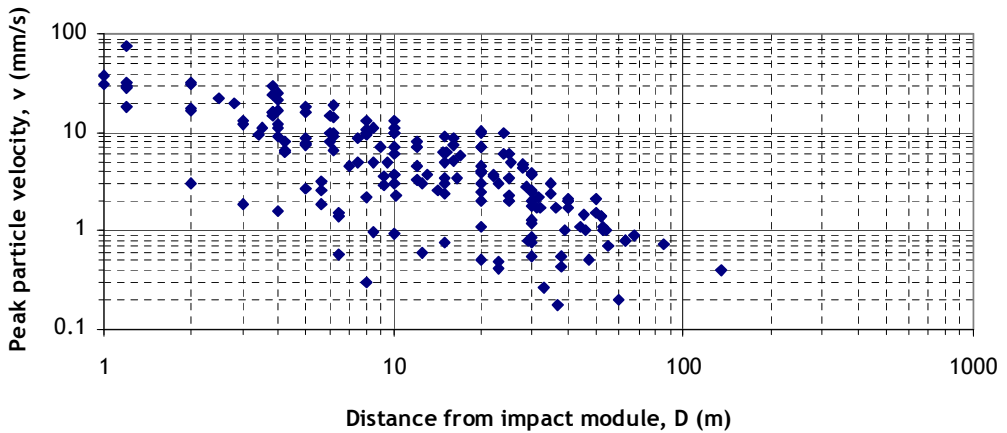


Figure 2: Vibration results for 25 case study sites

6 DATA ANALYSIS

The initial analysis of the data has resulted in the plots shown in Figure 3. The graph illustrates the linear relationship on the log-log scale of v , the peak particle velocity (PPV), to D , the distance from the source, with the “power” function being of a similar form to the Raleigh wave decay.

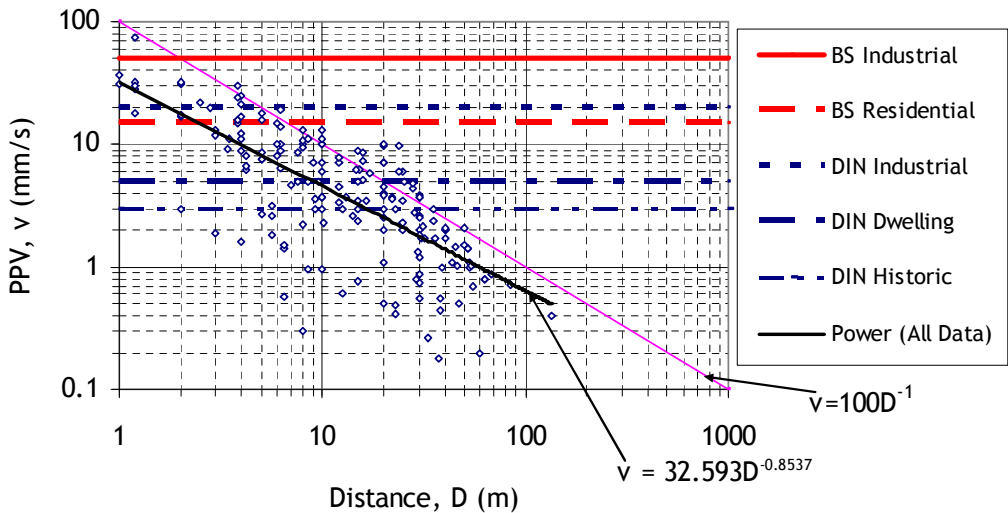


Figure 3: Vibration trends and limits

The conservative or lower level of the British and German guideline values for PPV limits (i.e. at the low frequency end of the vibration spectrum, shown in Table 1) are indicated on Figure 3.

An arbitrarily drawn simple relationship is also shown on Figure 3:

$$v = 100D^{-1} = 100 / D \quad (1)$$

where v is the peak particle velocity in mm/s and D is the distance from the impact module to the measurement point. Equation (1) accounts for over 85% of all data and over 75% of the data for D between 10m and 30m.

Equation (1) is in the same form as the power equation shown on Figure 3 and using it to compare with the guidance values suggests that industrial buildings can be approached to between 2m and 5m during impact rolling, while residential buildings can be approached to within 7m to 20m. The German code indicates a buffer of at least 25m for historic or particularly sensitive structures. With the more sensitive structures, equation (1) appears to be quite conservative, while with the less sensitive structures it fits well with current empirical protocols adopted on impact roller projects.

The examination of vibration decay during heavy tamping or dynamic compaction on soft waste material (Brandl et al. 2005) resulted in the power function shown in Figure 4. Figure 4 also includes the power function for the impact roller data from work on a capped refuse tip (waste). The further analysis of this (and other) comparative data is the subject of on-going research.

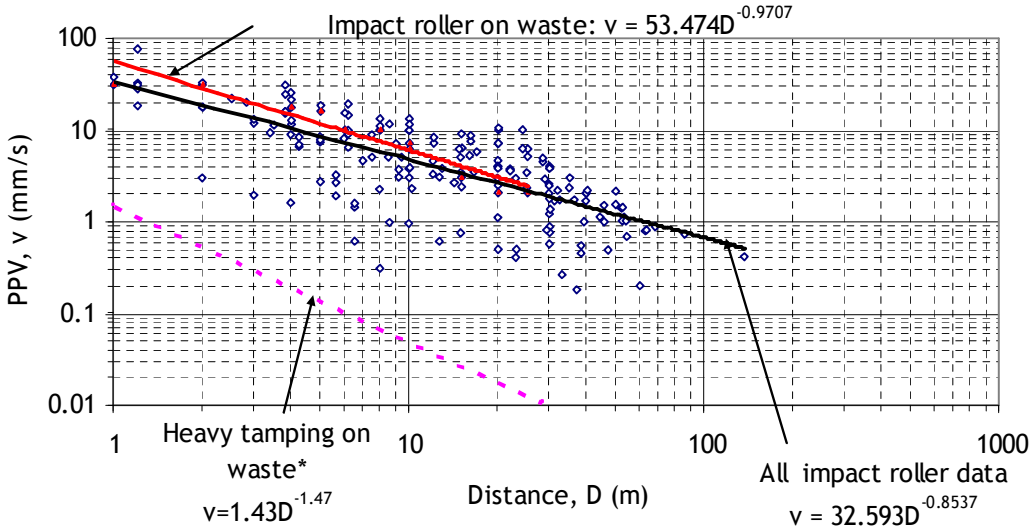


Figure 4: Comparison of heavy tamping with impact rolling
* Brandl et al. 2005

The current data set of vibrations associated with the 8t “square” impact roller includes results for the various ground characteristics and material types, as well as measurements taken in and perpendicular to the direction of travel. These will be the subject of further research and analysis relating to energy transfer. Also on the agenda for research is the development of an energy measurement system that is integrated with the impact roller.

7 CONCLUSIONS

The accumulation of vibration data on construction sites employing the standard 8t “square” impact roller has accelerated recently to provide a substantial database for analysis. In the first instance, the data set fits the general form anticipated from past experience with the decay of ground vibrations as measured by the peak particle velocity, and is consistent with expectations for the Raleigh wave form.

A simple expression, $v = 100 / D$, is suggested for initial evaluation of the potential magnitude of ground vibrations resulting from the use of the 8t “square” impact roller (where v is the peak particle velocity in mm/s and D is the distance to the impact module in metres). Although this expression is consistent with overseas guidance and local experience, and encompasses over 85% of all the case study data, it should nonetheless be used with caution, particularly in the distance range 10m to 30m, as ground characteristics (and other factors) affect the rate of vibration decay.

ACKNOWLEDGEMENTS

Case study vibration data originate from reports by Heggies Australia, Terrock Consulting Engineers, GKN Geotechnics, NSW RTA and Vipac Engineers & Scientists, and the author is grateful to the various clients associated with these projects for access to vibration and geotechnical data for the purposes of this research, and to Roger Bailey of Roger G Bailey & Associates, Mark Blake of Heggies Australia, and Alan Richards and Adrian Moore of Terrock Consulting Engineers, for their assistance.

REFERENCES

- Avalle, D. L. (2004). *Ground improvement using the "square" Impact Roller - case studies*, 5th International Conference on Ground Improvement Techniques. Kuala Lumpur: 101-108.
- Brandl, H., Kopf, F. and Paulmichl, I. (2005). *Fading away vibrations during heavy tamping*, Proc. 16th Int. Conf. on Soil Mechanics and Geotechnical Engineering, Osaka, pp. 1159-1162.
- British Standards (1993). BS 7385 Evaluation and measurement for vibration in buildings. *Part 2: Guide to damage levels from groundborne vibration*. UK, BSI.
- Clegg, B. and Berrangé, A.R. (1971). *The Development and Testing of an Impact Roller*, The Civil Engineer in South Africa, Vol. 13, No. 3, Mar., pp. 65-73.
- Clifford, J.M. (1976). *Impact Rolling and Construction Techniques*, Proc. ARRB Conf., Vol. 8, pp. 21-29.
- Clifford, J.M. (1978). *The impact roller - problems solved*, The Civil Engineer in South Africa, Vol. 20, No. 12, Dec., pp. 321-324.
- Deutsche Norm (1999). DIN 4150 Structural vibration. *Part 3: Effects of vibration on structures*. Germany.
- Dowding, Charles H. (2000). *Construction Vibrations*, 2nd Ed., C. H. Dowding, U.S.A.
- Pinard, M.I. (1999). *Innovative Developments in Compaction Technology Using High Energy Impact Compactors*, Proc. 8th ANZ Conf. on Geomechanics, Hobart, pp. 2-775 to 2-781.