VERIFICATION OF THE EFFECTS OF ROLLING DYNAMIC COMPACTION USING A CONTINUOUS SURFACE WAVE SYSTEM

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ABSTRACT

Impact rolling or rolling dynamic compaction (RDC) has been used to redevelop the site of an old waste tip. The fundamental principle of RDC is a non-circular drum rotating about one corner and falling to impact the ground, while being towed at 10-12km/h. Surface wave measurements show that the RDC has been effective in improving the strength of the material below ground surface. The successful application of the RDC resulted in a cost-effective and environmentally sustainable solution.

1 INTRODUCTION

The concept of rolling dynamic compaction (RDC) dates from some decades ago, although the extent of potential applications has expanded significantly since the 1980s. It is aimed primarily at compacting large areas of ground for the purposes of earthworks to facilitate the construction of buildings and roads. It is also used for the compaction of haul roads and tailings dams for the mining industry, and to compact previously filled ground, including waste material present in landfills (Avalle, 2004).

The RDC principle is illustrated in Figure 1, which shows a four-sided impact roller. Impact rollers have demonstrated compaction to depths of more than one metre below the ground surface (and more than 3m in some soils), far deeper than conventional static or vibratory rollers (Clegg and Berrangé 1971; Clifford 1976, 1978), which are generally limited to depths of less than about 0.5m. In addition, RDC is unique in that it is able to compact large areas of open ground effectively and efficiently. This is due mainly to its relatively high towed speed of 10-12km/h, compared with 4km/h for conventional vibrating drum rollers (Pinard 1999), and the relatively deep compaction achieved with only a few passes.

This paper presents a case study where rolling dynamic compaction has been used on a residential development overlying an old waste tip. The aim of the compaction process was to engineer the site to conditions suitable for the proposed dwellings. A continuous surface wave system (CSWS) was used to monitor the compaction effectiveness. Shear wave velocity measurements were taken to evaluate material stiffness parameters before and after the dynamic compaction process. This allows the assessment of the degree of improvement achieved on site with the use of RDC.

(a) (b)

Figure 1. Rolling dynamic compaction in the form of a 4-sided impact roller:
(a) in use on a landfill application ; (b) cross-section of the impact module.

2 SITE DESCRIPTION AND GROUND CONDITIONS

The site covers an area of approximately 2.2ha and forms part of a former basalt quarry. It is bounded by recreational land, a main road and residential properties. Quarrying took place from the early 1960s for about 10 years, after which the deepest part of the quarry was filled with domestic refuse and this was complete by the late 1970s (Avalle and McKenzie, 2005).

Basalt had been quarried to the deepest depth in the central third of the site, and this area had been filled with refuse, observed to be about 3-4m thick, and capped with 2-3m of quarry overburden. Most of the site was covered with reworked quarry overburden, comprising silty to sandy clay with fragments of basalt. Significant settlement had occurred in the central part of the site, indicating the zone of buried waste (Figure 2).

Development plans required substantial re-levelling of the site surface, including filling in the depressed central zone and cutting from the higher natural ground, to facilitate the provision of roads and drainage. The ground conditions at the time presented a challenge for the design of footings and pavements. Complete removal of the old refuse or a piled solution were both considered unacceptable options from environmental and cost perspectives.

Figure 2. Panorama of depressed central area during preliminary site stripping (Avalle and MckenzieMcKenzie, 2005).

3 GROUND IMPROVEMENT PROCESS

The ground improvement process comprised the stripping and stockpiling of most of the existing capping over the refuse (leaving a minimum cover of 0.5m so that waste was not exposed at the surface) and the use of RDC to densify the fill material. RDC was accomplished using an 8t 4-sided (or "square") impact module towed in a frame by a 4-wheel drive tractor, a technique that has been utilised for various applications around Australia for more than 20 years (Avalle 2004).

The excavated quarry overburden overlying the refuse was stockpiled and tested for suitability as final capping material. The RDC applied over the refuse filled area was controlled by surface settlement monitoring, with rolling continuing until "effective refusal" was observed, i.e. there was no further significant measurable settlement. "Effective refusal" was determined in this case by averaging the measured settlements over the whole area and observing the rate of increase on a plot of impact roller passes versus average settlement (Avalle and McKenzie, 2005).

Other filled areas away from the buried refuse were also impact rolled. Subsequently, the capping over the refuse was replaced as engineered fill in the conventional manner, and finally proof-rolled with the impact roller. Natural soil sourced from the high part of the site was used to surcharge the capped refuse. Subject to the results of in situ tests and settlement monitoring, allowance had been made for the potential provision of geogrid reinforcement within the capping over the refuse filled area to reduce the risk of significant long-term differential settlements.

4 VIBRATION MONITORING

Vibrations induced by compaction can be a potential source of nuisance to people or damage to surrounding structures. Field measurements of the magnitude of vibration are useful to assess this risk. In the present case, vibration measurements were collected at the site boundary, particularly with respect to the nearby residences. Measurements of peak particle velocity (PPV) were made using Minimate Plus vibration monitors at 6m, 17m and 46m from the edge of the roller activity area, respectively for stations B, C and A (see Figures 3 and 4).

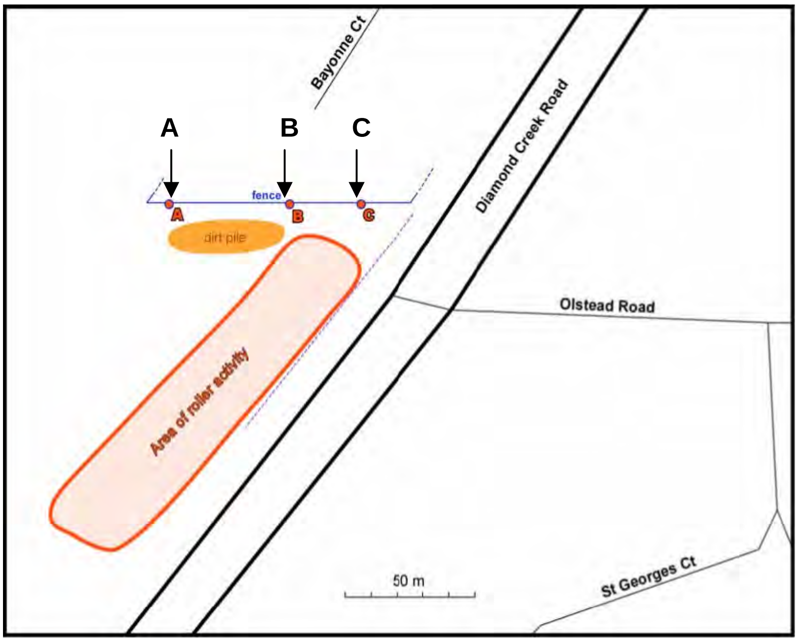

Figure 3. Monitoring locations in relation to area of compaction activity.

Figure 4. Location of vibration monitors.

The vibration monitors were used in continuous recording mode for the entire time the impact roller was operating. A typical histogram output is shown in Figure 5, in which it can be seen that the maximum levels were recorded during the first passes of the roller. The 6m distance was set for the purposes of an initial trial, and the maximum recorded PPV was

8mm/s. Figure 5 shows a reduced maximum PPV value when the impact roller was operated further from the fence line. The maximum PPV value remained less than 1mm/s at 46m (station A).

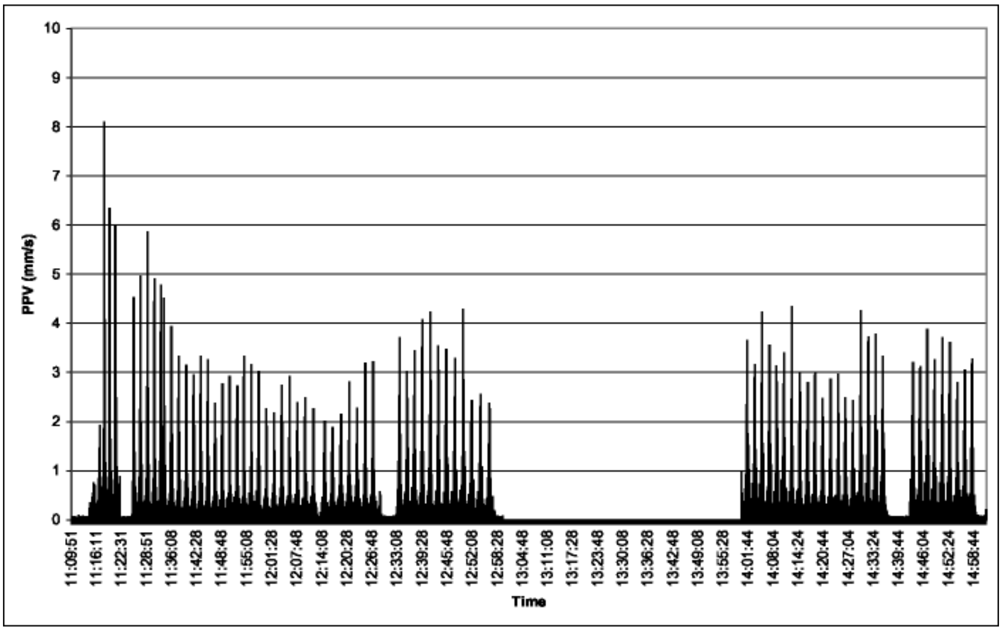

Figure 5. Ground vibration at station B (closest distance = 6m).

Figure 6 shows the maximum PPV values recorded against distance where the roller was the closest to the monitoring stations. The nearest residence was just over 20m for the isolated occasions where the impact roller approached the closest boundary. Based on the results shown in Figure 6, it was concluded that nearby residences were unlikely to experience a peak particle velocity greater than 2-4mm/s, which is below the structural damage criterion of 10mm/s that was imposed on this site by the local authority.

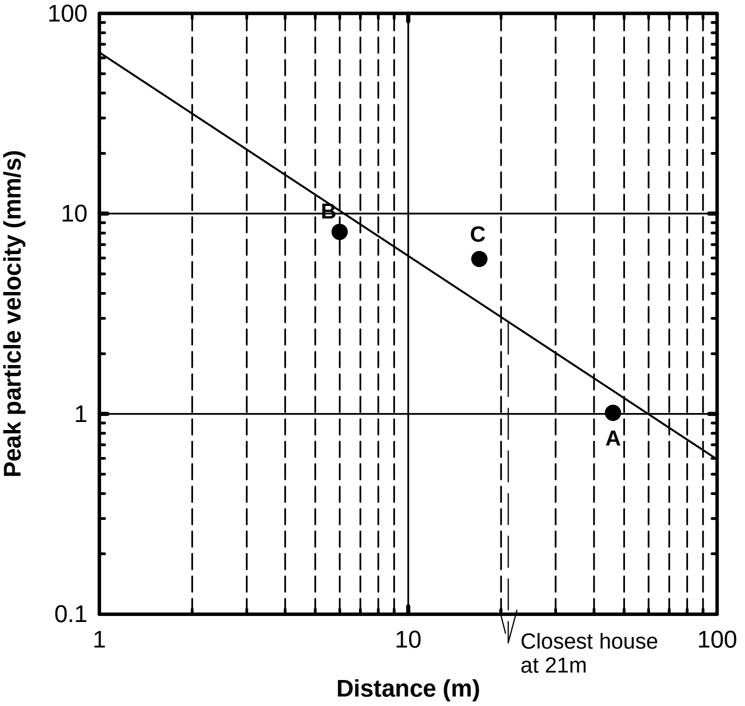

Figure 6. Distance versus peak particle velocity.

Figure 7 gives a clear picture of the dependency of peak particle velocity on the scaled energy over the distance from the impact point measured in the waste fill. A scaled energy factor for the RDC has been calculated by dividing the square root of the potential energy of the impact module (the 8t module falling approximately 0.16m) by the distance from the point of impact. Data by Lukas (1986), involving loose decomposed waste compacted dynamically (dynamic compaction), is also shown in this figure for comparison. The peak particle velocity achieved with RDC is generally lower than the one achieved with conventional dynamic compaction. It is also evident that the ground vibrations induced by RDC on this particular site should have been perceptible but not disturbing to people.

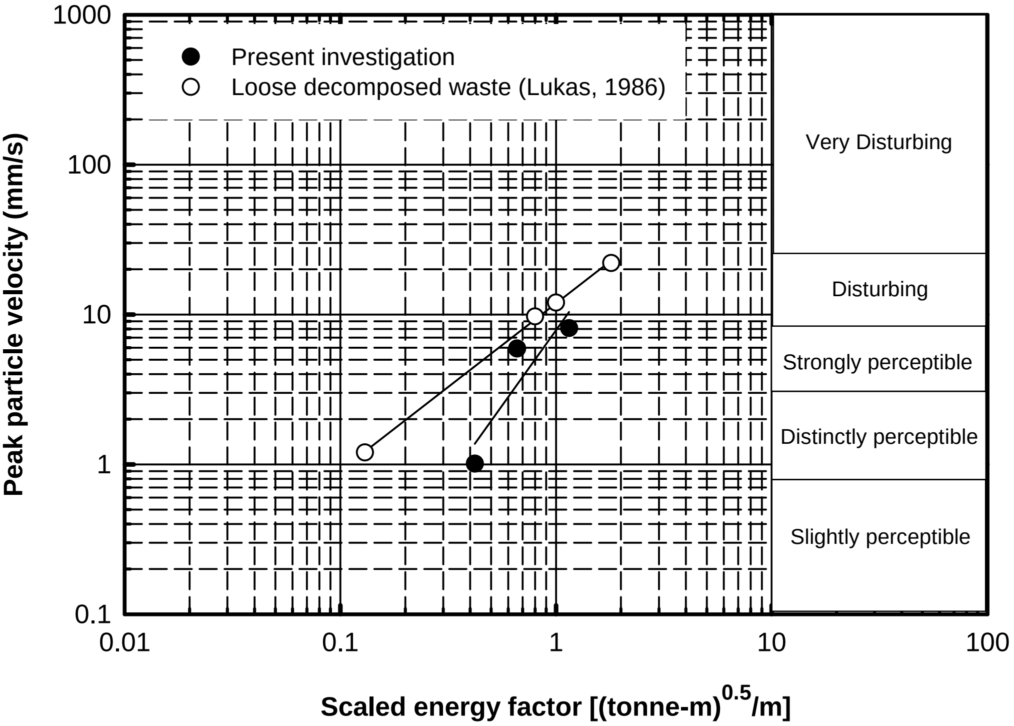

Figure 7. Scaled energy factor versus peak particle velocity (modified from Lukas, 1986).

5 GROUND IMPROVEMENT QUALITY CONTROL

The control of the efficiency of a given ground improvement technique is of a paramount importance since it provides the confidence that certain design criteria have been met. However, in the case of municipal solid waste fills, it is difficult to obtain a reasonable evaluation of the stiffness of the fill by means of traditional testing methods (Bouazza et al, 1996; Bouazza and Gambin, 1997).

The evaluation of ground modification must ideally be fast to reduce equipment downtime, to produce results in the field for immediate assessment, to be customisable for investigating any zone of interest and to directly evaluate the improvement of the properties as a function of depth without recourse to empirical correlations. In this respect, non-intrusive methods based on surface wave systems such as the Spectral Analysis of Surface Waves (SASW) technique and the Continuous Surface Wave System (CSWS) are ideal tools to speed up the control process and have proved to be reliable in characterising solid waste landfills (Kavazanjian et al., 1996; Van Impe and Bouazza, 1996; Bouazza and Kavazanjian, 2000; Abbiss, 2001; Avsar and Bouazza, 2004). The surface wave methods are particularly attractive for landfill investigations because of their non-intrusive nature, which eliminates many of the health and safety concerns typically associated with intrusive boring and sampling programs, and because they “average” the properties of the waste mass over a relatively large volume of material..

In the present investigation, a continuous surface wave system (CSWS) was utilised to verify the ground improvement process selected for the site. It makes use of Rayleigh (surface) waves which propagate within a zone approximately one wavelength in depth (Stokoe et al., 1994). In ground where the stiffness changes with depth, these surface waves are dispersive in nature, which means that they travel at a velocity that is dependent upon frequency or wavelength. A single CSWS survey can be set up and carried out in about one hour, producing a stiffness depth profile with around 50 measurements. The seismic control unit incorporates software that controls an electromagnetic vibrator, which is set oscillating at a series of fixed frequencies (Figure 8). A typical vibrator has a capability of generating surface wave frequencies of 5 to 200 Hz. The vibrator generates Rayleigh waves which travel parallel to the surface at a depth of around one wavelength. These surface waves are detected by a row of sensors or "geophones" and the velocity of the wave is measured. The time history of particle velocities measured at each geophone is transformed into the frequency domain by Fourier transformation and the phase angles are determined for a given frequency at each geophone. The phase angles are plotted against the location of the geophones as shown in Figure 8.

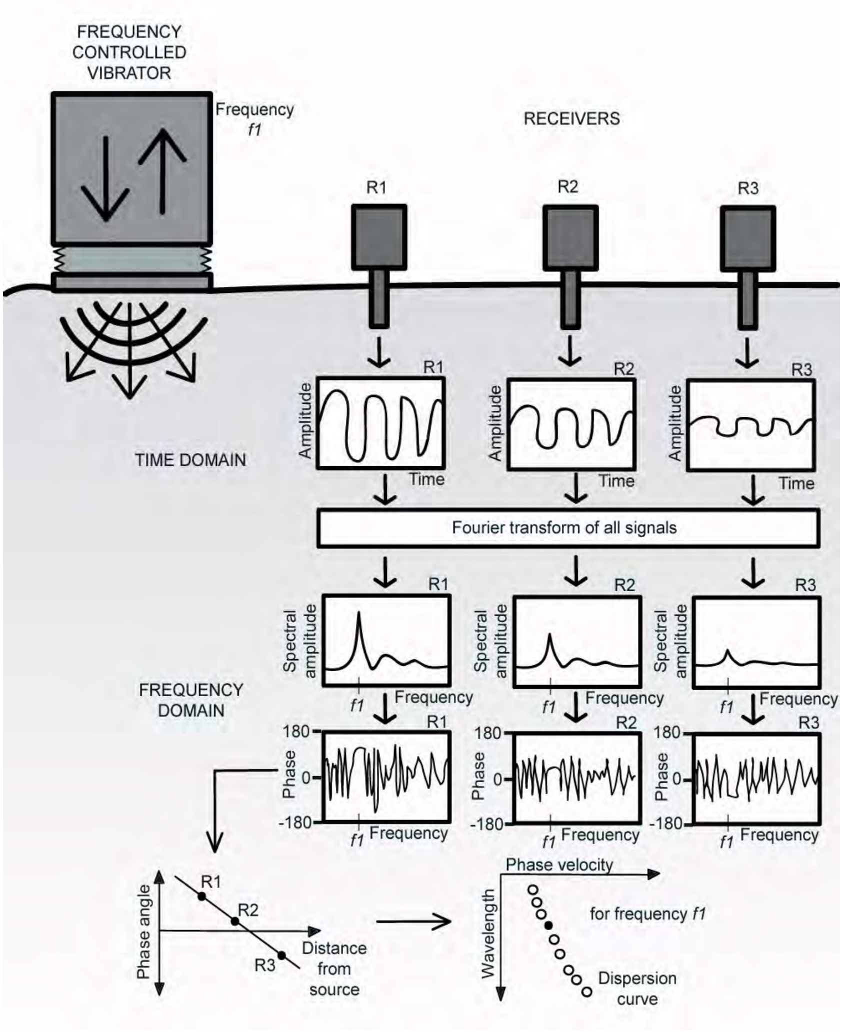

Figure 8. CSWS procedure (adapted from Matthews et al, 1996)

The resulting dispersion curve can be inverted using a variety of different methods to give the velocity-depth profile from which the stiffness-depth profile can be determined. The wavelength depth method is the simplest, but least exact, of the methods. It is of practical value because it offers a relatively quick way of processing data on-site and so enables preliminary assessment. In the wavelength/depth method the representative depth is taken to be a fraction of the wavelength λ. That is, λ/z is assumed to be a constant. A ratio of 2 is commonly, but arbitrarily, used (Ballard and McLean, 1975; Abbiss, 1981). Gazetas (1982) recommended that 4 is used for λ/z at sites where the stiffness increases significantly with depth, and that 2 is suitable at more homogeneous sites. A ratio of 2 has been used in the present investigation. If one of the other available techniques is used (e.g. Haskell-Thomson matrix method or finite element forward modeling), then the wavelength/depth method can provide a useful initial estimate of the velocity-depth profile to input to the other algorithms.

Typical results of the variation of shear wave velocity versus depth, before and after compaction, are given in Figure 9 for different locations. These figures indicate that most of the improvement is concentrated in the near surface material (i.e. to depths $\leq$2m). All results demonstrate that ground improvement has occurred since shear wave velocity is directly related to the material stiffness. The evident strength gain enabled the design of the final capping to be completed without the requirement to include geogrid reinforcement, a significant cost saving to the developer.

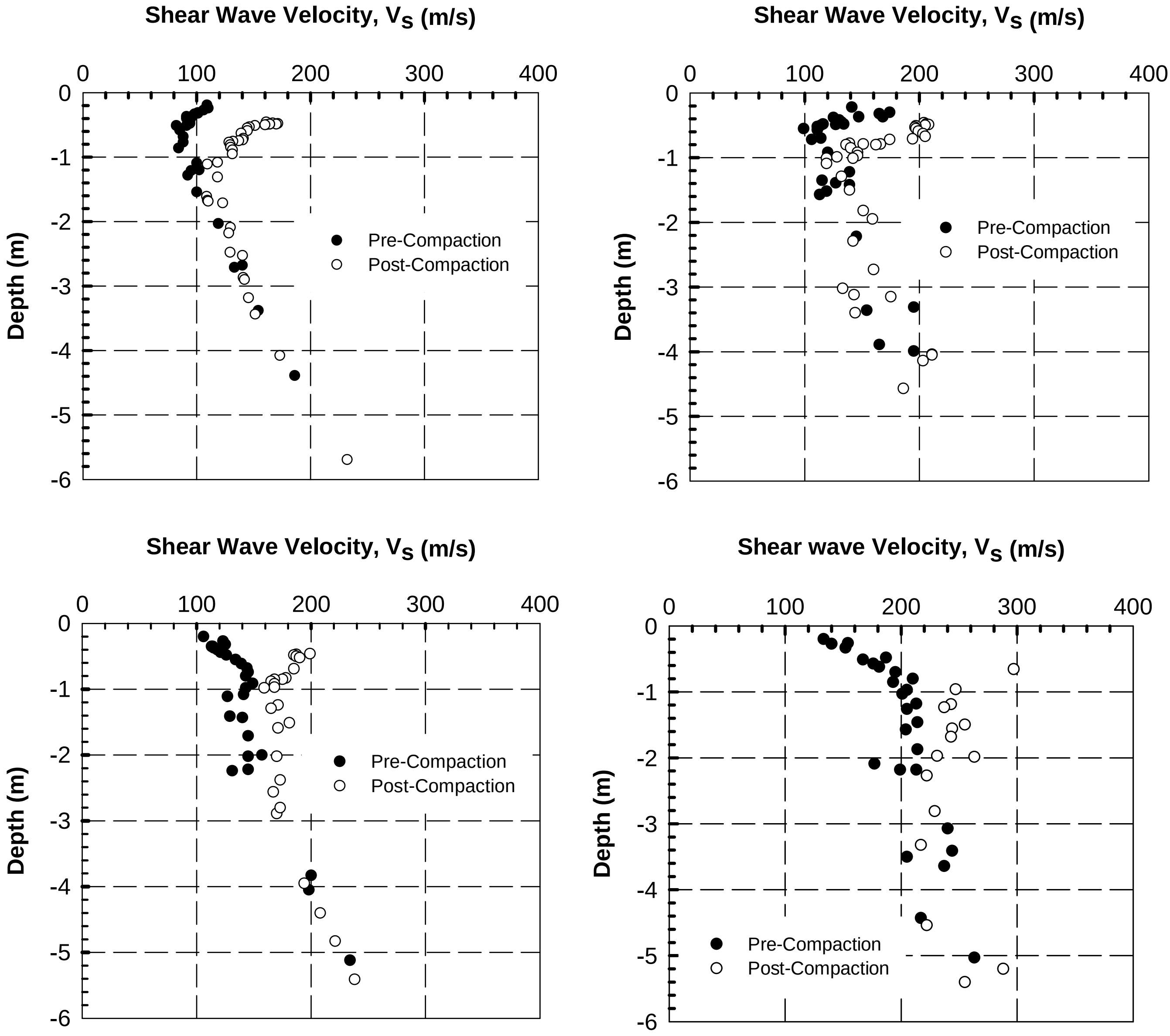

Figure 9. Shear wave velocity versus depth at different locations

6 CONCLUSIONS

Non-invasive evaluation of the effectiveness of the compaction process adopted for the site shows that most of the improvement is concentrated in the near surface material (i.e. to depths ≤2m). The evident strength gain enabled the design of the final capping to be completed without the requirement to include geogrid reinforcement.

Vibration monitoring indicated that vibration levels at the closest house were unlikely to exceed 3mm/s, which is in accordance with the levels outlined in the job specifications (<10mm/s). Ground improvement using the rolling dynamic compaction (RDC) method has proven to be successful in preparing what was initially a geotechnically challenging site with a history of quarrying activity and waste disposal, for residential development. More importantly, the use of this method resulted in an environmentally acceptable and cost-effective solution.

7 ACKNOWLEDGEMENTS

The authors extend their appreciation to the Client, the Fortunato Group; to the project designers, the Bonacci Group; and to the developers, Pacifica Corporate Developments, for permission to utilise technical data obtained during site preparation. Vibration monitoring was carried out by Terrock Consulting Engineers.

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