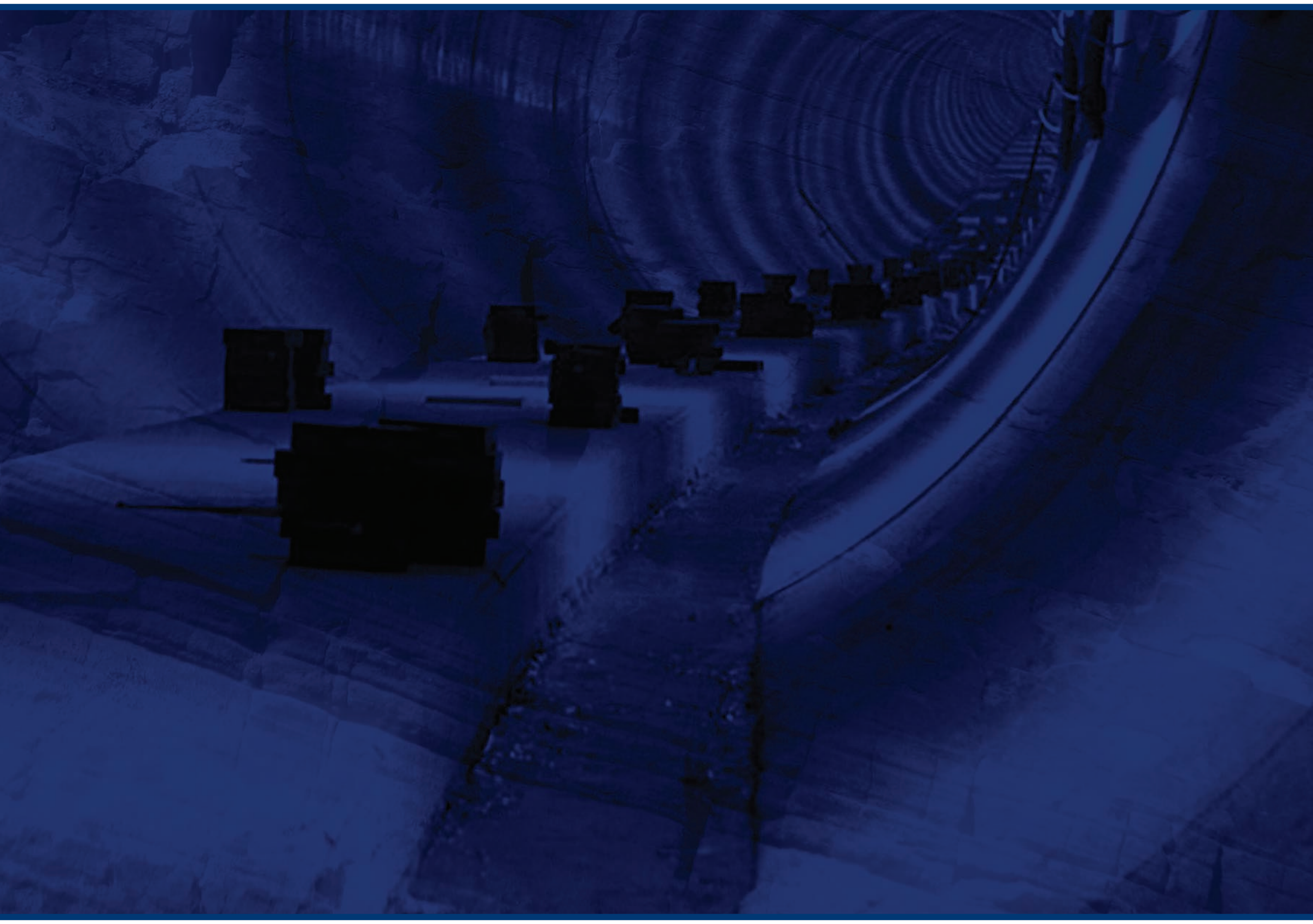
PROCEEDINGS

2018 AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIAN SYMPOSIUM

Geotechnics and transport infrastructure

Wednesday, 24 October 2018, 8:00am – 6:00pm
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER

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PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2018 Australian Geomechanics Society Victorian Symposium on 'Geotechnics and transport infrastructure' held on 24 October 2018.

In recent years Victoria has seen significant investment in transport infrastructure as part of a plan to manage the demands of a growing population and expanding urban fringe. The construction of Melbourne Metro, a second crossing of the Yarra River, rail and freeway upgrades as well as numerous level crossing removal projects are just some of the major transport projects currently underway in Melbourne and regional Victoria. Many of these projects carry numerous complex geotechnical challenges.

The 2018 Australian Geomechanics Society Victorian Symposium covers a variety of geotechnical challenges associated with transport geotechnics and present overviews of current infrastructure challenges, state of the-art practices, innovation, new research results and case studies demonstrating applications of advanced techniques and cost effective solutions in the construction and design of local transport infrastructure. The Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of transport infrastructure and associated geotechnical challenges and applications.

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Compaction QA limitations: benefits of alternative testing methods

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ABSTRACT

Density testing has been applied widely in quality assurance (QA), yet because of its widespread usage, this now acts as an impediment to the development of alternative methods of testing. Many incorrect inferences are made from density testing. Limitations and issues associated with traditional density testing inferences are shown with case studies. Modern geotechnical and pavement designs are based on modulus and strength values. It is therefore reasonable to investigate the feasibility to use alternative test methods for QA purposes, which measures these parameters directly. A state-of-the-industry study was completed to identify test methods that have the potential to: (a) reliably provide a direct measure of the strength or in-situ modulus value; and (b) offer significant time savings in turnaround time of QA test results. Comparisons of density with alternative in-situ testing show the latter provide significant benefits to the industry.

Keywords: density, compaction, quality assurance, earthworks, in-situ testing

1 INTRODUCTION

Quality Assurance (QA) assessment of earthworks remains dominated by the 1930s Proctor laboratory density compaction model coupled with the California Bearing Ratio (CBR) test. Over the past two decades, field compaction and testing equipment have moved ahead of these commonly employed QA techniques routinely used in Australia. Density tests are lag indicators and contractors often continue placing additional layers to avoid significant equipment standby costs. Yet density per se is only an indicator of CBR – which is then correlated to strength or modulus – the key parameters used in design. Hence density is a 2nd order correlation index at best with significant transformation errors.

Note that design may require other types of testing (eg soaked tests). This paper focuses on the QA testing aspects.

Modern geotechnical and pavement designs are based on modulus and strength values. It is therefore reasonable to investigate the feasibility to use alternative test methods for QA purposes, which measures these parameters directly. A state-of-the-industry study was completed on behalf of Queensland Main Roads and ARRB to identify test methods that have the potential to: (a) reliably provide a direct measure of the strength or in-situ modulus value; and (b) offer significant time savings in turnaround time of QA test results.

Field result trials were used to bench mark various alternative equipment and compared with traditional density QA measurements. Reliability, benefits and limitations of these equipment not traditionally used in transport infrastructure projects were tested on live projects. A key summary only is presented at the end sections of this paper due to page limitations.

The emphasis is to show through case studies the many (incorrect) assumptions in compaction currently occurring in industry. The alternative testing and their ranking summary from field trials are presented. The data used to derive that ranking will be presented in future papers.

2 COMPACTION OVERVIEW

2.1 Compaction History

Density testing has been applied widely in quality control, yet because of its widespread usage, this now acts as an impediment to the development of alternative test methods in the industry. Look (2014 and 2016) discuss some of the underlying assumptions in the traditional QA compaction model. The emphasis on density has led to the belief that it is the key parameter, yet it is an index only, i.e. we assume an increased density means an increased strength or modulus.

Although technology has now advanced to measure those parameters directly, Australia still uses density testing as the main quality evaluation parameter because of our longstanding experience. The compaction model has not advanced with the change in compaction equipment (Figure1).

2.2 Compaction Basics

Compaction is carried out to achieve improvements in soil properties such as strength, modulus or permeability. During construction these properties are not traditionally measured. Instead density is the index used. The density ratio (aka relative compaction) compares the compacted field density with the laboratory maximum dry density (MDD), which can be Standard or Modified compaction.

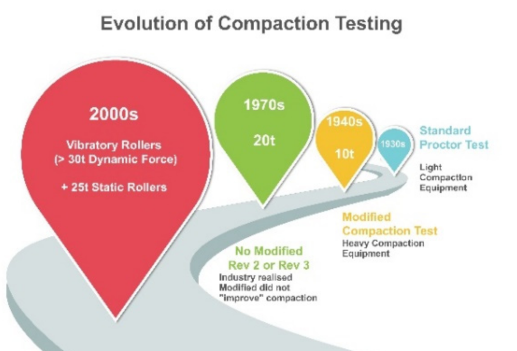


Figure 1. Compaction History

$$Density\ Ratio = \frac{Field\ Density}{Max\ Dry\ Density}$$

Several assumptions are then made. These include:

1. There is a direct and reliable relation with density and CBR, strength or modulus;
2. The reported density measurement is accurate;
3. As the density ratio increases the CBR, strength or modulus increases;
4. The higher energy imparted to the soil via higher number of passes, increases the density ratio and hence also the CBR, strength or modulus;
5. The additional passes improve the density ratio because the field density increase with the maximum dry density unchanged for a given soil.

These assumptions are each discussed in more detail as they are all incorrect for some materials.

A specified density ratio is really a targeted means to reducing the air voids. This requirement is often confused with 2 supporting recommendations in Standards. Figure 2 illustrates the concept of requiring the Density Ratio to achieve the reduction in air voids with the 2 supporting recommendations of the moisture ratio and the lift thickness. The target moisture ratio is climate dependent (Look, 1994) while the target lift thickness is equipment dependent. A recommendation should not be given the same emphasis as a requirement.

3 CBR VS DENSITY RELATIONSHIP

The California Bearing Ratio (CBR) has been traditionally used as indicative of the material strength and modulus. A higher density is generally expected to increase the CBR value. However, for expansive clays it is the after-soak value that governs the design. The 5-point soaked CBR is required for such subgrade materials as a 1-point CBR value is meaningless, as the latter does not investigate the equilibrium condition. Both density and moisture change with time.

Look (1996b) shows this relationship for Cooroy Clays. This material has a median maximum dry density (MDD) of 1.62 t/m^3 and optimum moisture content (OMC) of 21.5% at Standard Proctor Compaction. Figures 3 shows the CBR vs compacted density from 11 laboratory tests of soaked 5-point CBR tests, with a corresponding 4 day soaked CBR at each point.

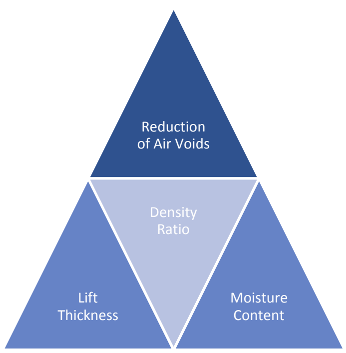


Figure 2. Aim, Requirements and recommendations for compaction control

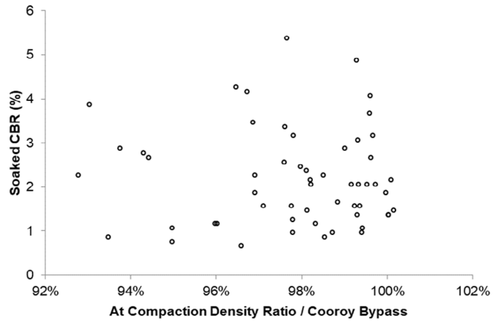


Figure 3. Soaked CBR vs Density Ratio

Figure 3 (varying moisture ratio in the 5-point test) shows increasing the density ratio above 92% has no effect on CBR. For these expansive clays, the density after soaking is more important than the as compacted density ratio and the initial compacted moisture ratio (Figure 4). The data in Figure 3 is combined with the after-soak density to illustrate its dependency and also to show the effect of the initial moisture ratio range (labelled in graph). The lower the initial moisture the greater the swell, and the lower the CBR value.

For this clay, the lowest and highest CBR are obtained from the dry of OMC (< 85%), and with compaction at OMC > 110%, respectively. That lab testing targeted both equilibrium moisture content established after a few years of monitoring and the targeted range for construction (Look, 1995a).

4 ACCURACY OF THE CBR TEST

Like density ratio, the CBR is only an index to another property. In pavement design, the CBR is related to the modulus. But this relationship varies considerably as seen in Figure 5 (Heukelom and Klump,1962).

An engineer typically uses the density ratio or CBR value in the test report. Both these tests apply only when the oversize does not exceed 20%. Look (2016) found that 23% of reports used in Quality Assurance did not account for that over size correction, and this data was from completed "passing" projects. The engineer blindly uses the reported value without questioning its validity.

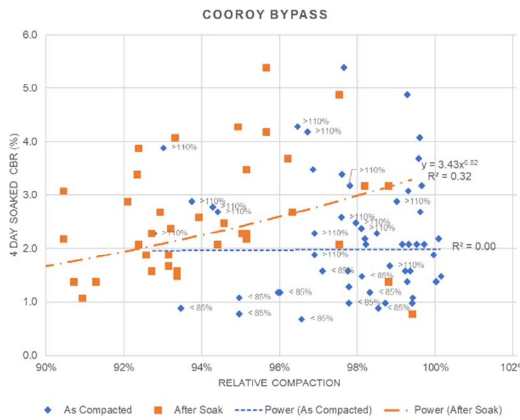


Figure 4. Soaked CBR vs Density Ratio as compacted and after soak with moisture ratio effects

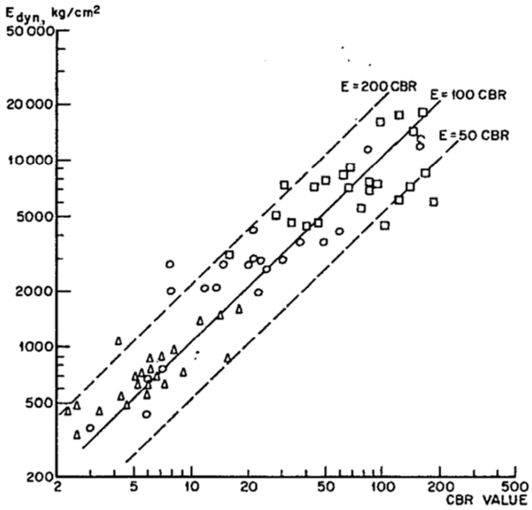


Figure 5. Modulus vs CBR relationship

Lacey et al. (2016) showed how the soaked CBR plateaus due to this effect as the "strong" oversize material is discarded during the CBR test (Figure 6). The effect of soaking also contributes to this reduced value. In this case study the high soaked CBR of 13% suggests little dependency on soaked vs unsoaked values. That case study demonstrates that the residual soil or weathered rock would have the same lab CBR despite the self- evident fact that the rock is significantly stronger than the soil. The blind use of these CBR values is common within the profession.

Rallings (2014) highlights the poor reproducibility and repeatability with the CBR test. Less than less than 60% of CBR results were within ± 30% of median value. Additionally, AS 1289 (2014) for the density test requires 4 to 7 days minimum curing time for the preparation of the sample. This curing time can have a significant effect on the result. Then a 4, 7 or 10 day-soaked for the CBR test. These "optimal" test and lag times are summarised in Figure 7.

5 DENSITY RATIO VS MODULUS

As the density ratio increases the strength or modulus is expected to increase. Typically, a 95% relative density is specified. However, this relative density does not corelate directly with modulus values as shown in Table 1 for 3 materials in trials tested in Queensland. Different materials have different modulus values irrespective of the same 95% relative density achieved.

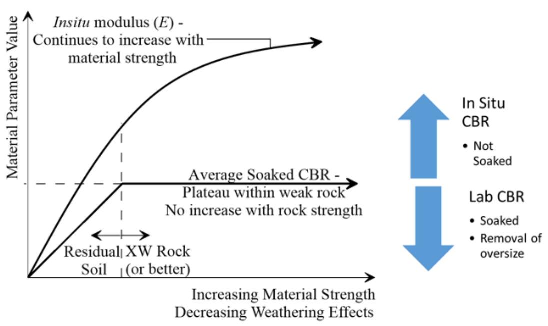


Figure 6. Lab CBR vs field values on residual soils

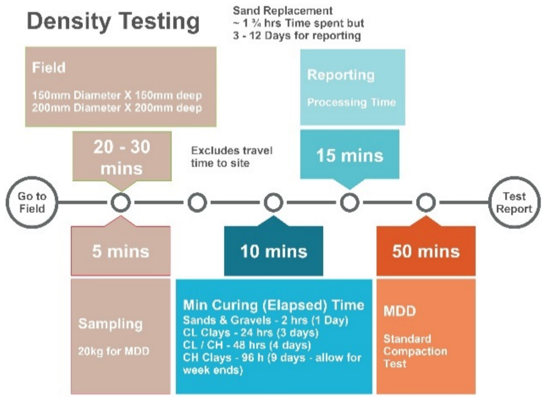


Figure 7. Lag time for density testing

Table 1: In-situ E correlated to 95% Relative Density

Fill Material Origin	Plate Load Test (PLT) E_{V2} (MPa)	Light Falling Weight Deflectometer (LFWD) $E_{LFWD-100kPa}$ (MPa)
Sandstone	60	45
Interbedded Siltstone / Sandstone	35	25
Basalt	50	30

Figure 8 shows that both Type I and Type II errors are occurring when density ratio is used as the QA assessment. Some "Passing" LFWD results have failed the 95% Relative Density specification (Type I error). Some "failing" LFWD results have passed the 95% Relative Density specification (Type II error). There is also a varying depth of influence depending on the energy drop or plate size adopted.

6 EFFECT OF NUMBER OF PASSES WITH STRENGTH OR MODULUS

Look and Lacey (2017, 2018) describe the results of field trials with different materials, lift thicknesses, moisture contents and 2 different vibratory rollers with varying number of passes.

The high energy imparted with a high number of passes, increases the density ratio. Engineers assume the strength or modulus is also increasing. These trials showed that additional compaction effort beyond 6 passes resulted in a reduction in shear strength (Figure 9) at T1 and T2, and no change at T3. A borehole shear test was used in-situ to measure the strength of the compacted granular fill.

These results show that material breakdown occurs when the placed fill is derived from a weathered rock source. Beyond 6 passes, an improved density ratio may still occur, but the strength decreases.

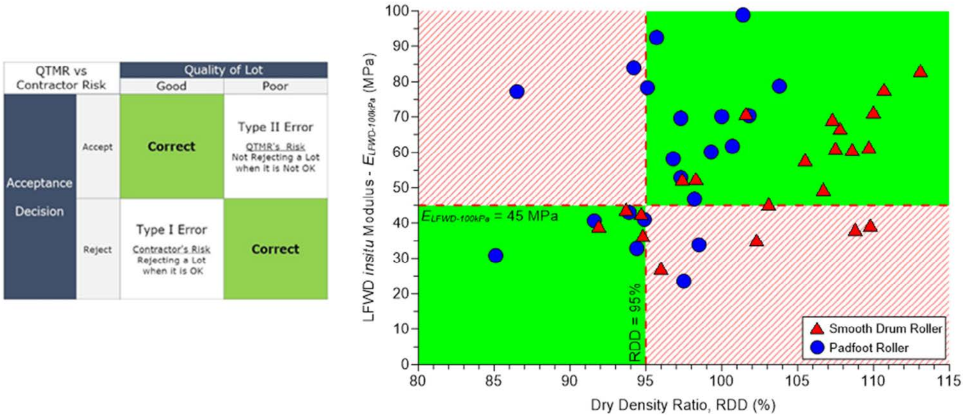


Figure 8. T3 Sandstone Trial – Relationship of Density ratio and in situ modulus

7 EFFECT OF NUMBER OF PASSES WITH MDD

The additional passes improve the field density with the maximum dry density assumed near constant for a given soil. Figure 10 shows that the Sandstone source material had a reduction in MDD at 8 passes. By reducing the MDD the density ratio still increases, and engineers wrongly assume this is due to an increase in the compacted field density.

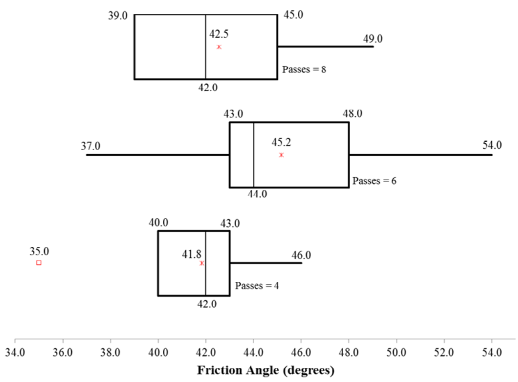
The basalt source material had negligible change in MDD irrespective of number of passes (Figure 11).

These MDD results independently support the BHST strength results (Figure 9) with a reduction of shear strength at 8 passes.

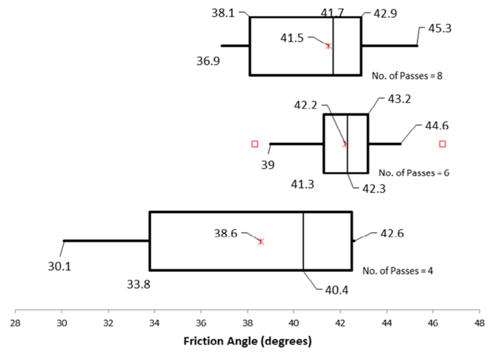
8 ALTERNATIVE EQUIPMENT

The above shows that the historical reliance of density testing and CBR results for QA purposes face a number of issues/limitations (Lacey et al., 2017). Aside from the above-mentioned technical issues, these traditional tests are lag indicators (Figure 7).

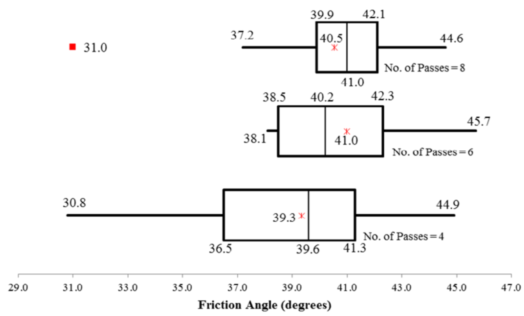
The time lag to complete laboratory evaluation of sampled materials, provides a bottle neck during construction. During this time, the contractor typically continues work and advances fill placement above the lift (without waiting for acceptable QA results to become available). If non-conforming QA test results are received, significant costs of removing and replacing both the non-conforming material and the overlying material are incurred.



T1: 35 No. BHSTs for Sandstone Fill



T2: 23 No. BHSTs for Basalt Fill



T3: 36 No. BHSTs for interbedded Siltstone/ Sandstone

Figure 9. In-situ measured friction angle with number of roller passes applied for various materials.

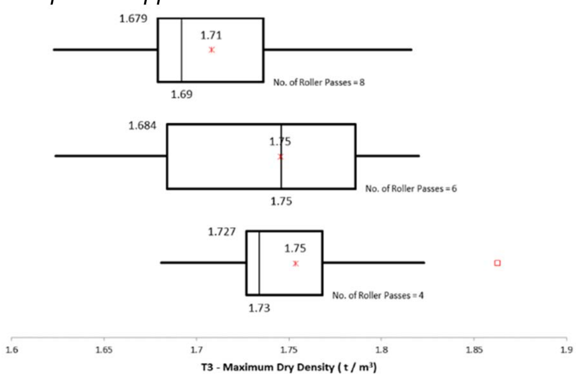


Figure 10. T3 Sandstone Trial – MDD variation.

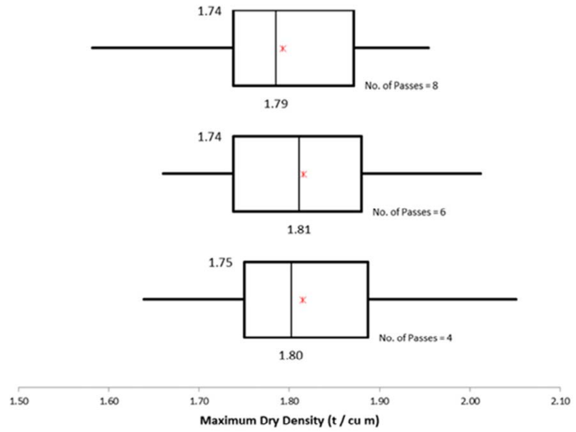


Figure 11. T2 Basalt Trial – MDD variation

Australian Standards require a Density Oversize correction. This applies when greater than 20% of material exceeds 19 mm or 38 mm for Mould A and B size, respectively. This is not consistently being applied across the industry, with 22% of 235 samples examined not applying that correction (Look 2016).

The benefits of In-situ testing for QA purposes is readily apparent. Over the past 2 decades, several devices have been developed that provide a more direct measure of the modulus or strength of an in- situ material. However, these various "values" are not consistent with each other. An evaluation of these devices (Lacey et al., 2017) resulted in a matrix of evaluation versus usage (Figure 12) and based on the following weightings:

- Accuracy, repeatability and reliability of equipment (30%)
- Requirement/Duration / Ease of results processing to report measured parameter (25%)
- Duration of field completion of test (20%)
- Operating Cost (15%)
- Principal Cost (10%).

These weightings are for comparative purposes only and will vary based on a project specific or application being considered.

These alternative QA compaction methods do not directly measure density. Comparing with density has conversion issues (Figure 8) and was discussed by Look et al. (2018 webinar) and Look and Lacey (2018).

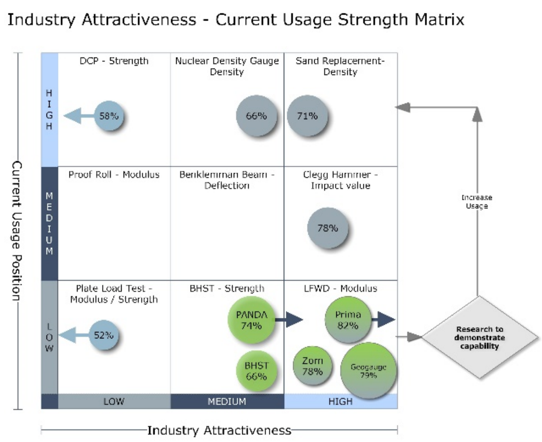


Figure 12. Attractive versus Usage

Additionaly, the zone of influence is different for the various equipmnent (Figure 13).

Field testing on "live" projects at various sites and on varying materials were carried out in parallel with the usual density QA testing (Figure 14). The range of equipment considered is shown in Figure 15.

These tests have so far validated the initial evaluation shown in Figure 12. The reader is referred to the references at the end of this paper for further details. This testing shows that density may be precise but is not accurate. No test was both accurate and precise. Density testing takes longer time as compared to current in situ testing technology. The commonly used Dynamic Cone Penetrometer (DCP) was found to be neither precise nor accurate at 100mm.

9 CONCLUSION

Current QA relies on density and CBR testing. These tests are not accurate and take significant time for results to be reported. Issues and limitations of traditional density testing were presented. Several in-situ devices have been available to industry for the past 2 decades and this research reported herein shows these have significant benefits. A summary of some of the key findings for comparison of various QA testing is provided in Table 2. Its derivation is not shown in this paper. Other factors include amount of data and cost. Research is ongoing to provide Standards for these alternative tests to be more widely adopted in industry.

10 ACKNOWLEDGEMENTS

Dr David Lacey was active in the acquiring and analysis of data for the trials presented.

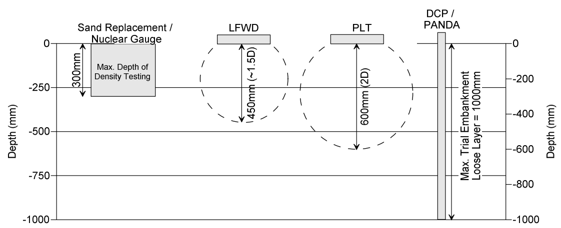


Figure 13. Zone of Influence

Figure 14. Various equipment used at project site

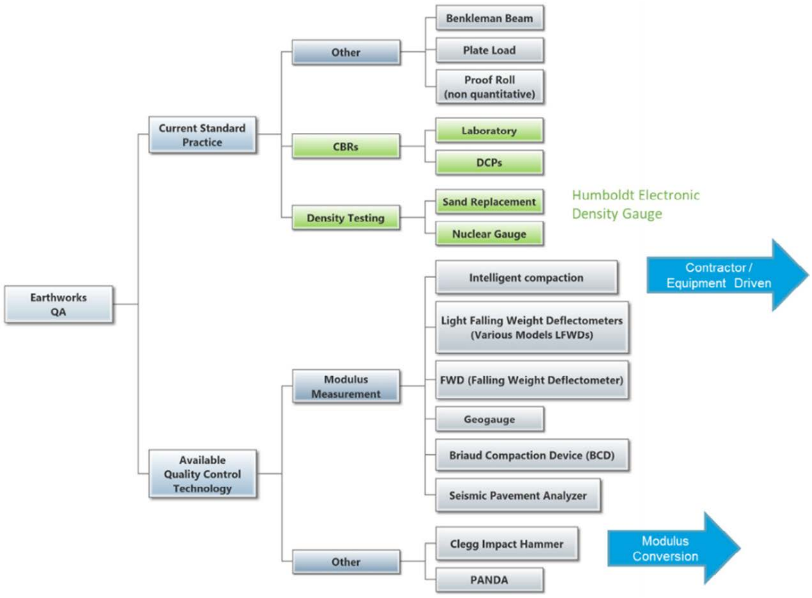


Figure 15. Overview of Range of QA testing considered (Look et al., 2018)

Table 2: Summary comparison of Equipment used

	Accuracy	Precision	Time (T)
1.	PLT	Sand Repl.	LFWD Zorn T
2.	PANDA	Nucl Gauge	Geogauge 1.3T
3.	LFWD Prima	Geogauge	PANDA 1.4T
4.	Clegg	LFWD – Prima	DCP 1.8T
5.		LFWD – Zorn	Clegg 2.3T
6.	Density	Clegg	Prima* 2.6T
7.	LFWD Zorn	PANDA	Nucl Gau 6T↑
8.	Geogauge	DCP	PLT* 6T
9.	DCP	PLT	San Rep. 10T↑

* Complete Stress Strain response provided – not provided by other equipment ↑ Larger Reporting time

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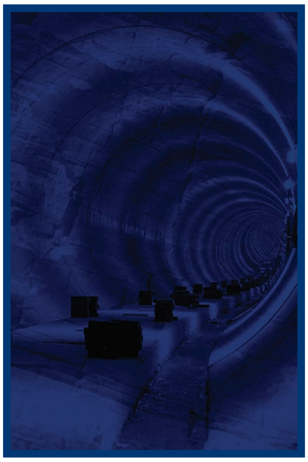

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