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Rolling dynamic compaction for haul road construction and maintenance - an update

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ROLLING DYNAMIC COMPACTION FOR HAUL ROAD CONSTRUCTION AND MAINTENANCE – AN UPDATE

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ABSTRACT: The construction and management of haul roads remains a critical element in the efficient operation of all mines. Significant effort has been applied to design practices, extending the use of design charts and computer programs. Attention has been paid to the pavement materials and material properties, based on decades of geotechnical data and experience. Opportunities still exist for improvements to be realised in compaction protocols, particularly in the use of rolling dynamic compaction (RDC). RDC involves the delivery of a dynamic compactive effort using non-circular towed compactors, which are designed to deliver a combination of potential energy of a falling weight and kinetic energy mobilised due to the relatively high towing speed. The objectives include the proof-rolling and preparation of subgrade areas, exposing soft spots and weak zones and often establishing a sufficiently competent raft layer, as well as deep lift compaction offering cost-efficient construction of ramps and haul road pavements with programming benefits. The ability to compact deeper lifts allows fill particles to be larger without inhibiting the compaction process, which increases the sustainability of the process through reducing the constraints on the fill materials by allowing a larger maximum particle size. Case studies are cited where RDC has been trialled on several mine sites and many mines have benefited from the use of the technology. The continued attention to improving haul road construction will result in less road maintenance, less vehicle damage and improved truck tyre life, and RDC offers a method of contributing to these improvements. The compaction energy of RDC offers more leniency in moisture conditioning where adequate compaction densities can be achieved with much lower water addition than conventional laboratory optimum moisture content. When applied to coarse surface layer materials RDC will generate sufficient fines to provide a high-friction tyre-friendly low-maintenance finish on haul road surfaces.

INTRODUCTION

Impact rollers have been utilised on mine sites for well over 30 years. They fall under the general category of "rolling dynamic compaction", or RDC, and comprise a non-circular towed module that impacts the ground at regular intervals delivering a dynamic compactive force. The benefits of the use of RDC in mining applications have been explored in the past (Avalle 2006, Scott Jaksa 2012, Thompson et al 2019), and include rock rubbilisation to minimise tyre wear and deep lift compaction. This paper summarises past experience and presents additional case study information to support the on-going development of confidence in the RDC technique for use in haul road construction, acknowledging the benefits offered in quality, programming, risk mitigation and cost.

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WHAT IS RDC?

RDC (impact rolling) comprises the densification of the ground using a non-circular compactor module, generally between 5 t and 12 t in mass, with three, four or five sides, towed at speeds of 10 to 12 km/h. The energy delivered by this means of compaction far exceeds that produced by conventional cylindrical drum rollers. It also far exceeds the comparative energy transmitted to a Proctor compaction mould in the laboratory used for the preparation of a moisture-density relationship curve.

This paper focuses on the 4-sided or "square" impact roller, as shown in Figure 1. Other shapes, such as 3 and 5-sided modules, operate in a slightly different manner and are not discussed further in this paper.

Figure 1: The 4-sided or "square" impact roller, with tow tractor

The opportunities offered by RDC are numerous, and include the following (Scott et al 2012a, Thompson et al 2019):

- Fast and efficient proof-rolling of subgrade areas to develop a denser, more uniform thicker subgrade for haul road construction;
- Identifying soft spots or weak zones that may need to be remediated in advance of the placement of fill;
- Allowance for the placement of thicker fill lifts, significantly increasing the production rate of well compacted fill;
- Thicker fill lifts permit the use of larger maximum particle sizes, reducing the constraints on the fill materials and improving the sustainability of the process;
- Delivery of a denser and more uniform road pavement end product, resulting in reduced road maintenance, reduced vehicle wear and tear, and increased tyre life; and
- The reduced requirements for the addition of water as the higher energy delivered by RDC makes it less dependent on maintaining conditions close to the Optimum Moisture Content (OMC) derived in the laboratory.

These points are explored further in the following sections.

THE COMPACTIVE ENERGY AND PRODUCTIVITY OF RDC

"Compaction is critical to the success of a road building project" (Thompson et al 2019); this statement applies equally to all types of roads, but particularly so in the capital-intensive mining sector. The condition of mine haul roads depends on numerous factors, not the least of which are the pavement materials and their means of compaction.

Research into the compactive energy of impact rollers has progressed significantly in recent years (Scott et al 2012a and 2012b, Scott et al 2019a and 2019b). The 8 t 4-sided impact roller has been shown to deliver approximately 24 to 30 kJ of energy per impact at typical operating speeds of 10 to 12 km/h (Scott et al 2019b), with depth effects theoretically predicted to vary from at least 0.75 m in cohesive soils to about 2 m in granular materials – in practice, greater depth effects have frequently been measured. These factors lend themselves to the application of impact rollers to deep lift compaction, thus allowing the maximum particle size limitation to be relaxed, e.g. permitting up to 375 mm diameter particles for loose layer thicknesses of 750 mm.

The relatively high energy delivered by the impact roller means that specified relative density levels can be achieved with moisture contents significantly below OMC. In haul road design, it is commonly accepted that vehicle maintenance requirements and tyre life are directly related to haul road conditions. Adding water (or drying back when borrow materials are over-moist) may be essential if material moisture contents are not close to OMC when utilising conventional drum rollers. However, being less sensitive to the actual field moisture regime, while still achieving specification, makes RDC attractive in terms of cost, water consumption and programme.

The production of compacted fill can be computed simply as follows:

$$P_{\text{compact}} = \frac{W_r\, v\, h}{n_{\text{passes}}} \tag{1}$$

where

P_{compact} Production rate (compacted cubic metres per hour) (m^3/h)
W_r Width of roller or rolled path (m)
v Speed (km/h)
h Compacted layer thickness (mm)
n_{passes} Number of passes required to achieve compaction specification

For the 8 t 4-sided impact roller, travelling on a wheelpath W_r of 2.3 m at a speed v of 11.5 km/h, working on a loose layer thickness of 1,200 mm, compacting it to a compacted thickness h of 900 mm, with n_{passes} = 6 passes (assumed for indicative purposes), will deliver about 4,000 m^3 of compacted material per hour, covering around 4,400 m^2 of surface area per hour, and involving the placement of approximately 5,300 m^3 of loose fill per hour. For runs with overlapping module prints, i.e. an effective rolling width W_r of 1.2m, the production rate of compacted fill is about 2,100 m^3 of compacted fill per hour.

APPLICATION EXAMPLES

The use of RDC for deep lift compaction on mine haul roads generally requires attention to the optimal lift thickness, both in relation to the rate of placement of the loose fill to maintain the productive value of the impact rollers utilised, as well as in relation to particle size limits and moisture requirements. It is frequently beneficial to undertake detailed verification trials to ascertain the most cost-effective and time-efficient parameters, and many methods are available for such trials (Scott et al 2016, Whiteley and Caffi 2013).

Trial sections can be set out in a suitable location, utilising the materials intended for use in construction, and instrumented and tested to obtain all relevant data to assist in the assessment of the technique. Scott and Jaksa 2012 outline the execution of a trial programme for thick layer compaction at a mine site. Obtaining the optimal arrangement of layer thickness and number of impact roller passes to deliver the requisite quality of compacted material forms the basis of any trial, and in the particular case study sighted, layers of 850 to 1,000 mm thickness were verified for between 10 and 30 impact roller passes, respectively, with the resultant benefit in the use of a larger maximum particle size.

CASE STUDY: COMPACTION TRIAL FOR HAUL ROAD CONSTRUCTION

In addition to the trial described in Scott and Jaksa (2012) for thick lift compaction of deep fill, another impact rolling trial was specifically undertaken for the construction of haul roads at a different mine site. The objective of the trial was to find an efficient relationship between the number of passes, placed layer (fill) thickness, moisture content and corresponding density that could be achieved with a 4-sided 8 tonne (Broons BH-1300) impact roller.

Target specifications of at least 95% SMDD (Standard Maximum Dry Density) were required. Compacted layer thicknesses up 1,500 mm thick were proposed for haul road sub-base and subgrade layers. The fill used to construct the test pad was dumped mining (shot rock) material, which was spread with a dozer and compacted with an impact roller. The fill material, its moisture content and placement were representative of the construction methods proposed for the project. Fill layers up to 1,500 mm were chosen for the compaction trial as shown in Figure 2. Different sections of the test pad were compacted using 10, 20, 30 and 40 passes of the impact roller, respectively.

A key advantage of the test pad configuration shown in Figure 2 was that all of the post-compaction testing could be undertaken at the same time, this was largely due to readily available space, equipment and shot-rock material on site, as well as a desire to make the post-compaction testing as efficient as possible. After impact rolling was completed, targeted testing using the following methods was undertaken to determine the effectiveness of the impact roller: dynamic cone penetrometer (DCP) testing, surface settlement measurements and field density testing at the base of test pits (benched excavations). Soil classification tests (particle size distribution and Atterberg limits) were undertaken on selected samples excavated from the test pits to quantify the properties of the fill material but are not included in the paper due to space constraints.

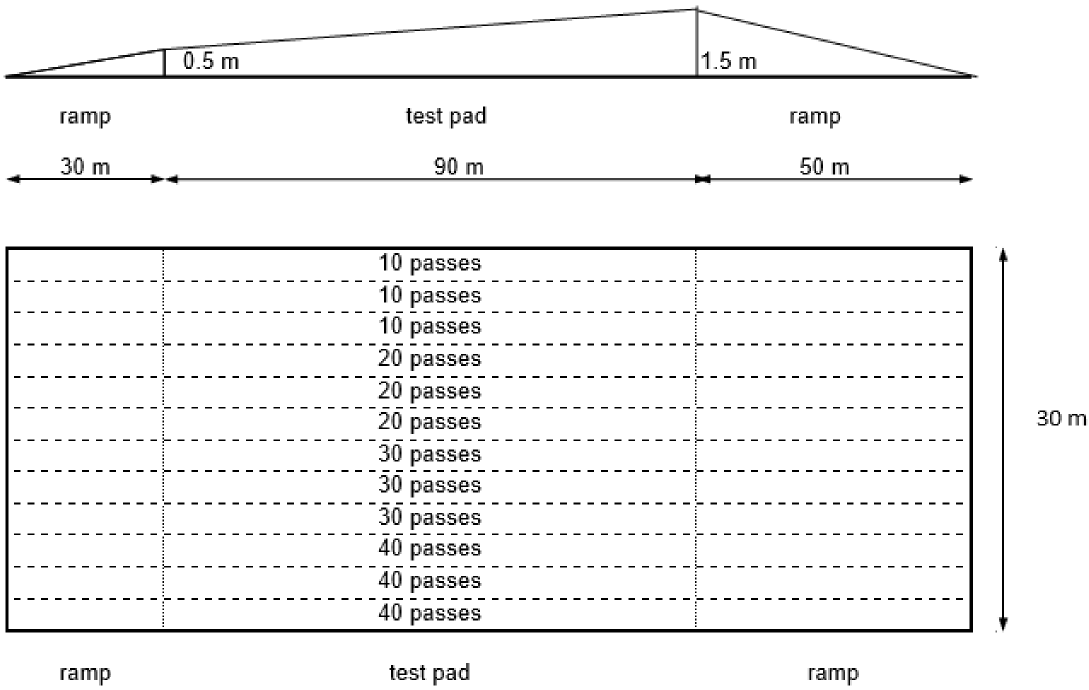

Figure 2: Test pad for impact rolling trial

Dynamic Cone Penetration tests were undertaken in accordance with AS 1289.6.3.2-1997. Figure 3 shows the average number of blows per 100 mm penetration versus test depth for 10, 20 and 30 passes, respectively. Due to damage to the equipment on oversized particles in hard ground, no DCP test results could be obtained in the 40-pass lane. It is evident in Figure 3 that there is noticeable improvement (higher blow counts) with increasing passes from 10 to 20 passes; however, there was minimal difference between the 20 and 30 pass results. Due to the presence of gravel, cobble and boulder-sized particles, DCP testing was often somewhat problematic.

Sixteen test pits were excavated in the centre lanes of the 10, 20, 30 and 40 pass sections of the test pad (4 no. in each section). The centre lane within each compactive effort zone was chosen for testing to be sure of accurately quantifying the applied compactive effort, as it is known that the impact roller has a lateral zone of influence extending beyond the wheelpath width, as described in Scott and Jaksa (2014). Test pits excavated to different depths enabled field density results to be obtained from varying depths. The test pits were excavated using a 32 tonne excavator with an 1,800 mm wide smooth bucket to minimise disturbance. Visually, the test pit excavations looked reasonably consistent across the test pad, although at some locations there was an obvious increase in larger particle sizes, including some instances of large boulders up to 1,700 mm in length. Generally, the sides of the test pits were stable and there was evidence of breakdown of the shot rock material and rearrangement of smaller particles around larger sizes due to impact rolling.

Of the 16 field density test results undertaken in accordance with AS1289.5.8.1-2007, all 16 test results recorded dry density ratios of at least 95% (with respect to the Standard Proctor compaction test used as a baseline for the specification), with 12 results recording dry density ratios of at least 98% SMDD as shown in Figure 4. There was no noticeable trend of increasing passes resulting in increased dry density; the test results obtained appeared to be more of a function of material variability. There was a general trend that dry density ratio reduced with depth below the ground surface; however, the test results indicated that the impact roller could successfully compact the shot-rock material in layers up to 1,500 mm thick.

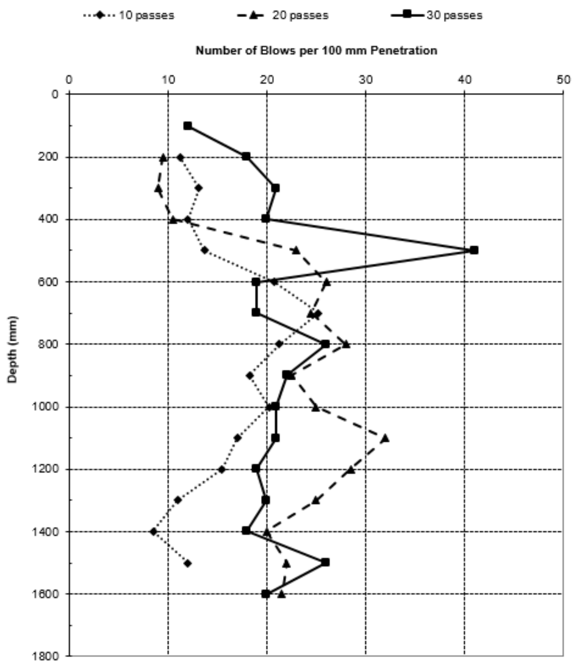

Figure 3: Dynamic cone penetration test results with increasing compactive effort

According to the 16 laboratory tests undertaken, the optimum moisture content of the fill material varied between 9 and 12.5% corresponding to a maximum dry density that varied between 1.85 and 2.07 t/m^3. The field moisture content varied between 4.4 and 9.6%, with field dry densities varying between 1.83 and 2.05 t/m^3.

The results of the compaction trial indicated quantifiable improvement between 10 and 20 passes of the impact roller, but minimal benefit in adopting more than 20 passes, providing that the material was suitably moisture conditioned and did not contain significant oversized material. An advantage of using the impact roller for the compaction of deep fill layers is that less screening of oversized particles is required when compared to deep fills that are placed and compacted using conventional circular drum rollers. Based on visual observations of excavated test pits, the quantity of oversized material was significant and removing large boulders from the shot-rock material was recommended such that the maximum particle size within the fill was restricted to nominally half to two thirds of the placed layer thickness.

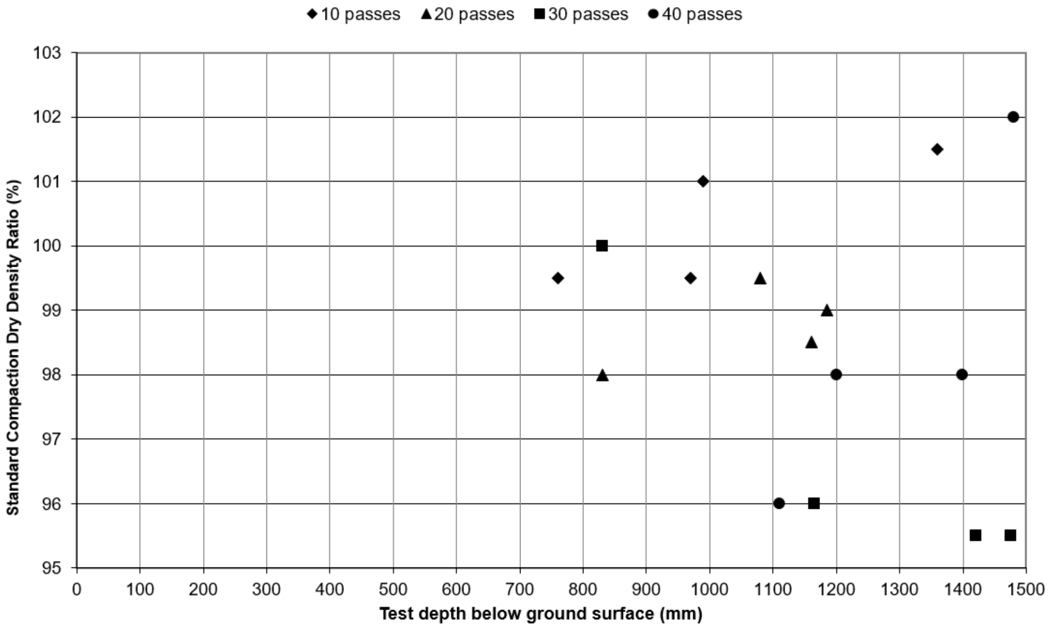

Figure 4: Dry density ratio versus test depth for varying passes

A key outcome of the compaction trial was to determine the optimum number of passes for the layer thickness, taking into consideration the equipment used to dump and spread the material and moisture conditioning. The results of the compaction trial enabled an appropriate method specification to be developed; a layer thickness up to 1500 mm could be successfully compacted with at least 20 passes of the impact roller to achieve the target project specification of 95% SMDD. Whilst there was a preference to place as deeper layer as possible, thinner layers with fewer passes may be better suited to complement the processes and equipment available on site.

VERIFICATION

The verification regime is an important aspect of deep lift compaction, as it may not be feasible (or desirable) to excavate an array of test pits to enable physical field density measurements through the full depth of the compacted layer on working haul road construction. A better approach has proven to be the intensive testing of trial pads using several testing techniques, with a resultant method specification and, if necessary, a non-intrusive verification technique. An example of this is provided by Whitely and Caffi 2013, where geophysics was employed alongside density, dynamic cone and electrical friction-cone penetrometer testing during intensive impact roller trials.

As an example of currently available non-intrusive geophysical techniques that deliver engineering properties of the materials, Heymann 2007 describes the use of Continuous Surface Wave (CSW) testing to obtain the stiffness profile in the top few meters from the surface. The other surface wave techniques, Spectral Analysis of Surface Waves (SASW) and Multichannel Analysis of Surface Waves (MASW) also provide information on the shear wave velocities of subsurface layers. They can all be utilised before, during and after impact rolling to qualify the overall improvement and depth of improvement, as well as to quantify the amount of improvement. The shear wave velocity is related to the Shear Modulus, and hence to the Young's Modulus, of the materials. The choice of testing methods will depend on the nature and scope of the project, the technical requirements and the specifications.

APPLICATION EXPERIENCES - RECONSTRUCTION OF COAL MINE ROADS

The constraints of reconstructing mine haul roads during active operations are substantial, with consistent water and construction material supply being the most influential. Other challenges include operational changes due to mine planning demands and traffic control. Speed of construction is essential to help minimise these challenges and to be able to maximise progress. Construction progress is determined by compaction and moisture conditioning capacities and the size specification of the available fill material. Adequate compaction is determined from experience and/or laboratory analysis, a certain water addition and the number of passes required by the available compaction equipment.

Conventional layered construction with traditional vibrating or static equipment is limited by shallow layer thicknesses and the need for near optimum moisture content (OMC) to achieve the desired compaction level.

In the mining environment fill quality and water supply can be influenced by:

- Drill and blast quality.
- Unpredicted variability of rock quality, especially in sedimentary sequences.
- Random oversized material supplies due to production demands (budgeted BCM/hour) preventing the loading operator from adequately selecting for size, where BCM, or Bank Cubic Metres, is the volume in situ prior to excavation/blasting, placement and compaction.
- Unnotified changes in material quality/specification.
- Hot weather (dusty) and equipment availability (e.g. water carts).

Time is of the essence in haul road reconstruction; longer than necessary construction adversely impacts production schedules which brings along with it challenges such as:

- Management pressure on production units to perform to budget.
- Reducing cooperation from production units due to the above.
- Weather delays, lightning, dust and rain.

Impact rollers (RDC) help address the variabilities delivered by the mining environment and have proven to be essential to maintain construction progress and quality. Fill quality will in the most part be highly variable due to the issues mentioned above. RDC units, when operated correctly are highly productive (over 2,000 BCM/hour, as discussed above). Thicker layers during construction allow for significant variability in particle size. The high energy delivered by RDC assists in breaking many of the oversized particles and to minimise voids in the fill.

Moisture conditioning in a highly productive and often restricted work site with conventional compaction equipment is difficult to maintain and will result in production delays. RDC with its high energy delivery readily achieves compaction with lower moisture contents; where there is a shortage of water, it may simply be necessary to add more RDC passes to achieve the desired density.

When working in a dynamic mining environment traditional quality control testing with people on the ground is undesirable and disruptive. Proof rolling by large loaded trucks or RDC and observation of the minimal layer deflection is ample confirmation of compaction quality.

CONSTRUCTION QUALITY AND THE ROLE OF COMPACTION AIDS

The construction quality of mine haul roads is reliant on several important factors after the alignment design phase, including:

- Drainage.
- Material selection, using the strongest and best available materials.
- Construction equipment, selecting the most appropriate equipment, from spreading bulldozers to compaction equipment that suit the material and water constraints of the site.
- Construction methodology that reduces voids in the compacted fill, maintains adequate moisture during construction, maximises production and compaction, and reduces lamination/separation in the constructed layers.
- Maintenance strategies that maintain drainage and road surface geometry.

A factor that can influence construction productivity and quality is the effectiveness of moisture conditioning. Achieving more even distribution of moisture and closing the gap to OMC during construction has two main benefits, the first being using lower energy to achieve the design compaction, (i.e. fewer passes with the RDC unit), the second being increased laydown rates (BCM/hour) resulting in quicker construction.

There are several techniques to achieve this, some being mechanical processes and another effective method is the use of polymer surfactants and dispersants. Surfactants are surface-active agents added to the compaction water at very low dosage rates (as low as 0.05%) that break the surface tension between the water and the soil allowing faster and more even dispersion of the water through the bulk material. This will result in direct water savings, easier to achieve compaction and lower void ratios. Dispersants polymers can be added into the compaction water to separate the fine soil particles from each other during compaction to reach the required compaction level using less compaction effort and water. The dispersing effect of the polymer at low dosage rates (approx. 0.3 litres per m^3 material) has a lubricating effect on the soil particles, offers good clay swelling reduction and can reduce the OMC of the material.

CONCLUSIONS

Impact rollers offer mine owners, mine earthworks contractors and truck operators and managers, an extremely effective technique to deliver subgrade proof-rolling and deep-lift compaction for haul roads. Attributes and potential benefits include efficiency of road construction and programming advantages, reduced constraints on materials and improved sustainability of the process, reduced road and vehicle maintenance, and increased tyre life, and improved risk management.

The 4-sided impact roller has been, or is being, used on at least 25 coal mines in Queensland, at least 16 coal mines in New South Wales, and, amongst others, mines in Victoria, South Australia, New Zealand and in several other countries, over the last 40 years or so. RDC is a technology that has a proven record in delivering quality mine haul roads.

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