Mining Applications and Case Studies of Rolling Dynamic Compaction

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ABSTRACT

Rolling Dynamic Compaction (RDC) is a generic term associated with densifying the ground using a non-circular roller. The application and use of RDC in the mining industry is increasing because of its ability to compact ground efficiently by means of a faster operating speed (10-12 km/h) and compaction of thicker layers than conventional circular rollers. Whilst conventional rollers are able to compact fill in layers up to 400 mm, thicker layers are able to be adopted using RDC for the construction of tailings dams and mining haul roads. Increased layer thicknesses enable larger particle sizes to be used, therefore greater reuse of mine spoil material can be undertaken with a reduced need to screen out large quantities of oversized materials. As well as demonstrating how RDC has been used effectively for the compaction of bulk earthworks at two different mine sites, this paper also discusses various aspects and factors associated with conducting a compaction trial on mine spoil materials.

Keywords: compaction, impact, roller, ground, improvement, mining

1 INTRODUCTION

Rolling Dynamic Compaction (RDC) is a generic term associated with densifying the ground using a non-circular roller module of 3, 4 or 5 sides, that rotates about its corners as it is towed, causing it to fall to the ground and compact it dynamically. A square impact rolling module is shown in Figure 1.

The use of RDC is increasing in the mining industry for applications such as proof rolling and construction of mining haul roads. Subjected to traffic movements by heavy haul trucks and other earthmoving equipment, the condition of haul roads can rapidly decline over time. The ability of RDC to gain an increase in strength of compacted material (thus increasing the bearing capacity) means that haul roads are more capable of supporting imposed stresses from heavy mining earthmoving equipment. The ability of RDC to detect weak (low density) areas or soft spots (zones of high moisture content in clayey soils) that can then be replaced or reworked reduces the potential for differential settlements to occur as a result of subgrade soils that do not have adequate stiffness. As explained by Avalle (2006), the ability of RDC to improve the uniformity and density of subgrade soils and haul roads makes it highly suitable as a proof roller. Improved haul roads greatly reduce the stress on haul truck frames and suspension, resulting in less rolling resistance, greater surface uniformity and reduced tyre temperatures, factors that all help to increase tyre life. As discussed by Avalle (2006), there is also reduced likelihood of rock spillage from haul trucks, thereby reducing the potential for damage to other haul road vehicles. As well as haul roads, RDC has been used on pit floors and tip heads (Broons 2012) to help break down and rubbilise large surface rocks that are potentially hazardous to haul truck tyres and therefore costly for mine operators in terms of replacement cost and potential loss of production if spare tyres are not readily available.

A current focus area of research by the authors of this paper is on low permeability covers that are constructed over mine waste materials. Covers or capping layers are typically used to reduce the percolation of surface water through to mine waste that could lead to environmental hazards. The application of RDC to create a low permeability cover in mining applications is similar to previously documented cases where RDC has been used in landfill environments, such as the case study described by Avalle and Mackenzie (2005). Due to space constraints, examples and applications of RDC for rubbilising rock and creating low permeability capping layers are beyond the scope of this paper, and are topics of future papers.

2 THICK LIFT COMPACTION OF MINE SPOIL MATERIALS

The focus of this paper is to present two case studies that demonstrate how RDC has been used effectively in the compaction of bulk earthworks of mine spoil materials. In particular, the ability of RDC to compact thick layers (500 mm or more) and use larger particle sizes that are commonly encountered in mining environments is discussed in examples where thick lift compaction was used for the construction of tailings dams and embankments. Greater recycling of mine spoil materials can be undertaken with a reduced need to screen out large quantities of oversized materials.

Deep fills have been traditionally undertaken by compacting soil in thin layers using relatively small particle sizes placed in a highly controlled manner; shallow density tests are typically undertaken in each layer to confirm performance specifications of the placed fill. Whilst conventional rollers can satisfactorily compact fill in layers up to 400 mm loose lift thickness, as quoted in AS 3798 “Guidelines on earthworks for commercial and residential developments” (Standards Australia 2007a); RDC can typically achieve thick-lift compaction in layers in the vicinity of 500-1500 mm depending upon the material composition, number of passes applied and specified target density ratio. AS 3798 recognises the ability of impact rolling for deeper compaction, suggesting that “alternative testing strategies may be appropriate” and that trial programs may be required to develop the most appropriate testing regime for any particular project or site”. This paper presents examples of trial programs and test methods via two case studies that are discussed in Section 3.

On mining sites where large earthmoving equipment are capable of moving and placing significant volumes quickly, having the ability to compact large volumes in a timely and efficient manner is an obvious advantage of RDC because of its ability to compact ground efficiently by means of a faster operating speed (10-12 km/h) and compaction of thicker layers than conventional circular drum rollers that rely on either static weight, kneading or vibratory action.

3 CASE STUDIES

Particle size distribution tests were performed as per AS 1289.3.6.1 (Standards Australia 2009) for both sites; typical results for each are shown in Figure 2. Site A consisted of tailings material that was fairly typical of a well graded sand with some gravel; 6% clay-sized, 80% sand-sized and 14% gravel-sized fractions, respectively. Conversely, Site B consisted of drag line spoil that was more variable; with 12% clay-sized, 16% sand-sized, 34% gravel-sized fractions, with the remaining 38% cobble- or boulder-sized particles. For Site B, the laboratory determined values of particle size distribution exhibited greater variability than for Site A.

Figure 1: 8-tonne square impact roller

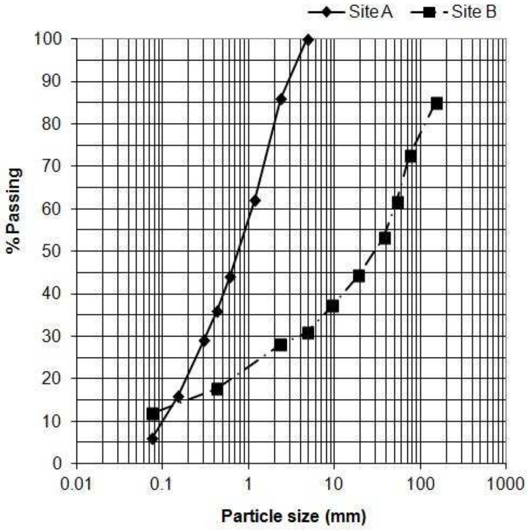

Figure 2: Typical particle size distributions for Sites A and B

The obvious differences in materials dictated that two quite different compaction trials were undertaken. For each case, the underlying objective of both compaction trials was similar; to determine an efficient relationship between the number of passes, layer thickness, moisture content and corresponding dry density ratio that could be achieved. For both sites, a 4-sided 8-tonne impact roller (as shown in Figure 1) was used. At both sites, the water table was located a significant depth below the excavated bench level. Some noteworthy differences and factors that affected each compaction trial are discussed in greater detail in the following sections.

3.1 Design and construction of test pad areas

For the compaction trial at Site A, a test pad approximately 3.6 metres high was constructed (in three lifts of 1200 mm) such that a plan area of approximately 8 m wide by 30 m long was available for testing at the top of the third lift (sufficiently wide so that 3 impact rolling lanes could be rolled to enable testing to occur in the middle lane so that it is representative of a larger scale operation and the effect of rolling adjacent lanes can be taken into account). The trial was conducted as a staged process with one lift placed, rolled and tested each day. The ability of the mine site to work 24 hours a day and utilise large loaders, excavators and haul trucks made the staged trial possible in a short timeframe, as the time to place significant earthwork volumes (even for a trial) should not be underestimated. Allowing for windrows on the sides and ramps at either end the test pad, it was estimated that at least 2500 m^3 of material was used for the trial. Whilst adopting multiple layers for the trial did add extra time, it did mean that the compaction trial could address one of the key concerns for the large scale operation; to determine if a target density could be achieved not only in a single layer, but also on the second and third layers placed above. Undertaking the trial in this manner was then representative of the construction of the tailings dam that was proposed.

The mine had the advantage of previously working with the impact roller for the maintenance of haul roads (albeit on slightly different material). The mine had a preference for adopting a layer thickness that would complement the operational efficiency of other equipment on site; based on these criteria, a maximum layer thickness of 1200 mm was adopted; intermediate testing was undertaken to provide representative results for varying number of passes over a range of depths.

For the compaction trial undertaken at Site B, a single layer, but much larger test pad in plan area, was adopted. The test pad was designed to be sufficiently wide so that 9 impact rolling lanes could be rolled; this enabled three separate zones of 10, 20 and 30 passes to be constructed that could allow testing after rolling to occur in the middle of each zone simultaneously. Given that one of the key objectives of this trial was to determine the thickness of fill that could be compacted for various compactive efforts, the height of the placed fill was benched so that it varied in thickness from 0.5 m through to 1.5 m. Whilst this process took some time and effort from both the surveyor and the dozer operator it did enable all post-compaction testing to be conducted in an efficient manner. Figure 3 shows the trial pad in plan and elevation. Whilst the total length (including ramps) was approximately 120 metres, the actual pad on which the testing was undertaken was of the order of 25 m x 50 m. To allow the impact roller to turn around and reach normal operating speed by the time it reached the ramp areas a nominal area of 170 m long by 25 m wide was cordoned off and used for the trial. It was estimated that approximately 2500 m^3 of material was used for the compaction trial; sufficiently large to be representative of a large embankment (supporting settlement sensitive infrastructure) that was proposed.

For both sites, the impact roller was used to proof roll the sub grade prior to placement of any fill material to ensure there were no soft spots that required rectification prior to commencement of placed fill.

3.2 How was ground improvement using RDC verified?

At Site A, verification of RDC was undertaken using a combination of surveying of surface settlements, soil sampling, as well as a set of in situ tests that was performed after different numbers of passes of the impact roller to determine changes in the soil density profile. The in situ tests undertaken included penetrometer testing, field density testing and geophysical testing. For sites containing significant quantities of mixed soils or oversized particles (such as Site B) the use of traditional (intrusive) geotechnical investigation methods can be problematic (or a test of patience) if effective refusal is met prior to reaching the target test depth. Geophysical techniques are becoming increasingly common in such applications; methods such as MASW (Multi-channel Analysis of Surface Waves) and CSWS (Continuous Surface Wave System) as reported by Scott & Suto (2007) and Avalle & Mackenzie (2005), respectively, enable correlations of Young's modulus to be made from measurements of seismic velocity. At Site A, the Spectral Analysis of Surface Waves (SASW) geophysical technique was used successfully and complemented the other techniques used.

At Site B, verification was determined from combining surface settlement, penetrometer and field density test data. All testing was undertaken at the completion of rolling, with care taken to ensure the correct number of passes was applied to each test lane. Whilst suitable from a geotechnical perspective, geophysical testing was not undertaken at this site as it would have been problematic due to the noise that reverberated off the pit walls from a large number of vehicles that were working at the bottom of a pit floor where the test pit was located. Geophysical testing methods typically rely on geophones, which are sensitive devices that are used to record energy waves passing through soil; however, at Site B such signals would have been overwhelmed by local noise sources, rendering this technique unsuitable for this particular site.

Further to the methods discussed, Avalle (2004) offers a comprehensive list of testing methods that have been adopted prior to, and after impact rolling to quantify ground improvement. As explained by Avalle (2004) there is no simple rule that outlines which testing methods should be adopted or what the scope and nature of trial programs should be, as this depends on factors such as site conditions, budget, efficiency, risk and available equipment.

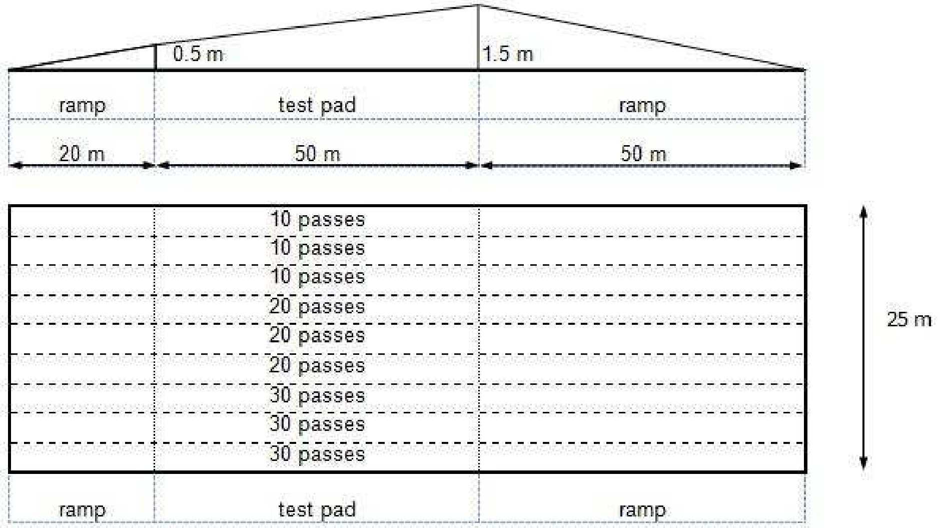

Figure 3: Elevation and plan schematic of trial pad for Site B

3.3 Discussion of test results

The relationship between dry density ratio and layer thickness was established for varying numbers of passes. The results from density tests undertaken after varying numbers of passes of the impact roller at Sites A and B are shown in Figures 4 and 5, respectively, along with polynomial curves of best fit to the measured data. It is interesting to note that the project specifications referred to modified and standard Proctor compaction tests respectively; space restricts detailed discussion on this topic. However, it is noteworthy that for Site B dry density ratios greater than 100% were measured, indicating that field compactive effort (a function of the number of passes and lift thickness) is greater than the compactive effort imparted by the Standard Proctor test under laboratory conditions. For Site A, the results of the compaction trial indicate that the target dry density ratio (95% compaction with respect to maximum modified dry density) can be expected to be achieved after 6 passes on layers up to 900 mm; or 10 passes on layers up to 1100 mm thick. For Site B, the results of the compaction trial indicate that the target dry density ratio (98% compaction with respect to maximum standard dry density) can be expected to be achieved after 10 passes on layers up to 850 mm thick; or 30 passes on layers up to 1000 mm thick. The true benefit of increasing the number of passes occurs at intermediate depths. As shown in Figure 4, within 600 mm from the surface only a small number of passes were needed to meet the project specification for Site A; conversely, below a certain depth (e.g. depths greater than 1000 mm for Site B as shown in Figure 5) the specified density ratio was not obtained despite increasing compactive effort. Based on the results obtained, more than one unique solution could be presented to the mine operators, from which they could then assess the benefits for themselves (taking into account their site conditions) of adopting increasing passes or thinner layers.

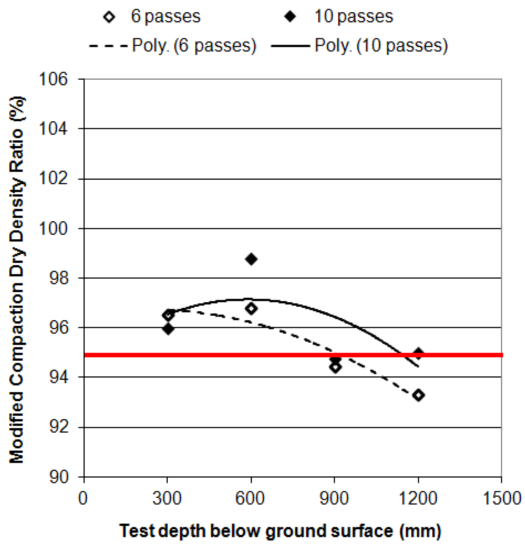

Figure 4: Dry density ratio versus test depth for Site A after 6 and 10 passes, respectively

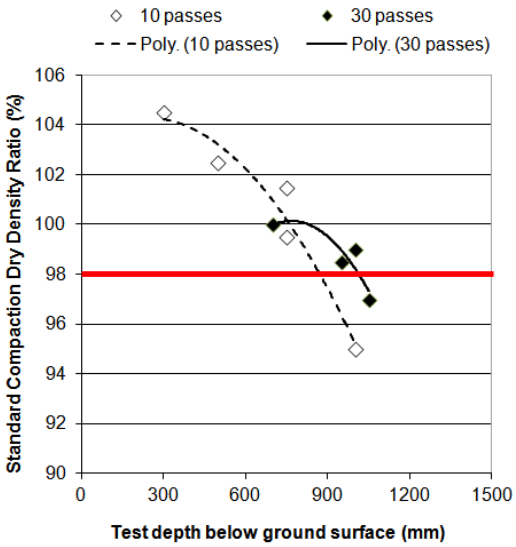

Figure 5: Dry density ratio versus test depth for Site B after 10 and 30 passes, respectively

4 THICK LIFT COMPACTION USING RDC AND AS 3798

It is the experience of the authors that, as most performance based specifications nominate a target density ratio, field density testing is commonly undertaken to verify thick-lift filling using RDC. The determination of field density testing using a nuclear density gauge (Standards Australia 2007b), is the current industry standard, and involves determining the in situ density at discrete locations within 300 mm below the tested surface, making it an ideal testing method where conventional surface compaction techniques and relatively thin layers (lifts) are used. However, in RDC applications involving thicker lifts such as at Sites A and B, verification using field density testing required excavation through compacted material to targeted bench levels across the test pad to determine the zone of influence. Scott & Suto (2007) used this method to help quantify ground improvement using RDC and correlated other test methods with density testing; they cited limitations such as lengthy test durations and difficulty with the testing process for mixed soils, particularly where oversized particles are present. Pinard (1999) discussed similar issues and also identified the large ratio between volume of material tested to that compacted and poor correlation between laboratory and field results (in heterogeneous soils) as further issues. The presence of oversized particles has the ability to constrain testing methods (and project specifications), making this a key area to be addressed in an impact rolling trial.

The ability of an impact roller to compact larger quantities of oversized material is an obvious advantage over compacting fill in thin layers; however, as noted by Avalle (2007) there are challenges associated with verification. Project specifications that follow the AS 3798 (Standards Australia 2007a) guidelines, that the maximum allowable particle size should not exceed two-thirds of the compacted layer thickness, are routinely used. As explained by Mostyn and Ervin (2007) it is not uncommon to see earthworks specifications that reference AS 3798 by stipulating a minimum relative compaction, whilst also allowing coarse material (greater than 20% retained on a 37.5 mm sieve) to be used via the specification of a maximum particle size. AS 3798 would define Site B (47% and 15% retained on 37.5 mm and 150 mm sieves, respectively), as a “coarse material” that is to be compacted to a method specification rather than a density ratio. Compaction testing in accordance with AS 1289 (Standards Australia, 2003a and 2003b) allows for correction of oversized material provided that it contains no more than 20% of particles coarser than 37.5 mm. Where coarse material (such as mining spoil) is used for filling, it is not uncommon for the post-compaction quantity of coarse material to exceed these limits. For such coarse material, testing in accordance with AS 1289 is not valid because the test does not give reliable results in circumstances where rock-to-rock contact limits the compaction that can be achieved in the compaction mould. Whilst this was recognised as a limitation, density testing on a sub-set of the material with less than 20% passing 37.5 mm was undertaken to provide a guide to the density requirements.

As Mostyn and Ervin (2007) reinforce in their paper, the objective of AS 3798 is to provide guidance to those responsible for, or involved in the design, specification and control testing of earthworks for commercial and residential developments. Just as AS 3798 recommends that suitably qualified geotechnical professionals need to be consulted for fill depths greater than 5 metres, similar input and guidance from experienced geotechnical personnel is also required when conducting trials and verification of deep compaction using RDC.

5 CONCLUSION

Australian Standard AS 3798 recognises deep compaction by impact rolling as an alternative procedure for earthworks, stating that trial programs may be required to develop the most appropriate testing regime for any particular project or site. This paper presents the results from two impact rolling trials that investigated the ability of RDC to compact mine spoil materials in thick lifts. Whilst the objectives of both trials was to identify an efficient relationship between the number of passes, layer thickness, moisture content and corresponding density that could be achieved, this paper discusses the application of AS 3798 to thick lift compaction using RDC and provides different approaches and guidance (by means of examples) of trial pad construction and verification test methods that could be applied to similar sites.

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