GROUND IMPROVEMENT USING THE "SQUARE" IMPACT ROLLER – CASE STUDIES

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Abstract

Manufactured and further developed in Australia over the last 20 years, the "square" Impact Roller has found a variety of applications in various parts of the world. Employing the well-established principles of rolling dynamic compaction, the Impact Roller densifies the ground to significant depths, without excavation or removal, allowing the retention of materials that may otherwise be considered unsuitable as engineering fill. It also facilitates the improvement of weak ground, either natural or man-made, breaking concrete and rock, and compressing waste.

Case studies are presented to illustrate various uses for which the "square" Impact Roller has been productively utilised. Its use on pre-filled land, such as in redeveloping "brownfield" sites, has major engineering and environmental benefits, while in the mining industry it finds effective use on haul roads, stockpiles and waste tips. Proof-rolling road alignments induces early settlement, identifying soft spots at an early stage, and its use on landfill sites can increase valuable void space by consolidating the fill. In the agricultural industry, the "square" Impact Roller has proven cost-effective in reducing water leakage from channels and storage reservoirs, enhancing the sustainability of relatively high water-use crops.

Alternative methods of monitoring the performance of the Impact Roller during site work and for verification testing are discussed, including density testing, static and dynamic cone penetrometers, settlement measurement, the Falling Weight Deflectometer and others. The paper concludes with recommendations for further research into the wider application of the "square" Impact Roller in ground improvement projects.

Keywords: Impact roller, square module, rolling dynamic compaction, ground improvement.

1. Introduction.

Broons Hire (SA) Pty Ltd manufactures the "square" impact roller in South Australia and modifications and improvements have been made over the years, particularly to cater for specialised situations such as mining applications.

The concept of rolling dynamic compaction dates from some decades ago, although the extent of potential applications has expanded significantly since the 1980s. The case studies presented in this paper illustrate the wide-ranging opportunities that the impact roller provides for cost and environmental benefits through this approach to ground improvement.

2. Background to Rolling Dynamic Compaction.

South Africa pioneered the early development of impact rolling as it is applied today, although some of the earliest uses of impact to densify the ground include Roman foundation rammers and Chinese swinging weights dating from the Middle Ages or earlier [1]. The mid-20th Century saw the development of dynamic compaction by French engineers, employing a relatively free-falling mass.

The potential advantages of in situ deep compaction using a mobile dynamic compactor were recognised by the 1930s, and a Swedish designer patented a towed impact roller of hexagonal cross-section in 1935.

About 20 years later, the South Africans took up the concept. The approach to the treatment of collapsing sands by direct, controllable impact led to the manufacture of the first full-size impact roller, a 7t concrete cube towed by a bulldozer, which caused serious difficulties for the towing unit and the driver. This was followed by a 5-sided towed unit, with springs that absorbed some of the horizontal component of force [2], as well as other different shapes and masses.

Further development continued and, in the mid-1970s, a 4-sided impact roller was patented, with a torsion bar springing system that evolved into the 4-sided towed impact roller employed today [3, 4]. Broons Hire (SA) Pty Ltd introduced this unit into Australia in the mid-1980s under licence, and since 1985 it has been manufactured in Australia and progressively improved by Broons.

The "square" steel module is filled with concrete and has a mass of approximately 8t. It is drawn in its 6t frame by a 200kW 4-wheel drive towing unit at a speed of 10 to 12 km/h. Figures 1 and 2 illustrate the shape and configuration of the "square" impact roller.

Figure 1: The "square" impact roller.

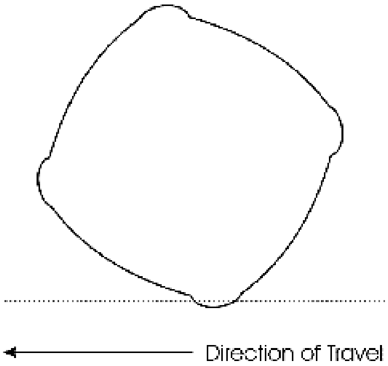

Figure 2: Cross-section of the "square" module.

From its earliest conception, the civil engineering potential of rolling dynamic compaction was evident and the South African trials demonstrated that impact rolling could have an effect to 1m or more, far deeper than any conventional static or vibratory roller. Impact rolling was found to be suitable for a wide variety of materials and was far less dependent on the material's moisture content to achieve the desired improvement. The impact roller's ability to equalise the density gradient across a site, developing a more uniform soil "raft", lends itself to a wide variety of applications, some of which are described in the case studies that follow.

3. Range of Applications.

Many and varied applications have been undertaken over the years, following on from the early work on collapsing sands and coal stockpiles. Applications have broadened over the last two decades and impact rollers are now used for the in situ densification of existing fill, such as on former industrial land or brownfield sites, raised land and landfills, mine haul roads and bulk earthworks. The principle common to all is the reduction in the volume of air voids in the impact rolled material. However, apart from improving the relative density of the material, this has the added effect of a general reduction in the material's permeability, a factor that has been utilised in the agricultural industry.

Pinard and Ookeditse (1990) and Pinard (1999) discuss the principles of impact rollers used in semi-arid areas to achieve a stiffer more uniform subgrade using less water during compaction and with little control on subgrade moisture content [5, 6]. This is a particular feature of impact rolling attractive to its application in Australia's agricultural sector [7].

Another non-engineering type application in Australia is the "rubblizing" of rock on open-cut mine waste tips. Truck tyres form the single largest cost item for operators of hard rock mines, particularly when the massive haul trucks are required to turn sharply on dumped spoil that includes protruding rocks. In addition, the increasing use of surface mining or milling equipment in hard rock quarrying, in lieu of drill and blast techniques, presents an opportunity to induce fracturing of the surface layers with the impact roller before extraction, improving production rates up to three fold. Similar procedures can be followed for the demolition of concrete pavements on roadways and airfields.

The following sections highlight specific types of application and provide case study information and data, where available. All the sites are in Australia, unless otherwise stated.

4. Brownfield Sites.

The widest application of the "square" impact roller in Australian metropolitan areas relates to the redevelopment of former industrial sites. Sometimes these "brownfield" sites are re-used for industrial purposes, but often they are developed for residential use, which generally requires more remediation due to a more sensitive end use.

In common to most existing industrial sites, the land has been filled. Generally, this fill has been required to provide a level base for slabs and pavements, but often more marginal land, zoned for industrial use, has had deeper amounts of fill placed over sometimes poor, soft or weaker soils. Over decades of use, fill materials have become contaminated and waste materials have been buried on older industrial sites. The challenge for the remediation team is to find a solution that is environmentally sound but also realising a cost-benefit to the developer.

Impact rolling provides an alternative to re-engineering existing fill. Materials that are environmentally suited to retention on site, but that may otherwise need to be taken off site if excavated, can often respond to impact rolling to produce suitable subgrade conditions. As an example of the response to impact rolling that such sites generate, Figure 3 reflects the settlement generated on a site in Melbourne, Victoria, which was surveyed on a 10m grid. Ground conditions comprise 0.7m to 3.0m of fill, generally consisting of a mixture of sand, gravel, silt and concrete rubble. As can be seen in Figure 3, the most substantial settlements were generated within the first 12 passes, and relatively little additional settlement occurs between 16 and 20 passes.

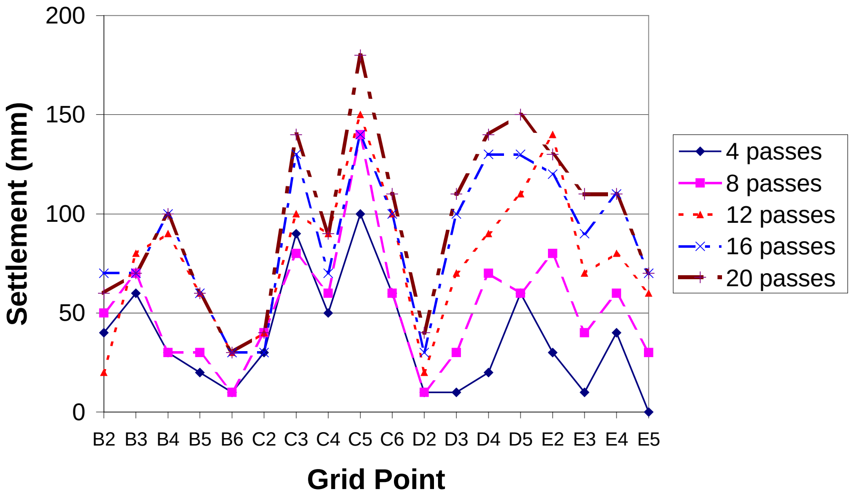

Figure 3: Settlement measurements on "brownfield" site.

5. Land Reclamation.

Land reclamation projects generally take the form of creating new land at the edge of a water body or raising land that is at or close to the water table or sea level. Frequently, the fill material is sand that is dredged from the sea or river floor, usually placed hydraulically into or onto the area being reclaimed. The "square" impact roller has been used on many such projects to produce a soil "raft" of significant thickness to reduce differential settlements and accommodate infrastructure. This has been undertaken in most Australian states, in the United Kingdom, Hong Kong and the Netherlands. Figure 4 illustrates the density improvement, in terms of standard compaction, after 12 passes on a filled site in the Netherlands, comprising uniform fine sand, with the water table deeper than 2m below ground level.

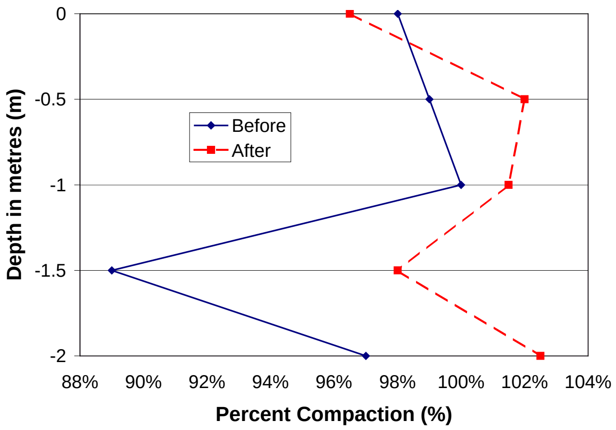

Figure 4: Density improvement in dredged sand fill.

The results show that there is a significant improvement to a depth of at least 2m. The evident reduction in density at the surface relates to the disturbance associated with the impact roller's leading edge, and is a common feature that requires final compaction with a conventional roller.

6. Pavement Reconstruction.

A significant innovation for the reconstruction of rural roads in Australia has been realised through the use of the impact roller. The impact roller has been used on a regular basis by a number of local councils on rural roads where there are no sewers or other services below the pavement, while more caution is required in metropolitan areas due to the myriad of shallow underground services.

One of the biggest problems for rural roads is localised or more widespread failure due to poor subgrade conditions. The major benefit of the impact roller is that the subgrade can be improved from the surface, without the need to remove any material. Sealed pavements and even concrete-stabilised base courses are broken up under impact rolling, leaving a material suitable as the new sub-base. Sufficient settlement is usually induced by impact rolling, as shown in Figures 5 and 6, so that, after shaping and conventional rolling, a new base course and wearing course can be laid without further earthworks.

Figure 5: Road reconstruction in South Australia.

Figure 6: Settlement induced by impact roller.

The effect of impact rolling on the subgrade is clearly shown in Figure 7, which illustrates Dynamic Cone Penetrometer (DCP) test results on the centreline of a South Australian road. The correlation with California Bearing Ratio (CBR) is taken from the AUSTROADS Pavement Design Guide [8]. The improvement in the subgrade zone from 0.3m to about 0.7m has manifested itself within 12 passes of the “square” impact roller, with little further gain up to 20 passes.

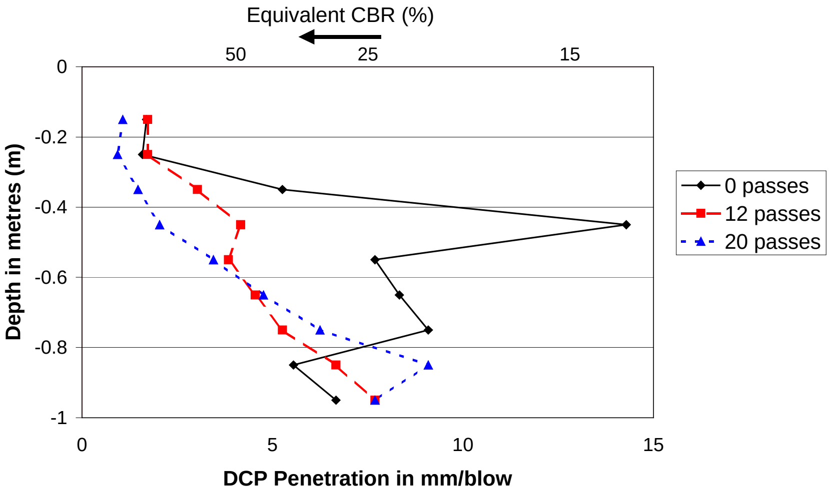

Figure 7: DCP test results for road reconstruction project.

7. Landfills.

The provision of adequate landfill void space in and around existing and developing cities is an ever-growing problem. As a general rule, landfill operators utilise a unit that combines compaction and dozing, which compacts while it traverses and spreads the fill material and can also spread soil cover. While this approach generally serves the purposes for which it is deployed, the extent of future gross and differential settlement that occurs in refuse tips is still substantial. When such sites are later turned over to, say, recreational use, problems frequently arise with differential settlement and associated risks to site users.

The “square” impact roller has been utilised on numerous landfills, particularly in Victoria, Queensland and Western Australia, as well as other Australian states and overseas. Due to the extremely variable and heterogeneous nature of waste, and difficulties associated with testing such materials, there is a limited amount of quantified output from impact roller work on landfills, most users relying on observational techniques to substantiate the impact roller’s effect.

Figure 8 shows the measured settlements during trials with a “square” impact roller on a disused landfill in Queensland. Two locations were selected from the data set to illustrate the variable response that can be expected on such sites. The landfill had a soil capping of approximately 1m thickness overlying the waste material and the trial alignment was subjected to 90 passes. Modest settlements of 200mm to 250mm were recorded after approximately 40 passes where the fill was shallowest (less than 3m thick). However, where the fill was deeper than 5m, a maximum settlement of approximately 700mm was recorded after 90 passes.

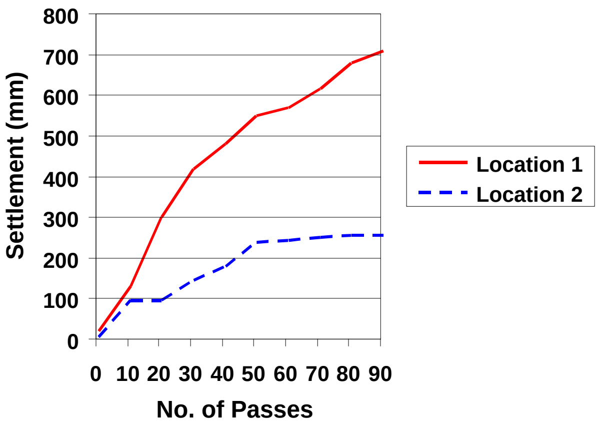

Figure 8: Settlements at two locations on a landfill site.

The above data (Figure 8) suggest that the use of the impact roller on landfills at various times during the placement of the fill is likely to provide additional landfill capacity during the filling process. Initial cost estimates indicate that this is an attractive scenario, particularly as the cost of waste disposal continues to rise.

8. Agricultural Sector.

In the Australian agricultural sector, impact rolling has been utilised since the early 1990s to address problems with leakage from water storages and channels for the cotton and rice industries. More recently, impact rolling has been successfully deployed in the construction of pads for beef cattle feedlots, where environmental constraints require properly engineered facilities.

Anecdotal evidence of the successful application of the impact roller to reduce leakage from water storages has been reported, and impact rollers were trialled to assess the potential to seal highly permeable areas in rice fields, where reductions in infiltration were reported after only 3 to 6 passes in some cases. Other trials in channels and on channel banks concluded overall that seepage is significantly reduced in channels and drains by surface treatment. The “square” impact roller was found to be well suited to the confined conditions in channels and on their banks due to its mobility and relatively small turning circle [7].

In 2000, Clyde Agriculture conducted infiltration tests in conjunction with impact rolling at one of their cotton water storages near Bourke, New South Wales. The procedure adopted followed the principle of the double ring infiltration test, with 1m diameter metal rings embedded within a 5m square pond, the fall in water level being measured within the ring. Figure 9 presents the infiltration rates inferred from the graphs provided by Clyde Agriculture. The data reflect a significant improvement after 6 to 12 passes of the impact roller. This limited data set appears to support the anecdotal evidence of the efficacy of impact rolling.

In conjunction with channel bank improvement works in 2001, Murrumbidgee Irrigation at Leeton, New South Wales, commissioned field density tests before and after impact rolling. Improvements in the in situ relative density were apparent after 15 passes, as can be seen in their data, summarised in Figure 10 as a percentage of standard compaction.

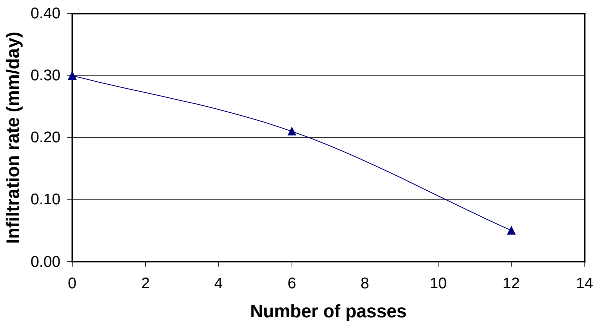

Figure 9: Infiltration test data for a cotton water storage.

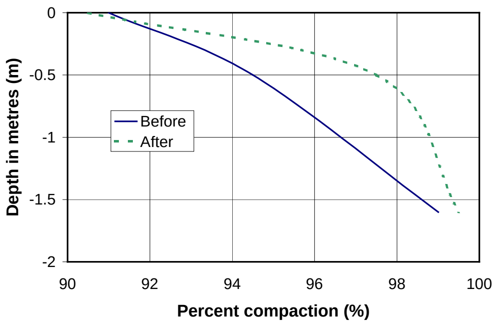

Figure 10: Field density tests on channel banks for rice irrigation.

The ground improvement generated by the “square” impact roller in the agricultural sector offers significant environmental benefits. Water loss through permeation from water storages and channel banks is reduced, which reduces the impact on groundwater and soil salinisation. The reduction in irrigation water consumption improves the environmental sustainability of high water-use crops.

Broons has recently adopted a modified infiltration test procedure, which is intended for use in conjunction with channel improvement works [7]. Early results indicate the possible viability of this simplified test, although time factors for readings can be lengthy. Further research is recommended.

9. Mine Waste Tips.

The mining sector was an early advocate of impact rolling to reduce the incidence of spontaneous combustion in coal stockpiles, a use that still continues in South Africa today. In Australia, the "square" impact roller has been utilised on numerous mine sites to improve mine haul roads, in the construction of tailings dams and to compact the capping over waste rock cells.

The most recent work undertaken by the "square" impact roller at a mine site is, however, a non-engineering application. On the hard rock open cut gold mines, spoil is carted by 300t haul trucks and end-tipped to form large waste rock tips. The trucks drive up onto the tip head and then turn through 180° and reverse to the edge to dump the load. During turning, the truck tyres are particularly prone to damage from protruding hard sharp rocks. The cost of truck tyres is the largest single cost to the mining operation of the largest open cut gold mine in Kalgoorlie, Western Australia.

Impact rolling on the tip head to "rubblize" the rock has the effect of breaking down larger sharper rocks, with an associated reduction in abnormal tyre wear. The "square" impact roller module is specifically modified for such mining applications and Figure 11 shows the impact roller adjacent to a 300t dump truck.

Figure 11: The impact roller and a dump truck on a mine waste tip.

10. Test Methods for Monitoring and Validation.

Many different test methods are utilised to verify the effects of impact rolling, varying dramatically from site to site and project to project. Some projects, in fact, include no quantitative testing, relying on anecdotal and observational evidence. It is considered that this variation is generally attributable to a combination of the client's, designer's and/or geotechnical engineer's preferences and experience with impact rolling, the readily available test equipment, budget constraints, the site's location and/or particular site conditions. Table 1 lists the tests encountered in the author's experience.

Table 1. Impact Roller Monitoring and Verification Test Methods.

Category	**Description**	**Comments**
Classification	Particle size distribution, Atterberg Limits, Emerson dispersion	Wide application, generally not suitable for heterogeneous fill with large particles
Continuous probe	Dynamic cone penetrometer (DCP), electrical friction-cone (CPT)	Provide output that may be correlated with CBR and strength
Earthworks	Field density, moisture content, laboratory compaction (MDD, OMC) and California Bearing Ratio (CBR)	Roads and general earthworks; tests represent a very small proportion of the material treated
Geophysical	Continuous surface wave	Highly specialised equipment and interpretation
Ground response	Clegg Hammer, continuous deceleration measurements	Indicative of response to roller, inconsistent correlation with engineering parameters
Observation	Visual or audible evidence	Subjective, but proven by trial and error
Permeability	Permeability tests, infiltration tests	Useful in the agricultural sector, some tests can be difficult to perform
Settlement	Precise measurement of ground deformation	Simple and effective means of quantifying impact roller effect
Strength	Falling Weight Deflectometer (FWD), static and dynamic plate load tests	Specialised tests: produce load-deflection characteristics and soil modulus values

The test method selected for a particular site may need to take account of ground conditions (e.g. fine-grained natural soils or heterogeneous fill with large inclusions), the proposed end use or specification requirement set by the designer, and the actual objectives of the impact rolling. At present, some combination of input from the client, design engineer, contractor, geotechnical engineer and impact roller supplier probably determines the testing regime.

In the agricultural sector, while simple settlement monitoring might be useful, it is considered that a combination of mechanical classification tests and field infiltration tests will assist with confirmation of the effectiveness of the treatment, as well as enhancing the understanding of the mechanism that is occurring. Density testing may also prove useful, particularly on projects such as the preparation for beef cattle feedlots.

Mining applications, on the other hand, are more likely to rely on observation and anecdote, in combination with measurable indicators that are critical to the commercial viability of the operation, such as tyre wear.

Appropriate testing protocols, before, during and after impact rolling, related to a range of end uses, site conditions and engineering specifications, combined with the advantages and disadvantages of testing equipment, is an area that the author considers warrants further research. An appropriate set of guideline specifications for various applications would also be of value to engineers and contractors.

11. Conclusion.

Rolling dynamic compaction has been proven to be effective for the deep compaction of materials in a variety of earthworks applications, as well as for non-engineering uses. While the “square” impact roller is acknowledged by many as a significant contributor to the fleet of construction equipment, there remains a minority who are yet to be convinced. There also remain other applications for which the impact roller has yet to be trialled.

It is considered that further research into the mechanism of impact roller effects and the development of geotechnical models for the various applications will provide a sound basis for the consideration of effective measurement techniques. The preparation and acceptance of guideline specifications for impact rolling, addressing the different applications, will assist designers and geotechnical engineers, and these can be further developed and tailored as the research effort progresses.

We are likely to see an increasing use of rolling dynamic compaction as its cost-benefit ratio improves with increasing excavation, haulage and landfill costs.

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