Effectiveness of Rolling Dynamic Compaction on an Old Waste Tip

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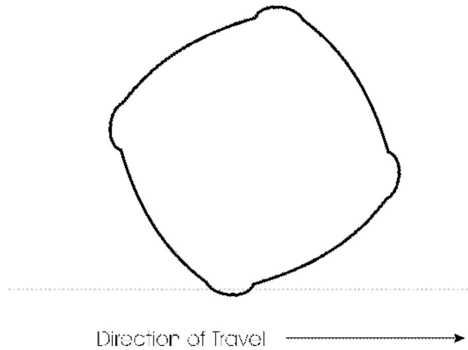
Abstract
A relatively new form of ground densification known as rolling dynamic compaction (RDC) has been used to redevelop an old waste tip site. The fundamental principle of rolling dynamic compaction is a non-circular drum rotating about one corner and falling to impact the ground. Surface wave measurements 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.

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 road and building construction, as well as for the construction of haul roads and tailings dams for the mining industry. It can also be used to compact filled ground, including waste material present in landfills (Avalle, 2004). The fundamental principle of RDC is a non-circular drum rotating about one corner and falling to impact the ground (Figure 1). Impact rollers have demonstrated compaction to depths of more than one metre below the ground surface (and more than 3 m in some soils), far deeper than conventional static or vibratory rolling (Clegg and Berrangé 1971, Clifford 1976, 1978), which is generally limited to depths of less than half of a metre to a metre. 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 (approx. 12 km/hr, compared with 4 km/hr for conventional vibrating drum rollers, Pinard 1999) and relatively deep compaction.

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 constant surface wave system (CSWS) was used to monitor the compaction effectiveness. Shear wave velocity measurements were taken to evaluate the waste 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 in landfill application; (b) cross-section.

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).

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

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.

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 rolling dynamic compaction to densify the fill material. Rolling dynamic compaction was accomplished using an 8t non-circular (4-sided or "square") impact module towed in a frame by a 4-wheel drive tractor, a technique 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. Rolling dynamic compaction 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. 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.

Vibration monitoring

Vibrations induced by the 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 performed at the site boundary, particularly with respect to the nearby residences.

Measurements were made at 6m, 18m and 46m, respectively, from the impact. The maximum velocity at 6m was 8mm/s and reduced to less than 1mm/s at 46m (Figure 3). The nearest residence was about 25 to 30m for the isolated occasions where the impact roller approached the closest boundary. Based on these results, it was concluded that the nearest residence was likely to experience a maximum peak particle velocity of 2-4mm/s

Figure 4 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. 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 clearly shown that the ground vibrations, induced by RDC, are not disturbing to people.

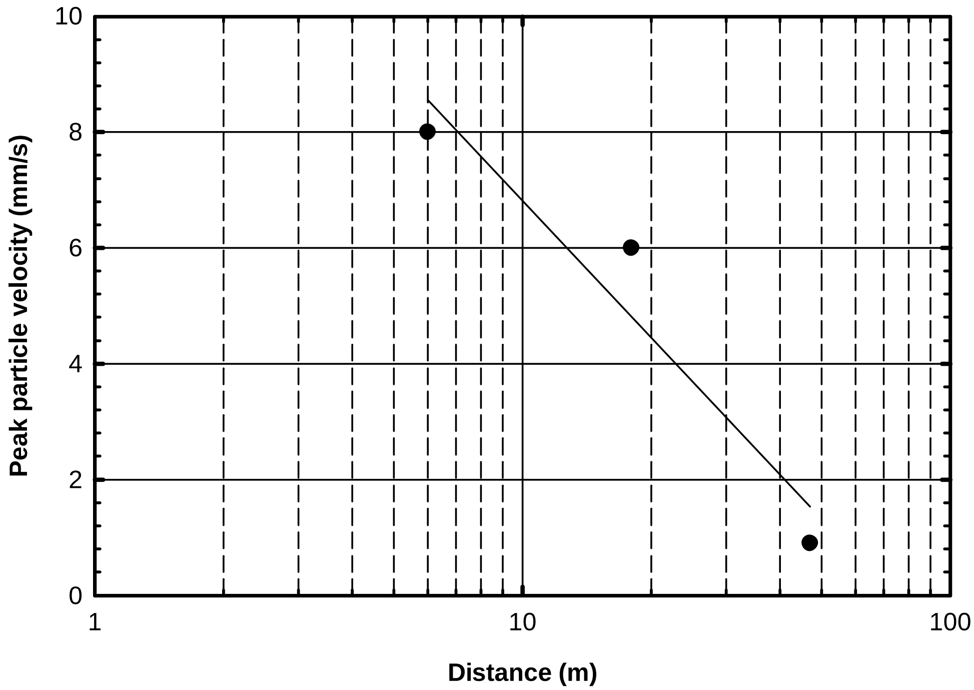


Figure 3. Distance versus peak particle velocity.

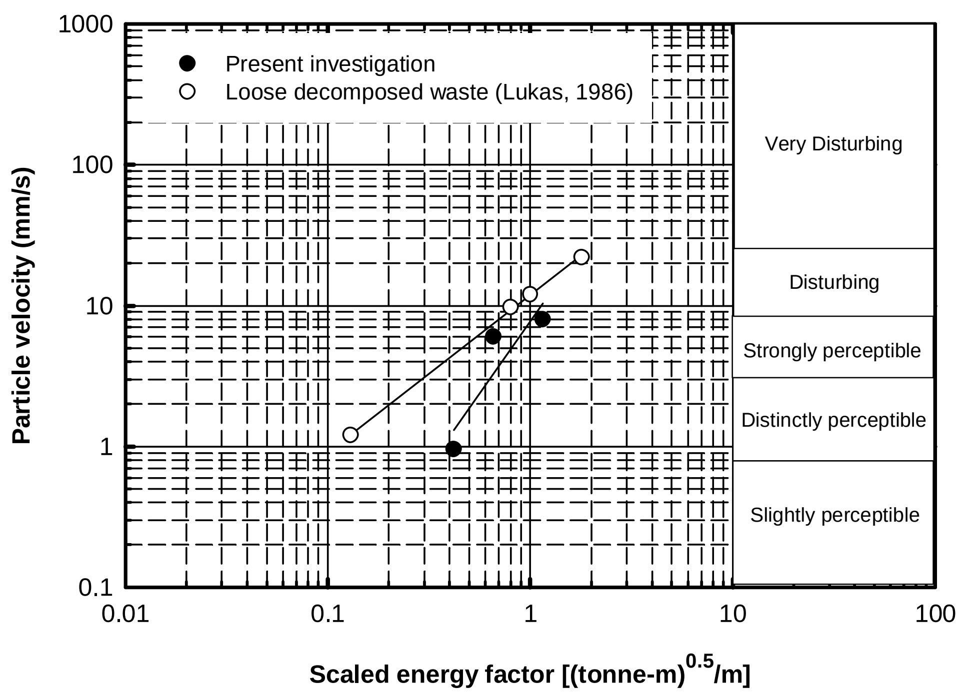


Figure 4. Scaled energy factor versus peak particle velocity (modified from Lukas, 1986).

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 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 & Bouazza, 1996, Bouazza & 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. A single survey can be set up and carried out in about one hour and produces 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. 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 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 & 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 5 for different locations. These figures indicate that most of the improvement is concentrated in the near surface material (i.e., to depths $\leq$ 2 m). 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.

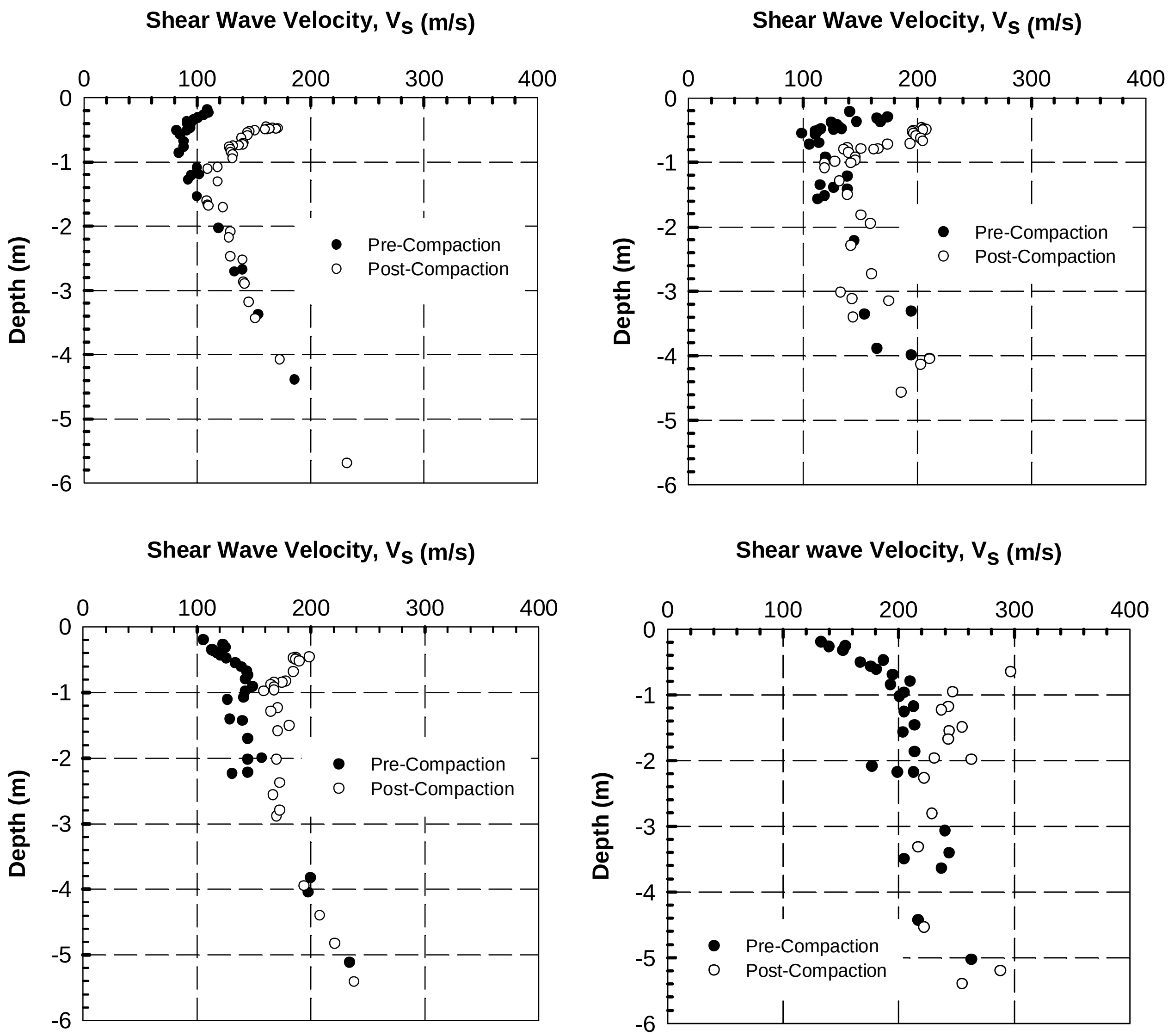


Figure 5. Shear wave velocity versus depth at different locations

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 ≤ 2 m). The evident strength gain enabled the design of the final capping to be completed without the requirement to include geogrid reinforcement.

Ground improvement using the rolling dynamic compaction (RDC) method has proven to be successful in preparing, 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.

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References

Abbiss, C.P., 1981. Shear wave measurements of the elasticity of the ground. Geotechnique, Vol.31, pp.91-104.

Abbiss, C.P., 2001. Deformation of landfill from measurements of shear wave velocity and damping. Geotechnique, Vol.51, No 6, pp.483-492.

Avalle, D.L., 2004. Ground improvement using the square Impact Roller - case studies. 5th International Conference on Ground Improvement Techniques, Kuala Lumpur, Malaysia, pp. 101-108.

Avalle, D.L. and McKenzie, R.W., 2005. Ground improvement of landfill site using the square impact roller. Australian Geomechanics, Vol. 40, No 4, pp.15-21.

Avsar, M.S. and Bouazza, A., 2004. Use of a geostatistical method to optimise spatial distribution of shear wave velocities in a landfill. Proceedings 9th Australia-New Zealand Conference on Geomechanics, Auckland, New Zealand, pp. 441-445.

Ballard R.F. and McLean, F.G., 1975. Seismic field methods for in-situ moduli. Proc. Conf. on In-situ Measurements of Soil Properties, ASCE, Vol.1, pp.121-150.

Bouazza, A. and Gambin, M., 1997. How to choose quality control testing of municipal waste after treatment by dynamic compaction? Proceedings 3rd International Conference on Ground Improvement Geosystems: Densification & Reinforcement, London, U.K, pp.54-60

Bouazza, A. and Kavazanjian, Jr., E., 2000. Characterization of municipal solid waste sites using the continuous surface wave method. Proceedings International Conference on Geotechnical and Geological Engineering, GeoEng.2000, Melbourne, Australia. (CD-Rom)

Bouazza, A., Van Impe, W.F. and Haegeman, W., 1996. Quality control of dynamic compaction in waste fills. Proceedings 2nd International Congress on Environmental Geotechnics. Osaka, Japan, Vol.2, pp.635-640

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, pp. 65–73.

Clifford, J. M., 1976. Impact rolling and construction techniques. Proceedings ARRB Conference, Vol. 8, pp. 21–29.

Clifford, J. M., 1978. The Impact Roller – Problems Solved. The Civil Engineer in South Africa, Vol. 20, No2, pp. 321–324.

Gazetas, G., 1982. Vibrational characteristics of soil deposits with variable wave velocity. Int. Journal For Numerical & Analytical Methods in Geomechanics, Vol. 6, pp.1-20.

Kavazanjian, Jr. E., Matasovic, N., Stokoe, K.H. and Bray, J.D., 1996. In-situ shear wave velocity of solid waste from surface wave measurements. Proceedings 2nd International Congress on Environmental Geotechnics, Osaka, Japan, Vol. 1, pp.97-104.

Lukas, R., 1986. Dynamic compaction for highway construction. Volume 1: Design and Construction Guidelines, FHWA/RD-86/133.

Pinard M.I., 1999. Innovative developments in compaction technology using high energy impact compactors. Proceedings 8th Australia-New Zealand Conference on Geomechanics, Hobart, Australia, Vol. 2, pp.775–781.

Van Impe, W.F. and Bouazza, A**.,** 1996. Densification of waste fills by dynamic compaction. Canadian Geotechnical Journal. Vol. 33, No 6, pp.879-887.