Trials and validation of deep compaction using the "square" impact roller

Derek Avalle
MSc(Eng) BSc(Eng) GDE PGCE MIEAust CPEng
Broons Hire (SA) Pty Ltd, Sydney, Australia

ABSTRACT

The use of non-circular impact modules for compaction, known as impact rolling, impact compaction or rolling dynamic compaction, has been gaining currency for a wide range of earthworks projects. Impact rolling has been shown to deliver significant improvements in soil strength or density to depths far exceeding conventional circular drum rollers. Now accepted in the Australian Standard for earthworks, and with documented experiences of impact roller performance, the technique can be considered for projects as varied as deep reclamation, major embankments and improving existing fill. In many cases, particularly with larger projects, a concerted trial programme delivers dividends in the form of confidence in the use of the technology, the most efficient methods for a particular application and the fact that the specification can be met in the most efficient manner. As much as trials are co-ordinated and controlled, so must the production work have an appropriate level of control and monitoring to ensure that the impact rollers are correctly utilised. This paper outlines several case examples where expenditure on detailed trials resulted in efficient impact rolling during productive earthworks.

1 INTRODUCTION

Compaction of soils during conventional earthworks can be achieved in a number of ways, most commonly in thin layers by conventional circular drum rollers. However, the use of impact rollers, which comprise non-circular modules rotating about their "corner" and falling to impact the ground, offer an alternative compaction solution that can prove most cost-effective. Impact rollers travel at a relatively high speed compared with conventional plant and they impart substantial impact energy into the ground, resulting generally in a much deeper compaction profile than with round rollers (Pinard 1999).

With the potential benefits of deep compaction offered by impact rollers comes the challenge of verification. Moving away from compaction of thin layers of soils with relatively small particle sizes, placed in a highly controlled manner, with shallow tests to quantify the density layer by layer, to the compaction of thicker layers or in situ materials, various options are open to the geotechnical designer with regard to specifying the earthworks to be carried out by impact compaction (Avalle 2004a and 2004b). Australian Standard AS 3798-2007, "Guidelines on earthworks for commercial and residential development" has recently been reissued, and impact rolling is now included as a recognised compaction method. However, guidance on monitoring and verification of impact roller works is not included.

This paper presents case study examples where trials were undertaken to establish a suitable methodology for the particular earthworks and to develop an appropriate validation strategy. The use of a detailed and carefully structured trial can add significant value to the project by developing the site-specific methods for impact rolling, monitoring and verification (Avalle and Young, 2004). Trials may also be necessary to determine whether the procedure will achieve the desired specification, and also to facilitate the efficient verification of the works once productive operations commence.

2 DEEP COMPACTION OF SAND

Port Coogee is situated on Cockburn Sound about 5km south of Fremantle, WA. Approximately 160,000m^2 of reclaimed land has been created by end-dumping local calcareous sand within a rock seawall, and ground improvement earthworks were completed in July 2007. The project is described by Hillman et al (2007). Initial trials with the Broons BH-1300HD "square" impact roller, with its 12t solid module, resulted in a method specification for the remainder of the works, with ground improvement achieved by impact rolling alone.

The trial programme was undertaken in a full production area, where the fill depth varied from zero at the former shore line, to a maximum of about 8m inside the seawall. Impact rolling was undertaken on the reclamation fill less than 1m above water level (see Figure 1). Testing with the electrical friction-cone penetrometer (CPT) was carried out before impact rolling, and then after sets of 10 passes, to a maximum of 40 passes. Settlement monitoring was also carried out during the trial.

Figure 1: Impact rolling at Port Coogee, WA.

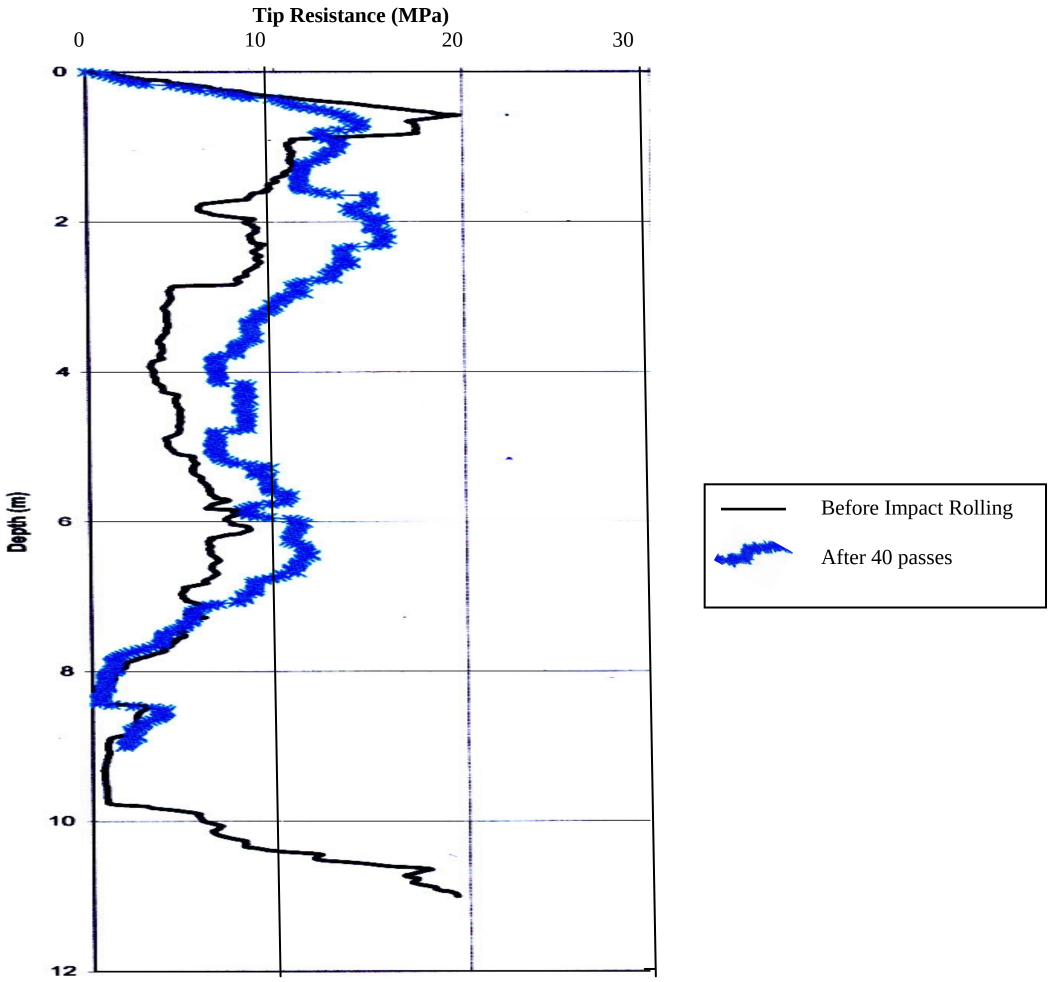


Figure 2: Example of CPT output during impact roller trial (BH-1300HD) at Port Coogee, WA.

An example of the CPT tip resistance profile during the trial, before and after 40 passes, using the unit with the 12t module, is shown in Figure 2. A significant improvement is evident several metres down, and the primary objective of achieving an acceptable profile in terms of liquefaction potential was achieved with 30 passes over all four stages of the project.

Two projects that employed Broons "square" impact rollers in Doha, Qatar, were also undertaken without any other form of post-reclamation ground improvement. The Pearl-Qatar is a multi-billion dollar off-shore island reclamation project and one of the largest real estate developments in Qatar. Since its commencement in early 2004, The Pearl-Qatar has emerged as the largest island in Qatar's waters. During this time, 400ha of new land has been created with a 32km shoreline, three coves, navigable canals and numerous other features. All land reclamation works were completed by October 2006 and two impact rollers provided the basis of the ground improvement.

The New Doha International Airport project (NDIA) in Qatar involved the reclamation of a 22km^2 area on the coast adjacent to the existing airport. Reclamation was completed during 2006 and the final stages of earthworks will continue until later in 2007. After various trials with heavy tamping (or dynamic compaction) and extensive trials with impact compaction, all ground improvement works were carried out using a fleet of Broons 8t and 12t "square" impact rollers (see Figure 3). The project and its compaction quality control system are discussed by Avsar et al (2006). Again, the CPT was used as the verification tool, after trials with settlement monitoring and field density tests, and large scale plate load tests (or zone load tests) complemented the verification process.

Figure 3: Impact rolling at the NDIA project, Qatar.

3 IMPACT ROLLING AFTER VIBRO-COMPACTION GROUND IMPROVEMENT

Broons "square" impact rollers are currently in use on four of the major reclamation projects in Dubai, UAE: Dubai Maritime City (DMC), Palm Jumeirah, Palm Jebel Ali and Palm Deira.

In all four cases, reclamation fill, comprising calcareous sand dredged from the Gulf, extends to depths of 10m to 20m, and deep ground improvement is undertaken using vibro-compaction methods (also known as vibrofloatation). The soil particles are rearranged and the material densified under the effects of a powerful vibrating probe lowered into the ground (see Figure 4).

Figure 4: Vibro-compaction at Dubai Maritime City, Dubai – note craters and tension cracks.

In Figure 4, which also shows the CPT testing rig in the left foreground on the left-hand photograph, the vibro rig is working with a pair of 20m long probes, approximately 4m apart, probing on about a 4m triangular grid. The ground surface in the treated area settles almost immediately 1m to 1.5m under the effects of the vibro-compaction, resulting in the craters and tension cracks evident in the right-hand photograph (Figure 4).

The resulting ground strength profile after vibro works tends to vary between probe locations and the relatively uncompacted shallow soil zone in between. In order to obtain the necessary degree of compaction and uniformity in the upper 2-3m, impact rolling is applied to the surface after vibro-compaction.

Intensive impact roller trials have been undertaken on all four sites. Figure 5 is an example of the rolling pattern adopted for impact rolling and quality control.

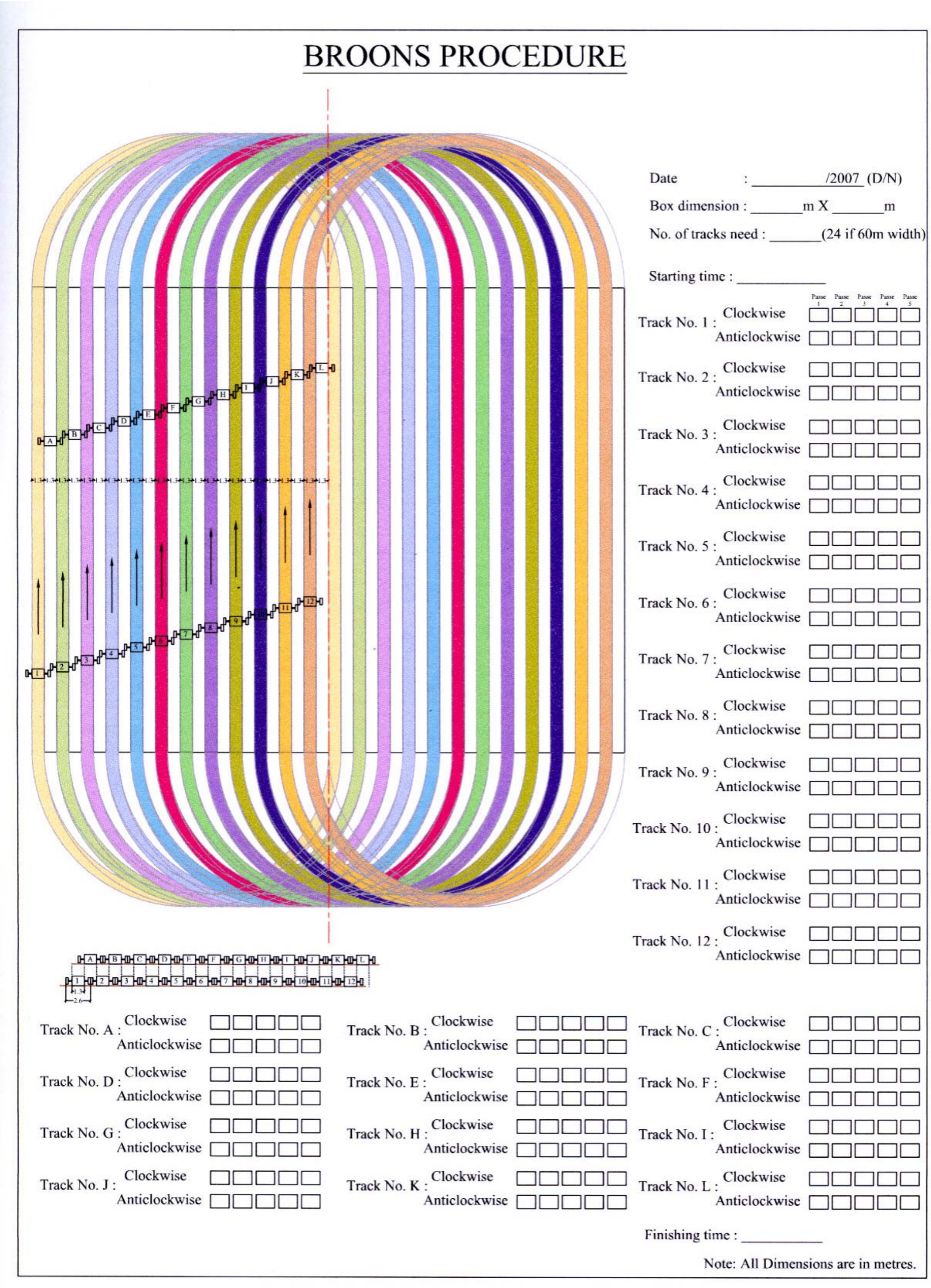
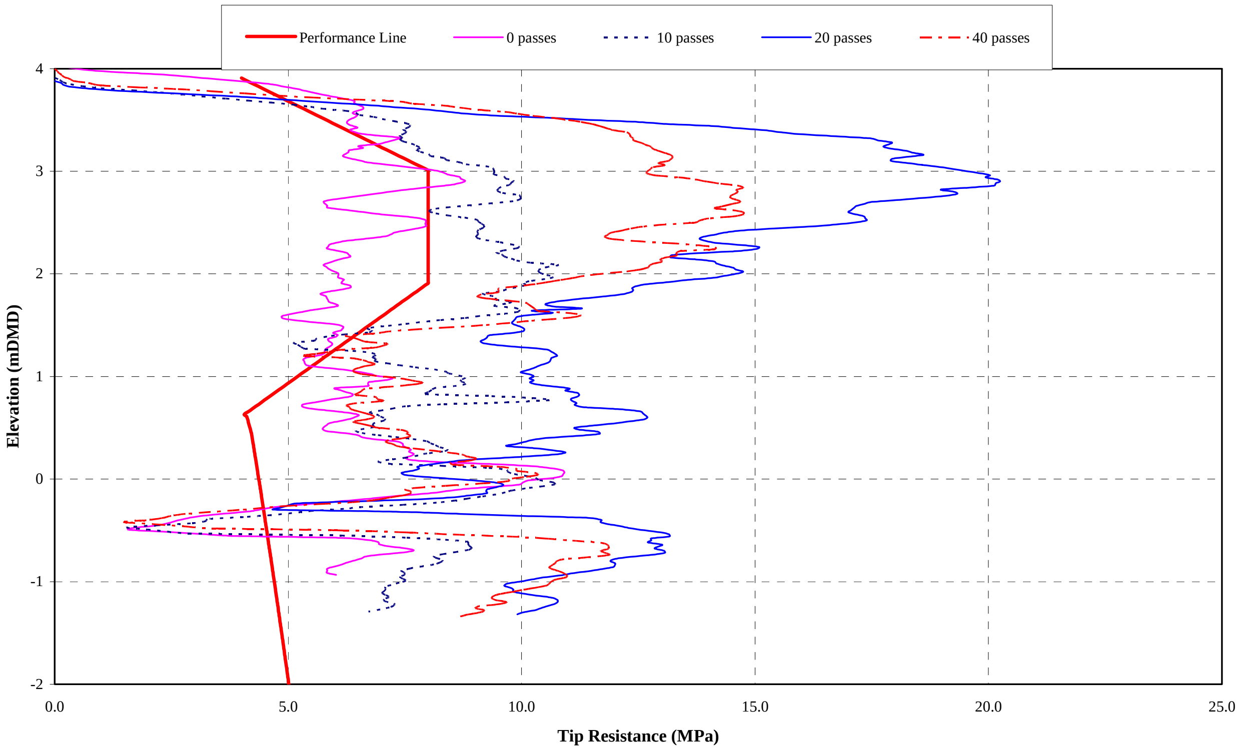


Figure 5: Example of rolling pattern and quality control form adopted at Palm Jebel Ali, Dubai.

Figure 6 includes examples of the CPT results during the trial at Palm Jebel Ali, using the Broons BH-1300 Impact Roller with its 8t solid module.



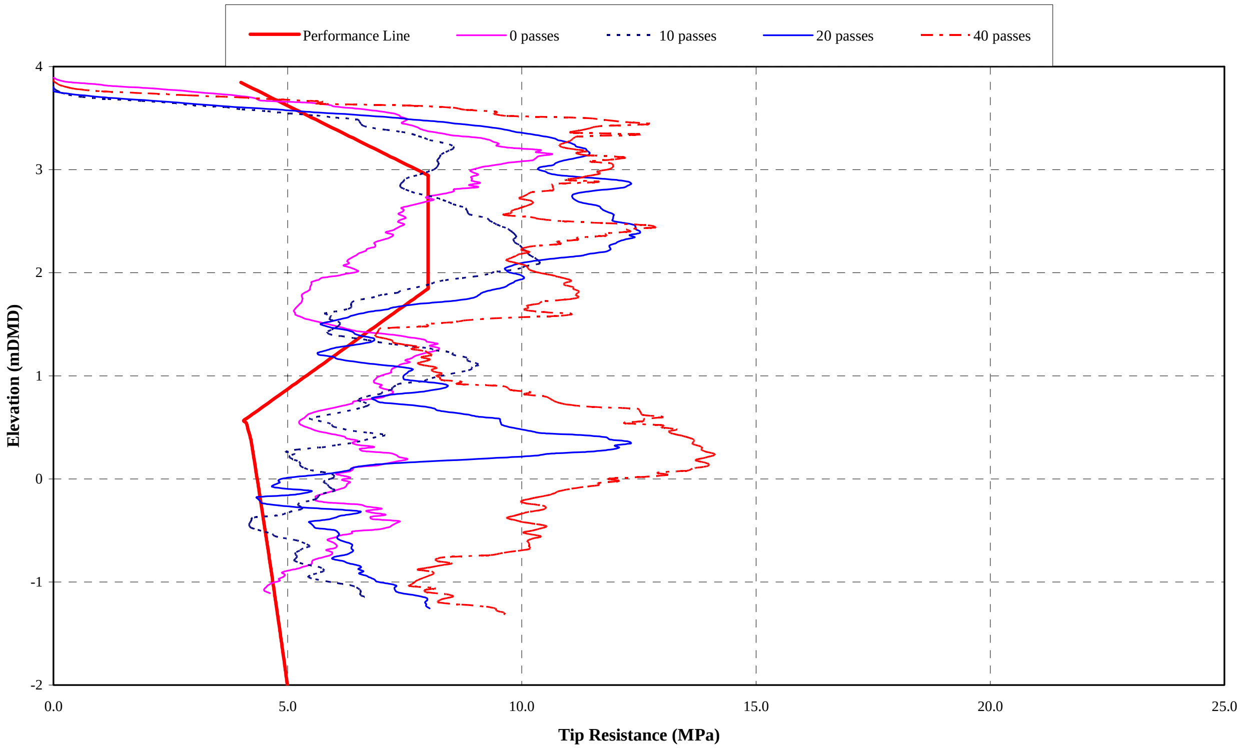


Figure 6: Examples of CPT results from Palm Jebel Ali trial (BH-1300), Dubai.

It can be seen from the above examples that a significant increase in cone tip resistance in the upper 3m is realised with 10-20 passes, generally achieving the requirements of the "performance line".

What has been clearly identified during all the projects in the Middle East is that a very high degree of control and supervision is necessary to ensure that the impact rolling is carried out as specified. In particular, the number of passes of the impact roller, its travel speed and track or wheelpath widths are critical to the development of an adequately dense and uniform soil "raft" across the site. Other factors, such as adding water, were also examined at NDIA (Avsar et al 2006) and found to be important.

The benefits of deep compaction using rolling dynamic compaction or impact rolling cannot be separated from the need for rigorous control of the compaction process, and a comprehensive trial, tailored to the particular application, will provide the necessary confirmation of the appropriate methodology and verification tools.

4 CLAY SOILS AND MIXED FILL

The compaction of fine-grained soils in thick layers or the ground improvement on existing cohesive soil or mixed fills comprise other applications where impact rollers have been efficiently applied. From deep lift compaction for flood mitigation embankments to thick fill densification on industrial sites, rolling dynamic compaction can be successfully applied in many cases.

After a series of full scale trials in 2004, a 22km long levee bank of average height 5m was constructed at the Curragh North Coal Mine by Thiess in 2005, using two Broons BH-1300 impact rollers to compact the fine-grained alluvial soils (mainly sandy clay/clayey sand). The soil was placed in 700mm thick layers and was given 15 passes to achieve the required 98% density ratio, and 20,000m^3 of material was placed per day. The key to optimum production was the trial programme, which was targeted at defining the most effective layer thickness to achieve the specification. Sections of embankment were constructed with multiple layers of different thicknesses, and a variety of tests were carried out, including settlement monitoring, Dynamic Cone Penetrometer and field density, and slots excavated for visual examination (see Figure 7). The project received a High Commendation at the 2006 Engineering Excellence Awards.

Figure 7: Trial embankment at Curragh North, Queensland.

A recently conducted trial of a filled site in Sydney is undergoing post-impact rolling tests and data assessment. The existing fill comprises mainly mixed soils and building rubble and extends to as much as 3m. Its removal and replacement was cost-prohibitive, and impact rolling offered a possible solution that would facilitate the proposed light industrial development. The selection of appropriate trial areas, rolling patterns and testing procedures remains the key to a successful trial. In this case (see Figure 8), a rolling pattern was adopted that delivered two areas, each with sub-areas of 10, 20, 30 and 40 passes, for subsequent testing with the Falling Weight Deflectometer. This data, in conjunction with settlements averaged for each of the sub-areas, will be analysed and assessed in relation to the end-use of the site, an exercise that is incomplete at the time of writing.

Figure 8: Trial underway on site in Sydney, NSW.

5 CONCLUSIONS

Impact rolling, impact compaction or rolling dynamic compaction, however it is named, can deliver significant benefits for earthworks projects. It often, however, requires a change in perspective from the conventional approach to bulk earthworks. On all major projects where impact rolling has been successfully employed, and on many smaller projects as well, the key to success has been in the design and execution of a carefully structured, controlled and monitored trial programme, with sufficient and varied testing before, during and after impact rolling. In addition, once production impact rolling commences, an appropriate quality control system needs to be implemented to ensure that the impact rolling is correctly applied. In particular, the verification testing needs to be carefully considered, as conventional tests may not be suitable in view of the depth of compaction improvement. The high productivity of impact rollers in producing compacted material to specification warrants its consideration for a wide range of earthworks applications.

6 REFERENCES

Avalle, D. L. (2004a). *Impact Rolling in the Spectrum of Compaction Techniques and Equipment*. Australian Geomechanics Society Earthworks Seminar. 16 August, Adelaide.

Avalle, D. L. (2004b). *A Note on Specifications for the Use of the Impact Roller for Earthworks*. Australian Geomechanics Society Earthworks Seminar. 16 August, Adelaide.

Avalle, D. L., and Young, G. (2004). *Trial Programme and Recent Use of the Impact Roller in Sydney*. Australian Geomechanics Society Earthworks Seminar. 16 August, Adelaide.

Avsar, S., Bakker, M., Bartholomeeusen, G., and Vanmechelen, J. (2006). *Six Sigma Quality Improvement of Compaction at the New Doha International Airport Project*. Terra et aqua, Issue 103 (June 2006).

Hillman, M., Tan, E. and Mocke, R. (2007). *Advanced Geotechnical Modelling and Monitoring for the Port Coogee Project*. Proc. Coasts & Ports Conf. 2007, Melbourne.

Pinard, M.I. (1999). *Innovative Developments in Compaction Technology Using High Energy Impact Compactors,* Proc. 8th ANZ Conf. on Geomechanics, Hobart, pp. 2-775 to 2-781.

Standards Australia. (2007). AS 3798-2007 *Guidelines on earthworks for commercial and residential developments*. Sydney.