

# **IMPROVING PAVEMENT SUBGRADE WITH THE “SQUARE” IMPACT ROLLER**

**Derek Avalor<sup>1</sup> and Roger Grounds<sup>2</sup>**

<sup>1</sup> Technical Manager, Broons Hire (SA) Pty Ltd, PO Box 436, Avalon NSW 2107, Australia

<sup>2</sup> South Australian Manager, Coffey Geosciences Pty Ltd, 14B Henley Beach Road,  
Mile End SA 5031, Australia

## **Synopsis**

**The “square” Impact Roller has been used to improve ground characteristics for many decades. Originating in South Africa, it has been manufactured and further developed in Australia for nearly 20 years. Utilising rolling dynamic compaction, the Impact Roller densifies the ground to significant depths.**

**Case study information is presented to illustrate recent uses of the “square” Impact Roller for subgrade improvement on two major transport related pavement projects in Adelaide, South Australia.**

**The alignment of a 5.5km four-lane road crosses low-lying land, largely reclaimed by uncontrolled filling over many years. During early 2003, the “square” Impact Roller was utilised over most areas to improve subgrade conditions, to identify “soft spots”, voids or undesirable matter, in order to enhance the overall performance of the final pavement.**

**The new terminal building and apron areas at Adelaide Airport will be founded on existing fill material. The use of the “square” Impact Roller in the preparation of the subgrade was the subject of a trial in April 2003. Detailed geotechnical testing and settlement monitoring were undertaken. Construction commenced in November 2003.**

**The paper discusses monitoring methods and verification testing, and recommendations are made for further research into these aspects and the development of guideline specifications.**

## **1 INTRODUCTION**

The “square” impact roller was developed in South Africa and came into productive use in the 1970s (Clegg and Berrangé, 1971, and Clifford, 1976 and 1978). Manufactured in Australia for almost 20 years, the “square” impact roller has undergone various modifications, particularly to cater for specialised applications.

The concept of rolling dynamic compaction dates from the first half of the 20<sup>th</sup> Century. The extent of potential applications has, however, expanded significantly since the 1980s. The case studies presented in this paper illustrate the opportunities that the impact roller provides for cost and environmental benefits through ground improvement on transportation projects.

## 2 BACKGROUND TO IMPACT ROLLING

South Africa pioneered the early development of impact rolling as it is applied today, although the Romans used foundation rammers and the Chinese used swinging weights to densify the ground (Munfakh, 2002). 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. More than 20 years later, the concept was taken up in South Africa for the treatment of collapsing sands by direct, controllable impact, which led to the manufacture of the first full-size impact roller (Clegg and Berrangé, 1971).

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 (Clifford, 1976 and 1978). Broons Hire (SA) Pty Ltd introduced this unit into Australia in the mid-1980s under licence, and since 1985 it has been manufactured in South Australia and progressively improved by Broons.

The 1.3m wide, 1.5m high “square” steel concrete-filled module 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 10-12km/h. Figures 1 and 2 illustrate its shape and configuration.



Figure 1: The “square” impact roller on a mine waste tip.

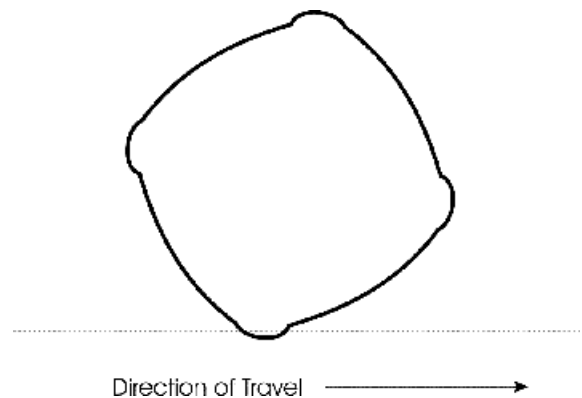


Figure 2: Cross-section of the “square” module.

From its earliest conception, the civil engineering potential of rolling dynamic compaction was evident and 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, with less dependence on the material’s moisture content. The impact roller equalises the density gradient across a site, developing a soil “raft”, lending itself to a multitude of different applications (Pinard 1999, Avalle 2004b).

Following on from the early work on collapsing sands and coal stockpiles, impact roller applications have broadened over the last two decades. The common principle is the reduction in the volume of air voids in the impact rolled mass, and the impact roller is now used for the in situ densification of existing fill, such as on former industrial land or brownfield sites, raised or reclaimed land and landfills, mine haul roads and bulk earthworks. In addition, apart from improving the relative density of the material, impact

rolling reduces the material's permeability, a factor that has been utilised in the agricultural sector (Avalle, 2004a).

Another non-engineering application in Australia is the “rubblizing” of rock on open-cut mine waste tips. Tyres on the massive 300t haul trucks (see Figure 1) form the single largest cost item for operators of hard rock mines, and the impact roller breaks down protruding rocks in the dumped spoil. Impact rollers are also used in surface mining, in hard rock quarrying to induce fracturing of the surface layers, and for the demolition of concrete pavements on roadways and airfields.

The following sections discuss the specific application of the impact roller on two current transport-related projects in Adelaide, South Australia.

### 3 THE PORT RIVER EXPRESSWAY

Construction of the Port River Expressway commenced in 2003. Its 5.5km alignment crosses marginal land to the north of current developed areas and it joins Port Adelaide to the Port Wakefield Road. A major purpose is to provide a heavy vehicle route between the port facilities, industrial areas in and around Port Adelaide and the national highway route in and out of Adelaide. Grain, livestock, wine and citrus are exported from Port Adelaide, and the Port River Expressway will divert heavy vehicles away from its central business district (Transport SA, 2004).

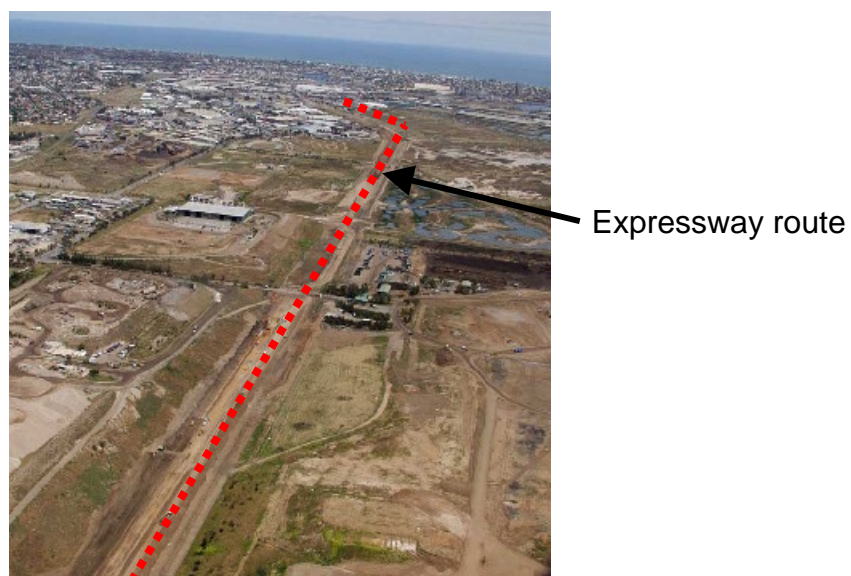


Figure 3: Aerial view of the Port River Expressway.

Difficult ground conditions posed a challenge to the geotechnical engineers, designers and contractors. The area is a low-lying coastal swamp with up to 5m of weak and compressible soils in some places and over 4m of non-engineered fill in others. Fill materials include scrap metal, tyres, building rubble and incinerated waste. Approximately 300,000m<sup>3</sup> of imported fill is being used to raise the level of the road by as much as 2-2.5m. Around 90% of this fill comprises recycled material (Hamlyn, et al, 2003).

The contract incorporates a “design, construct and maintain” arrangement, whereby the builder is required not only to maintain the road for 10 years, but also to restore it to a pre-agreed standard at the end of that period. Consideration of cost-effective and practical treatments of the subgrade along the alignment was driven by the above factors.

The removal of some isolated areas of unsuitable materials was carried out, but environmental considerations dictated that this should be minimised. Initially, pre-existing filled areas were treated with the “square” impact roller, a ground improvement technique widely utilised for non-engineered filled sites in that part of Adelaide.

Over a section approximately 200m long, a working platform comprising 0.5-1.0m of pre-existing fill material consisting of a mixture of soil, pavement materials and building rubble, was prepared with 6 passes of the “square” impact roller. Nine dynamic cone penetrometer (DCP) tests were carried out (Australian Standards, 1997) and the results are presented in Figure 4 as penetration rate versus depth, with inferred California Bearing Ratio (CBR) values indicated along the top (AUSTROADS, 1997).

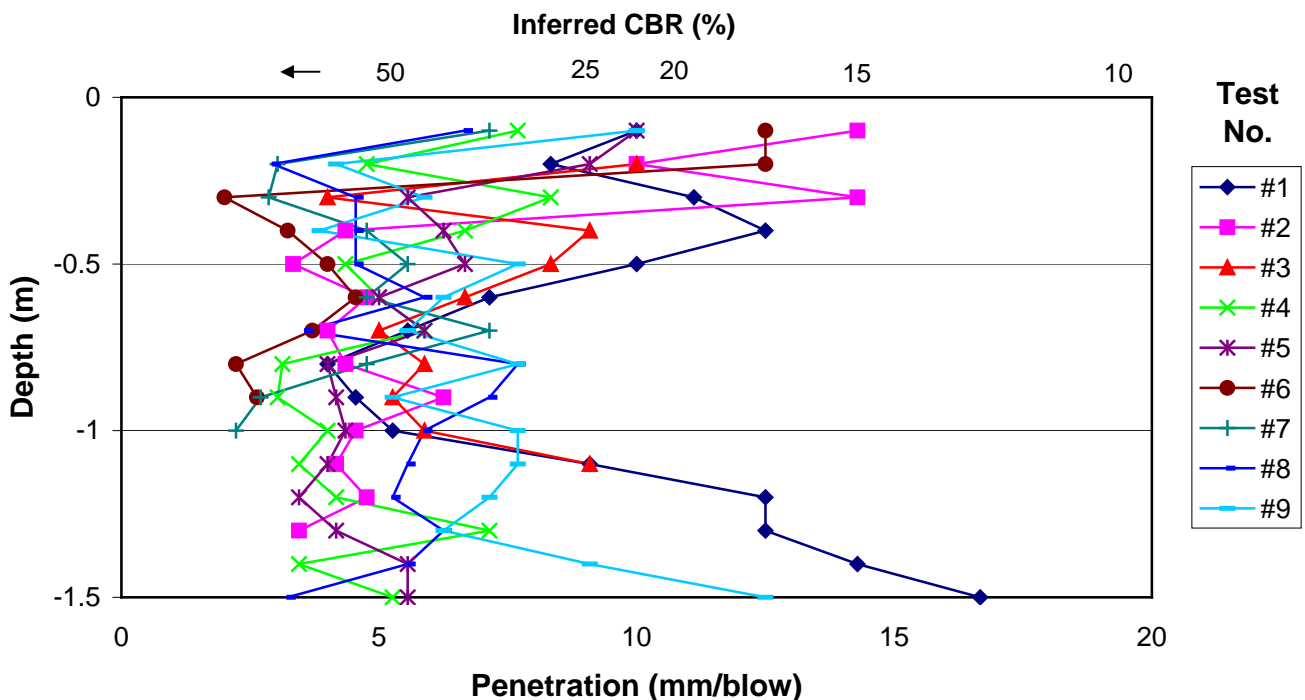


Figure 4: DCP Test Results

The results in Figure 4 suggest a relatively high degree of strength and uniformity in the material to a depth of at least 1m, particularly in the zone from 0.5-1.0m. The DCP does, however, have a disadvantage in relation to the effects of larger particles, which can, on occasion, result in “refusal” to penetrate at relatively shallow depths.

The range of settlements monitored during impact rolling on the working platform, where the above DCP tests were carried out, was 1-33mm at 3 passes, and 19-57mm after 6 passes. Average settlements were 19mm and 37.5mm for 3 passes and 6 passes, respectively, as shown in Figure 5.

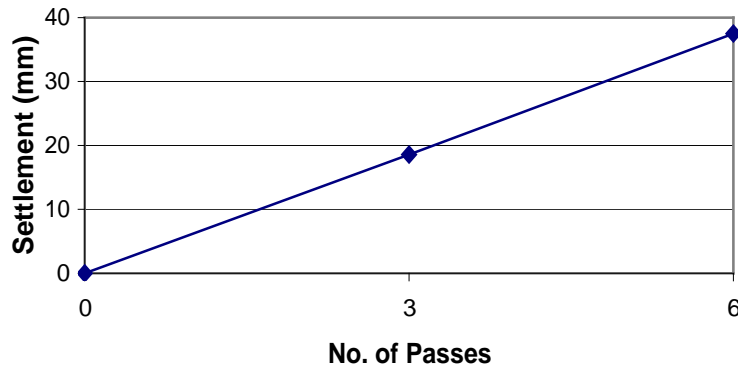


Figure 5: Average settlement on impact rolled platform.

Settlement monitoring was extended over a length of almost 1km of the alignment after 6 passes of the “square” impact roller. The results of 32 readings gave an average settlement of 40mm, ranging from a minimum of 5mm to a maximum of 93mm.

Proof-rolling with the “square” impact roller not only improved the strength and uniformity of the subgrade, but provided the additional benefit of being able to isolate soft spots rapidly and enact appropriate remedial treatment where necessary. These factors resulted in its wider use on this project than was initially anticipated, and virtually the whole alignment was proof-rolled with the “square” impact roller at subgrade level.

In view of the fact that the objective of the proof-rolling exercise was to densify the fill materials and identify any particularly weak or unsuitable fill or natural soils, the process was undertaken using an “observational” approach under full time geotechnical supervision. The alignment was deemed suitable for construction in areas where a nominal 6 passes of the impact roller did not expose any unacceptable ground conditions or materials.

#### 4 AIRPORT DEVELOPMENT

Work began in November 2003 on a two-year programme to construct a new terminal for Adelaide Airport. The new building will have 14 aerobridges and it will serve international, domestic and regional passengers (see Figures 6 and 7). It will be approximately 750m long and up to 110m wide, and construction includes over 130,000m<sup>2</sup> of heavy and light duty pavements and aprons.



New terminal



Figure 6: Aerial view of Adelaide Airport.

Figure 7: The future terminal.

Adelaide Airport was developed in an area of swampy ground. Poorly drained alluvial soils typify the area, with sand ridges and dune sand deposits also present. The original development involved the placement of imported fill to raise and level the site.

While the new building is to be supported on piles, the preparation of underfloor and pavement subgrade areas required an appraisal of alternative solutions. Disadvantages with the removal of existing fill and its replacement in thin layers in a conventional manner included the possible rejection of some excavated material due to oversize or unsuitability (requiring removal to tip and importation of replacement fill), the presence of weak and saturated soils at depth and the proximity of the groundwater table to the base of excavations.

Impact rolling was identified as a possible solution to provide an adequately uniform and dense subgrade without the need to excavate existing fill, and to facilitate a far speedier completion of the earthworks phase of the project. In order to provide support to the concept and to assist with the development of the specification for the work, a trial was conducted in April 2003.

The client established a trial area approximately 200m long by 20m wide, and this was investigated with trial pits, DCP tests, electrical friction-cone penetrometer tests (CPT) and field density tests prior to impact rolling. Ground conditions at the site comprise 1.3-1.5m of existing fill overlying firm to stiff clay and loose to medium dense sand, with the groundwater table previously identified at a depth of approximately 2-2.5m. Apart from clay, sand and silt soils, the fill includes bricks, concrete and rock fragments, with occasional reinforced concrete pieces and tree roots.

The trial strip was marked with chainage pegs at approximately 30m intervals. Pre-rolling tests included 18 DCPs, eight CPTs and three field density tests. The site was impact rolled in 200m long lines, each line having a different number of passes, as specified by the client. Lines were prepared with 6, 10, 15 and 20 passes, and the 20 pass line was further rolled to give 30 passes and 40 passes. Settlements were measured at various stages, at each marked chainage, by direct measurement from a string line.

After completion of the rolling programme, geotechnical testing included 18 DCPs, eight CPTs, 11 field densities and one plate load test.

Settlement measurements at each chainage for the various number of passes are shown on Figure 8, and Figure 9 illustrates the average settlement versus the number of passes, along with a polynomial trend line.

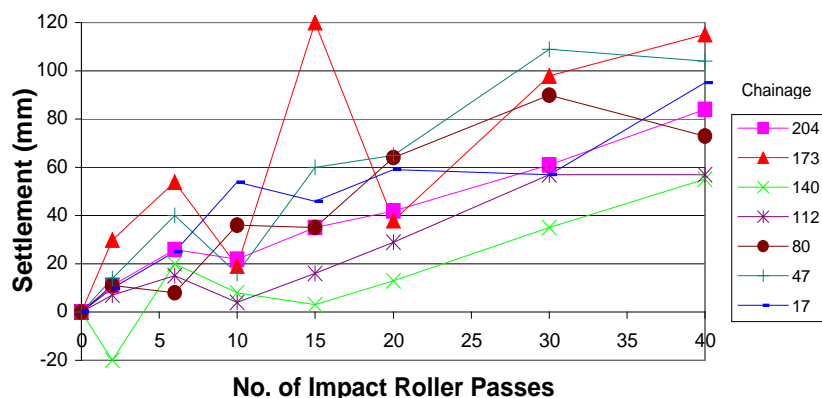


Figure 8: All settlement data.

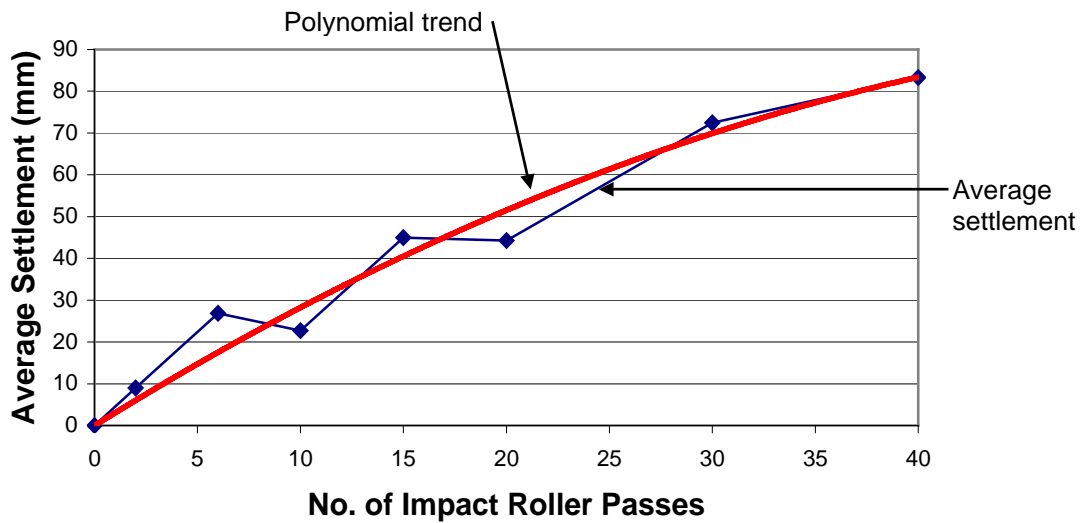


Figure 9: Average settlement.

Figure 8 suggests a differential response in terms of settlement, which is borne out by the fact that there had been a pre-existing pavement across the zone bounded approximately by chainages 110 and 150, reflected by the significantly smaller settlements at chainages 112 and 140. The trend line in Figure 9 confirms a reducing rate of settlement with increasing number of passes.

The DCP, with its small conical tip, is influenced by larger harder particles in the fill mass, and the data can be difficult to interpret. As an example of the results, however, Figure 10 exhibits some interesting attributes. The figure shows the average DCP blow count per 100mm penetration at the 28m offset (o/s) before rolling and after 40 passes (refusal at 0.8m), as well as at the 25m offset after 20 passes.

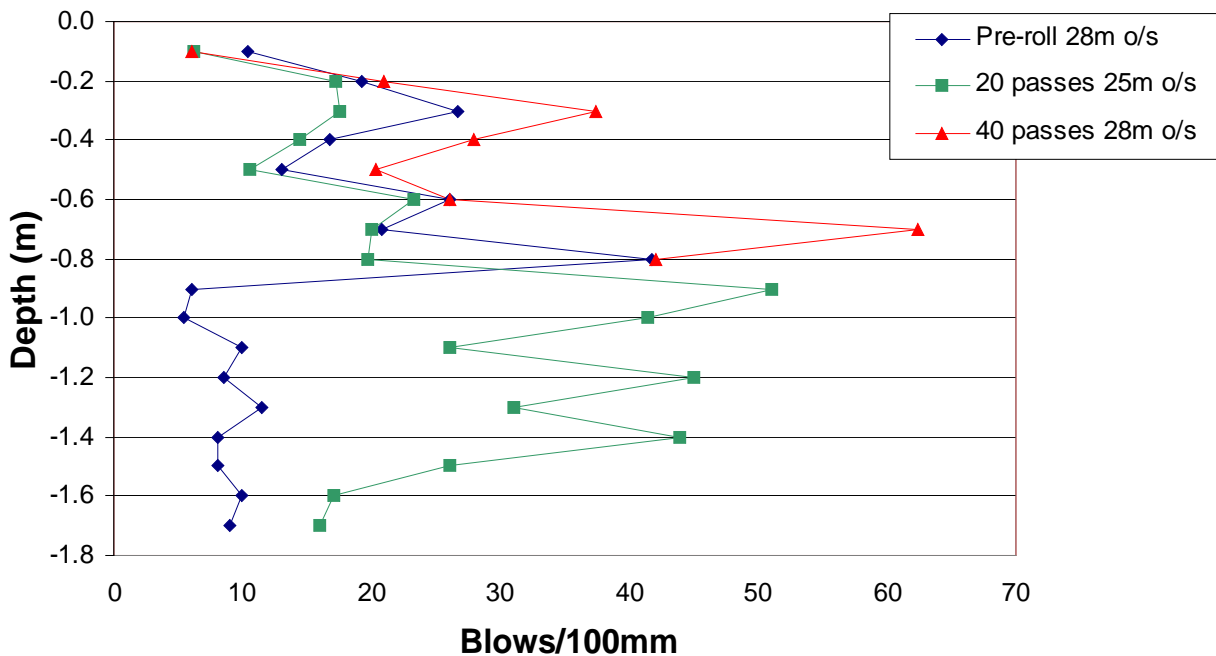


Figure 10: DCP penetration rate for 0, 20 and 40 passes.

While Figure 10 shows very little difference in the upper 0.8m between the pre-roll and 20 passes, there is a significant evident improvement down to 0.8m at 40 passes (test depth limited by refusal on hard particle) and below that depth after 20 passes.

Like the DCP, the CPT is generally most useful in fine-grained soils. Its use in heterogeneous fill that includes concrete and rock fragments often necessitates relief drilling and loss of continuous data. The CPT results are therefore intermittent in the fill zone to a depth of approximately 1.5m and there is no consistent indication of strength gain with the number of impact roller passes. As an example, plots of cone tip resistance versus depth at one location before and after impact rolling are shown in Figure 11.

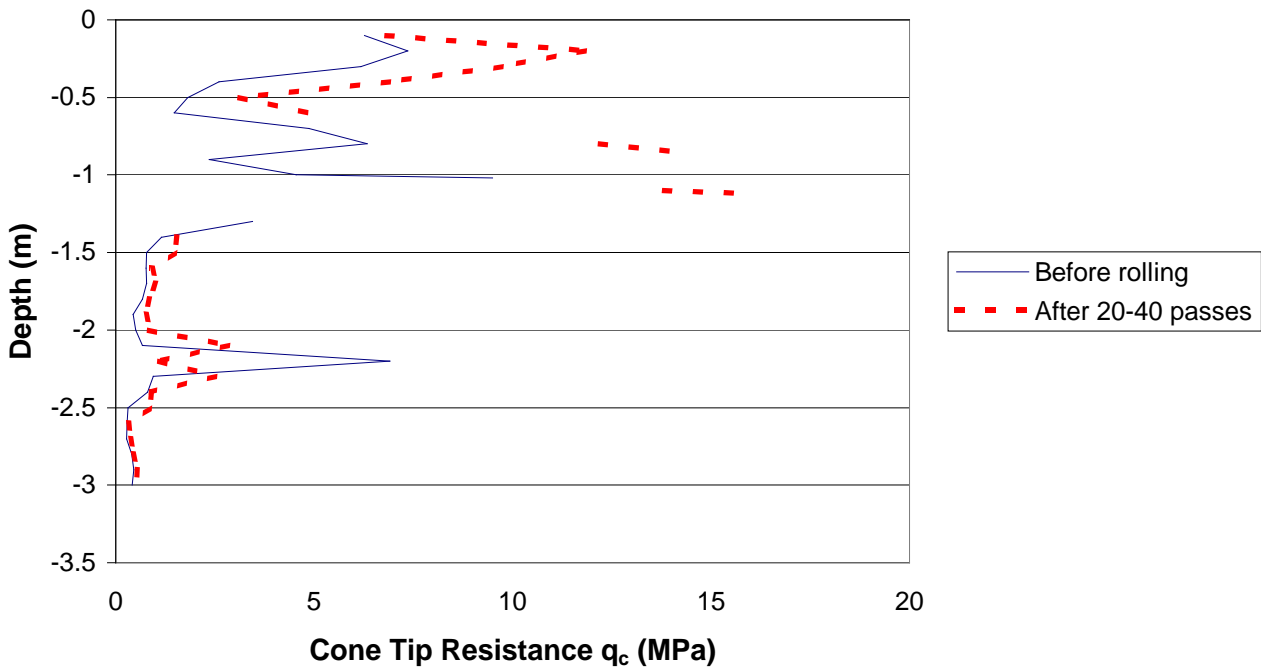


Figure 11: CPT results at chainage 173m, offset 28m.

Figure 11 appears to indicate an improvement in strength in the fill zone to 1.5m, the gaps in the lines indicating the zones of relief drilling. Below 1.5m there is little difference.

Field density test results indicated dry density ratios ranging from 75-100% based on Standard compaction (Australian Standards, 1995 and 2003) and there was no evident correlation between the density ratio and the number of impact roller passes. Density measurement in fill material of this nature, with a significant quantity of oversize material, cannot be considered very reliable.

The 320mm diameter plate bearing test was carried out at a location that had been given 10 passes of the “square” impact roller. Loosened surface material was removed and the test carried out to a maximum load of 80kN. The 20kN load increments were sustained up to 60kN, but not at the 80kN limit. Analysis of the results indicates a static elastic modulus (Young’s Modulus) of approximately 25MPa in the upper 0.6m of the fill.

On the basis of the trial programme, the client and the designers decided to adopt impact rolling to prepare all subgrade areas, with the minimum number of passes set at 12. At the time of writing this paper, construction had just commenced; proof-rolling over the proposed building footprint with the “square” impact roller was underway, but test data was as yet unavailable.



## **5 TESTING PROTOCOLS**

The adoption of appropriate testing protocols is the key to satisfactory verification of impact roller ground improvement works. Of the many different test methods that are utilised to verify the effects of impact rolling, dramatic variations occur from site to site and project to project, variations 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.

In the two case studies presented above, differences in testing strategy are clear. As a general proof-rolling tool to improve the subgrade by identifying soft spots at an early stage on the Port River Expressway project, verification of the impact roller's effect was by observation, with limited DCP testing and settlement monitoring in some areas. As part of the Adelaide Airport impact roller trial, however, a wider suite of tests was adopted, including settlement monitoring, and DCP, CPT, field density and plate load testing. The usefulness of some tests was somewhat limited due to the presence of large hard particles.

For major transportation projects, there are the additional options for the testing regime. For example, the falling weight deflectometer, dynamic plate load tests and geophysical tests, such as continuous surface wave and cross-hole seismic cones, offer alternative means of quantifying the strength and stiffness of subsurface strata. These often involve quite specialised equipment, which may prove cost-prohibitive, but a rational decision should be made in terms of the confidence limits associated with the proposed tests and the nature and scale of the project.

Overall, settlement monitoring has proven to be a robust means of quantifying the ground improvement effects of the "square" impact roller. The major difficulty is associated with the deformed surface and the selection of points of measurement. In general, the surface is lightly trimmed with a grader to remove the highest spots and fill the lowest, thus equalising the surface in readiness for surface settlement measurements and the next round of impact rolling. Settlement monitoring techniques include robotic total station, laser levels and direct methods, such as the string line used in the Adelaide Airport trial. Research is recommended into the range of appropriate testing protocols that can be applied to impact roller projects, and suitable generic guidelines may then follow.

## **6 CONCLUSION**

The "square" impact roller is a proven machine for pavement subgrade improvement. Two case studies reflect its use on current transport-related projects in Adelaide, South Australia.

The proof-rolling of nearly 5.5km of major arterial road subgrade has been an innovative use of the impact roller. The cost-benefit is likely to manifest itself through the improved performance of the road and the builder's savings on the maintenance contract.

Construction of Adelaide's new Airport has commenced, with the "square" impact roller being used to densify existing fill material. A trial programme that involved geotechnical tests before, during and after impact rolling influenced the specification for this work. Such trials can add significant value to contracts as some of the risk is taken out of the equation.

Both projects benefited environmentally from the use of the “square” impact roller through the treatment of non-engineered fill in situ and the reduction in off-site disposal of excavated waste materials, all of which adds to project cost-effectiveness.

## ACKNOWLEDGEMENTS

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