Vibration Measurement Methodologies: Mounting Techniques and Effectiveness

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ABSTRACT

Ground vibration measurements are widely used in acoustics and environmental assessments to evaluate vibration impact from sources such as construction, transportation, industrial activity and more. The accuracy of triaxial ground vibration data depends strongly on the mounting technique used to couple sensors to the ground and this paper's goal is to assess the commonly used mounting techniques and compare to some more creative yet easy to access mounting techniques (ie. Ground screws). Measurements are completed at multiple sites representing typical ground conditions, comparing surface-mounted, shallow-buried, mechanically anchored, and foundation mounted sensor installations. The influence of mounting technique on coupling quality, frequency response, measurement errors and measurement repeatability is evaluated under a controlled environment. This paper hopes to provide practical recommendations for field deployment of triaxial vibration sensors and support improved consistency and comparability of ground vibration measurements in acoustics and environmental assessments.

1. INTRODUCTION

Accurate measurement of ground-borne vibration is fundamental to a wide range of geotechnical and environmental application. In the construction industry, vibration monitoring is an invaluable tool to monitor and manage the vibration impacts generated from heavy machinery activities such as pile driving, tunnelling, excavation, blasting and drilling – all of which generate significant levels of low-frequency vibration. These activities can present substantial risks to surrounding buildings, structures and underground services. Despite the importance of geophone coupling, the question of optimal sensor mounting methodology in field conditions remains relatively underexplored in literature.

Poor coupling between the sensor and the ground surface can introduce artefacts including amplitude distortion, variations in frequency response, phase errors — all of which compromise the validity of predicted impacts (eg. peak particle velocity, PPV), which serves as the primary metric in most vibration damage and human comfort standards. The problem is compounded in field deployments where surface conditions are variable, access is constrained, and the time available for sensor preparation is limited.

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This paper presents a controlled experimental comparison of five geophone mounting methodologies (buried, screw, epoxy, taped, and sandbagged) subjected to repeatable impulsive loading generated by standardised weight drops. By holding the source energy and geometry constant across trials, the study isolates mounting method as the primary variable, enabling a direct comparison of the various mounting methods, their accuracy and stability.

The findings of this study are intended to provide an evidence-based framework for selecting geophone mounting strategies appropriate to various site conditions, and to highlight the potential for measurement errors when surface-mounted sensors are used in high-amplitude or near-field measurement scenarios.

2. EXPERIMENTAL PROGRAMME

A weight dropping system was created using a releasable cord attached to a 20 kg mass suspended in the air at 2 m above the drop zone. The testing surface varied with both a concrete bed and a hard packed gravel roadway. The impact location was situated 500 mm from the edge of the concrete, with ten geophones mounted to the ground using the five different methods to simultaneously record ground vibrations. Three mounting methods were conducted on concrete to simulate real world measurements of vibration impacts on a sensitive structure. The remaining two mounting methods were conducted in the roadway. Each of the five mounting methods were tested at both 1 and 2 m from the impact point. The offset distances selected are representative of near-field monitoring scenarios encountered in practice, such as vibration assessment adjacent to existing utilities [1].

To conduct the measurements, ten InstraLabs Vibration loggers were used with external tri-axial transducers. Five common methods of transducer mounting methodologies were selected for this study which are generally observed in the field. As detailed in AS2187.2-2006 [2], the preferred coupling method depends on site conditions. Suggested mounting methodologies include adhesive or mechanical bonding to a rigid surface, or where no rigid surface is available, an embedded transducer or transducer attached to an embedded tube is justifiable for consistency of results. It is noted that mounting with spikes are not recommended as a viable methodology. Figure 1 illustrates the mounting methodologies utilised for the testing.

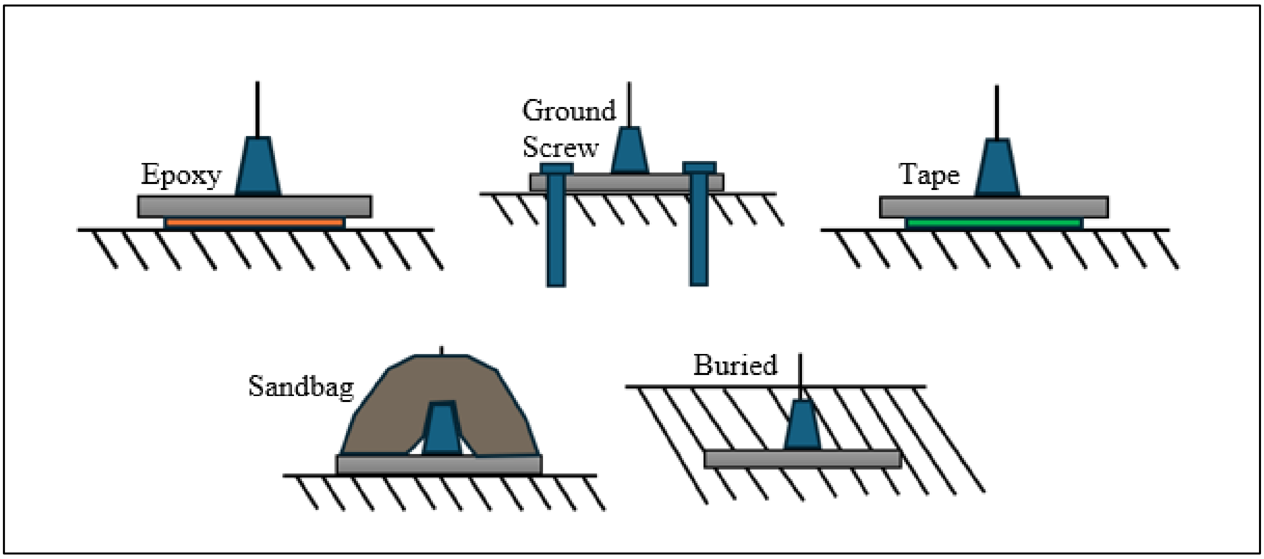

Figure 1: Five common methods of transducer mounting

The first transducer was buried 350 mm below surface level and then covered back up with loose soil before being compacted. The second transducer was placed onto the dirt roadway and secured using 220 mm long heavy-duty screw in pegs. The third and fourth transducers were mounted onto the concrete using Selleys Araldite epoxy adhesive and 1 mm thick gorilla tape. The fifth transducer was placed on the concrete surface with a weighted sandbag covering the sensor.

3. RESULTS

Controlled drop weight testing was conducted using a 20 kg mass released from a height of 2 m, generating a repeatable impact energy of approximately 392 J per drop on a compacted dirt roadway surface. Peak particle velocity (PPV) measurements were obtained at offsets of 1 m and 2 m across five geophone mounting configurations over 21 confirmed drop events. The surrounding measurement substrates included both concrete and compacted dirt roadway, with sandbag, tape and epoxy all being mounted on the concrete, and the ground screw and buried methods being utilised on the compacted dirt roadway.

Table 1 shows the results from the 21 drop tests.

Table 1: Monitoring results from drop test – Peak Particle Velocity (PPV, mm/s)

Drop #	*1 m from impact point (PPV, mm/s)*					*2 m from impact point (PPV, mm/s)*				
	Sandbag	Tape	Epoxy	Screw	Buried	Sandbag	Tape	Epoxy	Screw	Buried
1	26.6	21.4	19.5	54.0	31.8	11.2	8.7	8.9	9.3	8.8
2	33.0	26.6	24.8	46.6	24.8	12.5	9.0	8.5	7.7	5.8
3	34.2	28.2	30.3	60.1	16.6	13.2	10.9	11.4	7.8	6.6
4	31.4	25.4	18.4	45.6	24.9	11.6	8.4	7.9	6.8	7.5
5	22.8	16.9	14.9	44.8	25.0	9.4	6.3	5.5	7.1	7.6
6	26.4	21.8	21.8	61.2	23.7	10.5	7.7	8.2	9.4	7.7
7	23.6	19.5	20.8	88.8	27.9	9.5	7.4	8.5	8.3	7.7
8	25.0	20.5	20.6	75.8	21.1	10.4	7.6	7.2	7.5	7.4
9	25.3	20.2	19.0	34.7	20.9	9.7	6.3	5.6	6.1	7.0
10	-	20.3	19.4	48.0	20.7	10.5	7.1	7.1	6.8	7.7
11	-	-	24.5	76.2	16.5	8.9	7.7	8.8	9.2	6.6
12	-	18.9	21.2	70.7	16.7	7.9	6.2	7.5	7.4	6.4
13	-	20.9	20.7	53.5	18.7	10.5	6.1	6.5	6.0	7.5
14	-	20.6	20.5	35.4	14.4	10.6	7.3	6.2	5.6	6.3
15	-	21.2	23.0	52.6	16.4	9.5	7.5	7.8	7.8	6.7
16	-	15.5	15.5	21.0	15.3	7.9	5.2	4.2	5.4	6.0
17	-	-	20.9	73.8	18.7	9.1	6.7	7.4	7.9	7.6
18	-	-	22.7	59.8	13.2	9.7	7.3	8.8	5.6	6.2
19	-	-	14.0	22.4	13.3	8.2	5.3	4.6	5.0	5.4
20	-	-	18.1	34.4	19.7	9.6	5.4	5.3	5.2	7.5
21	-	-	20.7	38.2	-	4.9	5.3	8.9	8.8	3.5

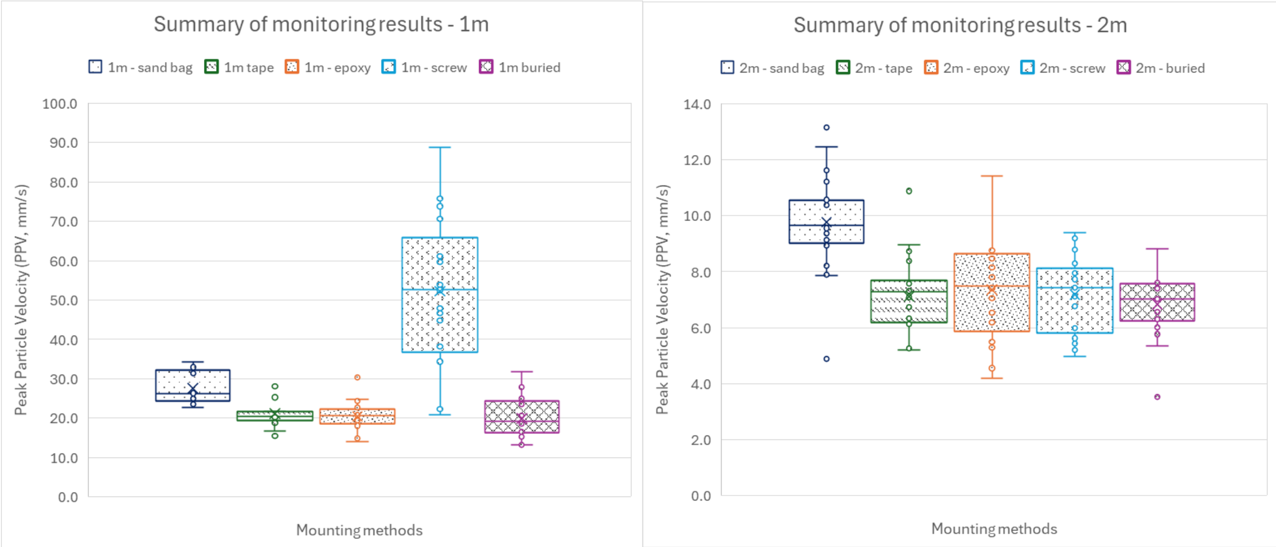

Figure 2: Summary of monitoring results from drop tests 1 and 2 m offset – PPV, mm/s

Measurements show that at the 1 and 2 m offset distances, the mounting methodologies all produced PPV measurements which are broadly consistent with one another. The one exception to this is with respect to the 1 m offset ground screw mounted monitor. As shown in Table 1 and Figure 2, the PPV values recorded at this location are in the order of 2-3 times the measured values from other mounting methods.

A detailed investigation into the cause of this showed greatly elevated levels in the radial component. This can be seen in Figure 3, where the peak velocity in the radial component for the screw mount method is substantially greater than other mounting methods.

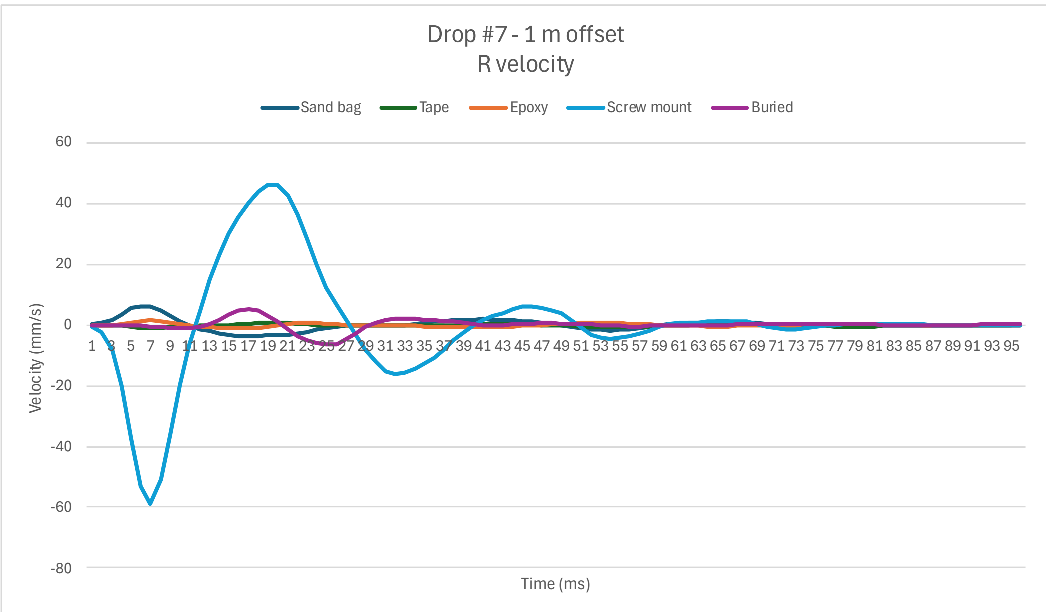

Figure 3: R velocity response at 1 m from 20kg drop #7 for multiple mounting types

Frequency domain analysis confirmed that the anomalous radial energy was concentrated in a narrow spectral band around 35–53 Hz — a frequency entirely absent from the transverse and vertical channels of the same sensor. The excitation shown in the radial component is most likely caused by mechanical coupling resonance rather than ground motion. The likely outcome is that the ground screws and geophone assembly resonate at a fixed natural frequency in response to the impact excitation, producing a large oscillatory signal in the channel aligned with the ground screws' rocking axis. The strong frequency response in the radial component can be seen in Figure 4 where a Fast Fourier Transform (FFT) was performed on the .wav data recorded at the screw mounted sensor.

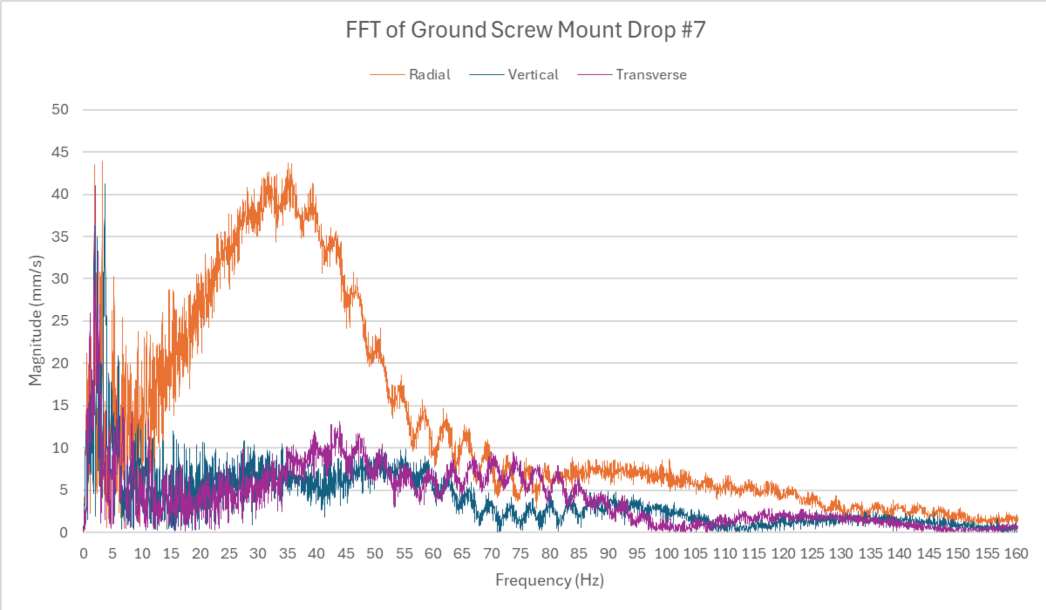

Figure 4: Fast Fourier Transform (FFT) of ground screw mounted monitor

By excluding this anomaly for measurements at the ground screw mounted logger, the adjusted PPV levels indicate what would typically be expected, and is in line with other mounting methods and with the deviations of monitoring results shown at 2 m. Improvements on the testing methodology would include altering the mounting methodology to incorporate at minimum 3 attachment points to ensure any radial movement generated by surface vibration waves are mitigated.

At the 1 m offset, where ground motion amplitudes were substantially higher, greater divergence between mounting methods can be observed. The sandbag mount exhibited the widest shot-to-shot variability, reflected in a high coefficient of variation relative to the other surface methods. This is attributed to inconsistent contact pressure between the sandbag and the geophone base across repeated drops, which allows partial decoupling under high-amplitude impulsive loading. Adhikari [3] and Robertson [4] detail examples of this at high magnitudes of ground vibration. Tape and epoxy bonding produced more repeatable results at this distance, suggesting superior coupling consistency.

At the 2 m offset, where near-field effects are reduced and coupling artefacts are less pronounced, the four surface-mounted methods (tape, sandbag, epoxy, and ground screw) produced PPV measurements broadly consistent with one another and with the buried reference sensor. This finding suggests that, under moderate amplitude far field conditions, all surface mounting methods provide adequate coupling fidelity for practical vibration monitoring purposes.

It is noted that at both the 1 m and 2 m offset distances, the surface mounted sandbag method produced median PPV measurements 37-38% greater than the median measurements for buried sensor measurements. Table 2 shows the calculated means and median measurements for all sensor measurements at both 1 and 2 m.

Table 2: mean and median of sensor measurements

	1 m from impact point (PPV, mm/s)					*2 m from impact point (PPV, mm/s)*				
	Sandbag	Tape	Epoxy	Screw	Buried	Sandbag	Tape	Epoxy	Screw	Buried
Mean	27.0	20.6	20.6	18.5*	19.0	9.8	7.0	7.4	7.1	7.0
Median	26.4	20.6	20.7	17.6*	19.2	9.7	7.3	7.5	7.4	7.0

*not applicable for comparison due to elevated radial component being removed from PPV calculation

4. CONCLUSIONS

The results of this study offer several practical conclusions for the selection of geophone mounting methodology in field vibration monitoring. Depending on the field circumstances, environment and other factors, preferred sensor coupling methodologies may not be available. This paper investigated the relative effectiveness of different coupling methodologies while excited by an impulse force generated by a 20 kg weight drop.

Five coupling methodologies were used and results show that all coupling methods may be used as a valid methodology for vibration measurements. Risks have been identified with both the sandbag and ground screw mounting methodologies, where insufficient ballast weight or a two-point ground attachment have the potential to introduce measurement artefacts through decoupling or mechanical resonance respectively. Care should be taken when undertaking these methodologies to ensure that adequate coupling is achieved depending on the available mounting plate and anticipated vibration. Whilst burial is the most commonly referred to method (as it eliminates free-surface amplification, suppresses rocking-mode resonance, and provides the most consistent coupling across a range of amplitudes), both tape and epoxy mounting methods produced very consistent comparable results with a low range of outliers.

Ground screw mounting systems, as utilised within this paper, demonstrated elevated radial channel readings attributable to a rocking resonance arising from the geometric constraint of the attachment. This does not present an inherent limitation of screw-based mounting as a methodology, but rather a consequence of the limitations in the available attachment geometry. Two screws define a single pivot axis, allowing rotational freedom in the perpendicular plane that is directly sensed by the radial channel under impulsive loading. This limitation is avoidable by increasing the number of attachment points to three or four, arranged to eliminate any single pivot axis and is expected to substantially reduce or eliminate the abnormal signal observed. Screw-based systems offer practical advantages over surface adhesives and ballast methods including greater mechanical stability, resistance to displacement under repeated high-amplitude impacts, and suitability for use on hard or compacted surfaces where buried installation is impractical.

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