COMPACTION AND COMPACTABILITY ASSESSMENT OF DIFFICULT SOILS – AN ALTERNATIVE APPROACH

I. Driscoll[1], **R. Kelly**[2], **S.Padina**[2] and M. Foweraker[2]
[1] Business Unit Technical Manager, Leighton Contractors, [2] Coffey Geotechnics

ABSTRACT

Typical Australian industry processes for verifying compliance of earthworks compaction can result in production delays and cost impacts when difficult soils are encountered. Difficult soils can comprise high plasticity clays and halloysitic clays. Insufficient curing of high plasticity clay samples during rapid compaction testing can result in unrepresentative measurement of maximum dry density and optimum moisture content. This can cause apparent non-conformances, trigger the requirements for proof rolling and incur delays to construction. Verification of lot conformity is often delayed until the following working day due to the period of time required for measurement of moisture contents. Halloysitic clays present a problem because their structure irreversibly changes when they are oven dried. Oven dried soil tested in the laboratory does not represent field conditions because the soils are physically changed. This can cause apparent non-conformances, unnecessary rework and consequential delays. An alternative approach to Australian industry accepted compaction testing has been developed by the UK based Transport Research Laboratory (TRL). The Moisture Condition Value (MCV) test is used to assess whether a soil is suitable for use prior to compaction. End product verification is achieved through on-going calibration to standard Proctor density tests and field certification using the nuclear densometer. The MCV apparatus and theory are introduced and an example of how the process is implanted from site investigation to construction verification is presented.

1 INTRODUCTION

The aim of earthworks in embankment construction is to produce a formation that has sufficient strength, stiffness and resistance to moisture to support the pavement throughout its design life. Fill is excavated from cuts or imported. Fill is placed in layers and compacted using heavy equipment. Acceptance testing is then performed and this generally comprises nuclear density testing to assess compacted bulk density, moisture content testing for comparison to specified ranges and rapid compaction testing performed in an on-site laboratory to assess the dry density achieved as a percentage of maximum dry density. Sampling for laboratory testing usually occurs towards the end of a days work and the results are usually not available until the next morning. If the testing falls outside the requirements of the specification a proof roll can be requested to assess whether the fill complies with engineering requirements. The proof roll might be performed in the morning and if the lot passes a proof roll then production might occur later that day. Production is delayed by at least half of one day. This process increases the risk of rain delays in northern NSW where 30% or more lost time can occur due to weather. The cost of rework can be in the order of 50% the direct costs of constructing each fill lot.

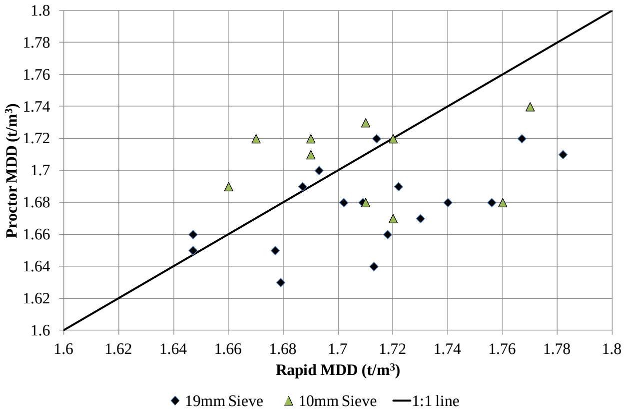
Laboratory tests can give misleading density and moisture results in high plasticity clays and halloysitic clays. Insufficient curing of high plasticity clay samples can result in unrepresentative measurement of maximum dry density and optimum moisture content. Typically rapid compaction tests result in values that err toward field dry density and field moisture content rather than maximum density and optimum moisture content. This can cause apparent non-conformances, trigger the requirement for proof rolling and incur delays to construction. Halloysitic clays present a problem because their structure and properties irreversibly changes when they are oven dried. The soil tested in the laboratory does not represent field moisture conditions because when the soils are oven dried the chemically bound water is removed, and thus physically changed, prior to laboratory compaction testing. This can cause apparent non-conformances, unnecessary rework and consequential delays.

The UK based Transport Research Laboratory (TRL) has developed an alternative approach to compaction testing that reduces the risk of un-necessary rework caused by delays in post compaction laboratory test data, while achieving the engineering requirements for embankment construction. This approach is now the standard testing and verification method used in the UK and was developed to reduce risk of construction delay, and increase rates of production. The British approach incorporates the TRL developed Moisture Condition Value (MCV) test to assess whether soil is suitable for compaction and uses the relationship between MCV and field moisture content. End product verification is achieved through ongoing calibration to standard Proctor density tests and field certification using nuclear density testing to determine compliance against the required dry density and moisture content. The MCV apparatus and theory is introduced. Results from tests performed on high plasticity clays and halloysitic clays sampled from the north coast of NSW are presented. An example of how the process is implemented from site investigation through to construction verification is presented.

2 TESTING OF HIGH PLASTICITY AND HALLOYSITIC CLAYS

2.1 HIGH PLASTICITY CLAYS

A comparison of rapid and proctor density test data has been performed in northern NSW on soils with a plasticity index of 35%. Nuclear densometer tests were performed and bulk samples collected in two separate construction lots for parallel rapid and Proctor density testing. These tests were performed to assess whether the amount of curing had an effect on the test data. Samples taken for rapid compaction testing were processed through a 10mm sieve and a 19mm sieve in the hope that curing would occur more rapidly when the soils are broken up into small pieces. Comparisons of maximum dry density (MDD) and optimum moisture content (OMC) obtained from the rapid and Proctor tests are presented in Figures 2 and 3. The data shows some correlation between MDD obtained from the two tests with the rapid test typically producing higher values for MDD than the Proctor test. The data in Figure 1 shows that there is no correlation between OMC obtained from the two tests irrespective of whether the samples were processed through a 10 mm or a 19 mm sieve



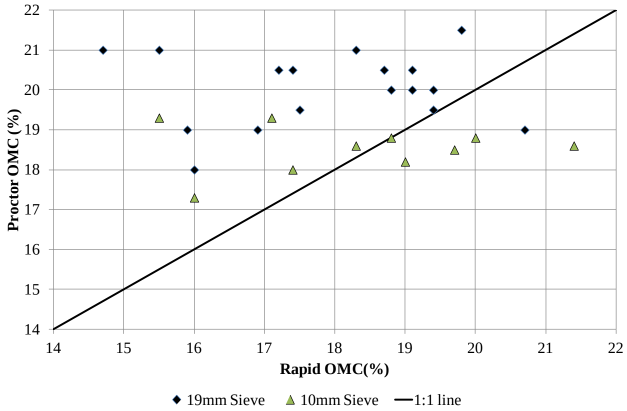


Figure 1: Comparison of rapid and proctor MDD. Figure 2: Comparison of rapid and proctor OMC.

All the data are plotted for comparison with air voids lines in Figure 3 along with field test results. The data shows that the rapid compaction tests produce results similar to the field tests. This indicates that moisture added to the rapid tests is not curing into the clays. In contrast, the Proctor data has lower MDD and higher OMC than the rapid test. The rapid compaction test would be expected to return lower field/laboratory density ratios and higher field/laboratory moisture ratios than the Proctor test. Therefore the probability that rapid compaction testing will result in false-positive failures and unnecessary rework is higher than if the Proctor test is used. However, it is impractical to use the Proctor test for earthworks control due to the long turnaround time required for each test.

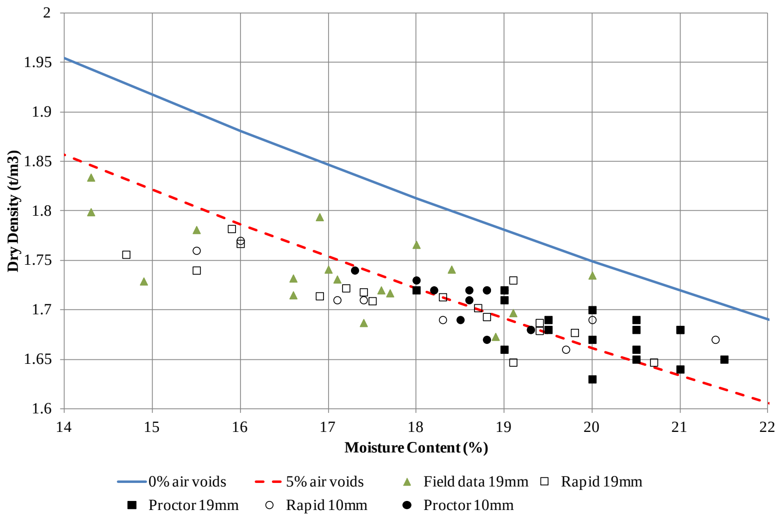


Figure 3: Comparison of field and laboratory test data.

2.2 HALLOYSITIC CLAYS

Halloysite occurs in two forms, as hydrated halloysite and as metahalloysite. Hydrated halloysite readily converts to metahalloysite on drying, a process which is irreversible. This process occurs partially in nature at temperatures of around 50ºC but is exacerbated by higher temperature drying (>60-70ºC), such as within a typical soil laboratory oven. This change in mineralogical properties from hydrated halloysite to metahalloysite has a direct effect on soil characteristics. Metahalloysite tends to have a lower Plasticity Index and Optimum Moisture Content than hydrated halloysite. In addition to these drying effects, remoulding of the soil is also known to affect its behaviour (Belloni *et al.*, 1988). Comparisons of air and oven dried moisture and plasticity data are shown in Figures 4 and 5.

Aurecon (2011) commissioned scanning electron microscopy testing to confirm the presence of Halloysite in basaltic residual soils north of Ballina. Photomicrographs are presented in Figure 6 and these clearly show the presence of Halloysitic minerals.

For compaction testing, oven drying has the effect of increasing the measured field moisture content with an associated reduction in MDD calculated from field bulk density data. The consequences of this are the same as for high plasticity clays.

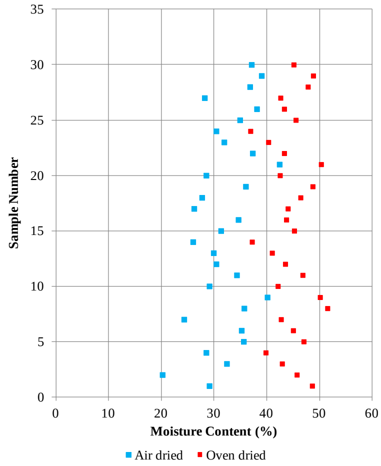


Figure 4: Comparison of air and oven dried MC.

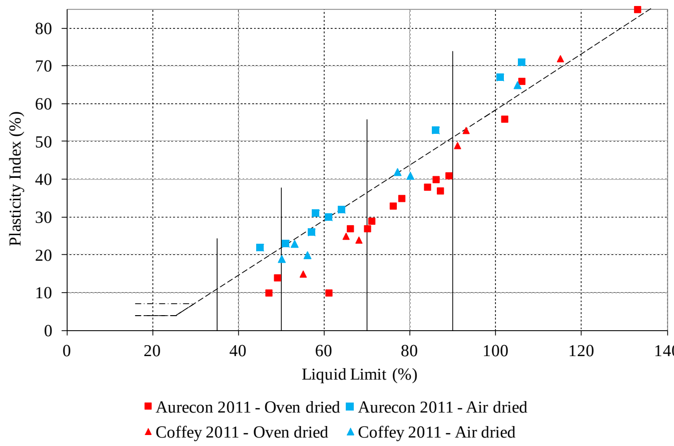


Figure 5: Comparison of air and oven dried plasticity chart

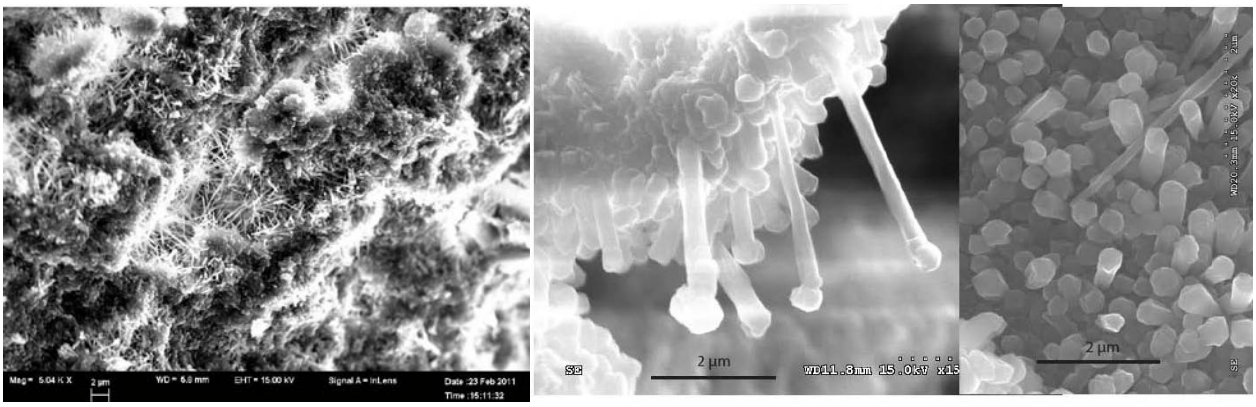


Figure 6: Photomicrograph of Halloysite mineral structure from samples obtained during the Aurecon 2011 T2E site investigations (Photomicrographs taken from Sietronics X-Ray Diffraction and Scanning Electron Microscope Analysis Report, report reference LS1030, dated March 2

3 MCV APPARATUS, INTERPRETATION AND RESULTS OF TRIAL TESTING

The MCV test was initially developed in 1976 by the UK Transport Research Laboratory (Parsons, 1976) for the assessment of the suitability of cohesive soil for earthworks without having to use laboratory based testing methods. Since then the MCV test has proven to be a rapid and reproducible means of assessing the suitability of materials in relation to specified moisture content limits. Use of the MCV for earthworks control is described in British Standard BS 1377-4:1990 and is also now an accepted European test method as described in EN 13286-46:2003.

Assessment of suitability of fill for earthworks is based on the moisture range that can be fully compacted using the machinery adopted by the contractor without rutting or heaving. The MCV test produces a linear relationship between compactive effort at full compaction, defined by the moisture condition value, and moisture content. There will be a range of MCV's that correspond to the range of moisture contents where compaction can be achieved and providing the on-site MCV testing at time of compaction falls within this range the fill material is deemed to be suitable for compaction. From practical experience in the UK since the development of the MCV test, it is accepted that for a cohesive soil to be suitable for compaction, a MCV between 8 and 13 is required. This process eliminates the need to measure moisture content for acceptance and eliminates issues relating to moisture contents of high plasticity and Halloysitic clays.

The MCV test apparatus comprises a 100 mm internal diameter mould, a 31kg base to provide stability in field conditions, a 97 mm diameter free falling hammer with a mass of 7 kg and an automatic hammer release mechanism with an adjustable drop height. The test is carried out using a constant drop height above the sample of 250 mm and the number of blows is recorded. The penetration of the hammer in the mould at any given number of blows is compared with the penetration for four times as many blows, the difference in penetration determined, and the test continued until the change in penetration is less than 5 mm. The Moisture Condition Value of a sample is then defined as 10 times the logarithm of the number of blows corresponding to a change in penetration of 5mm on the plotted curve. An idealised example of a typical test result plot as taken from BS1377-4:1990 is presented in Figure 7. The aim of the test is to develop a linear relationship between the MCV and moisture content as shown in Figure 8.

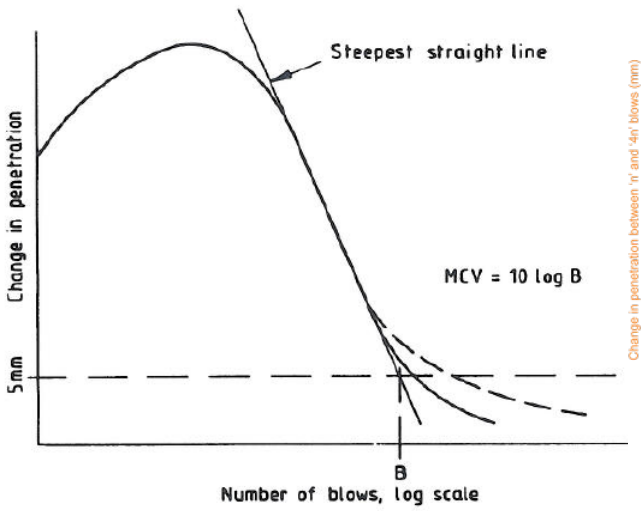


Figure 7: Typical MCV test plot (after BS1377-4:1990).

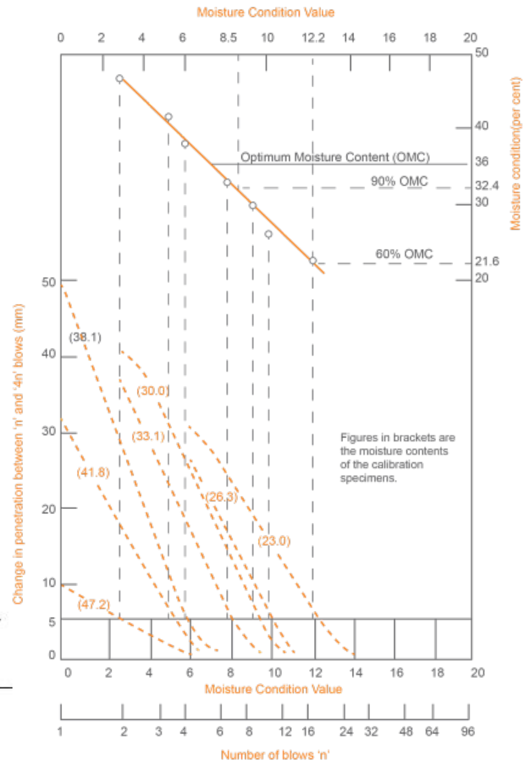


Figure 8: Calibration data.

A series of MCV tests were performed on clay samples with plasticity indices ranging from 29 to 39. A parallel series of Proctor compaction tests was also performed to assess OMC. The results are presented in Figure 9. A linear relationship between moisture content and MCV was obtained for all samples between MCV of 5 and 16. When MCV was greater than 16 the sample was too dry to achieve full compaction for the energy applied. The moisture content has been normalised by the OMC obtained from the Proctor tests on each sample. When presented in this fashion, the data indicates that the British range of acceptable MCV values correspond to moisture ratios ranging between 0.8 and 1.1. While it is possible to compact fill at a moisture ratio of 1.1, it is common in NSW not to exceed a moisture ratio of 1.05 and an equivalent MCV range could be 10 to 16.

Comparison of MCV and air-dried moisture content from a sample of halloysitic clay is presented in Figure 10. The linear correlation is again obtained indicating that the MCV can be used in these soils. The OMC for air dried halloysitic clays in an area near where the MCV sample was obtained is approximately 30% (Aurecon, 2011) and an MCV range of 8 to 13 corresponds approximately to moisture ratios in the order of 0.9 to 1.2.

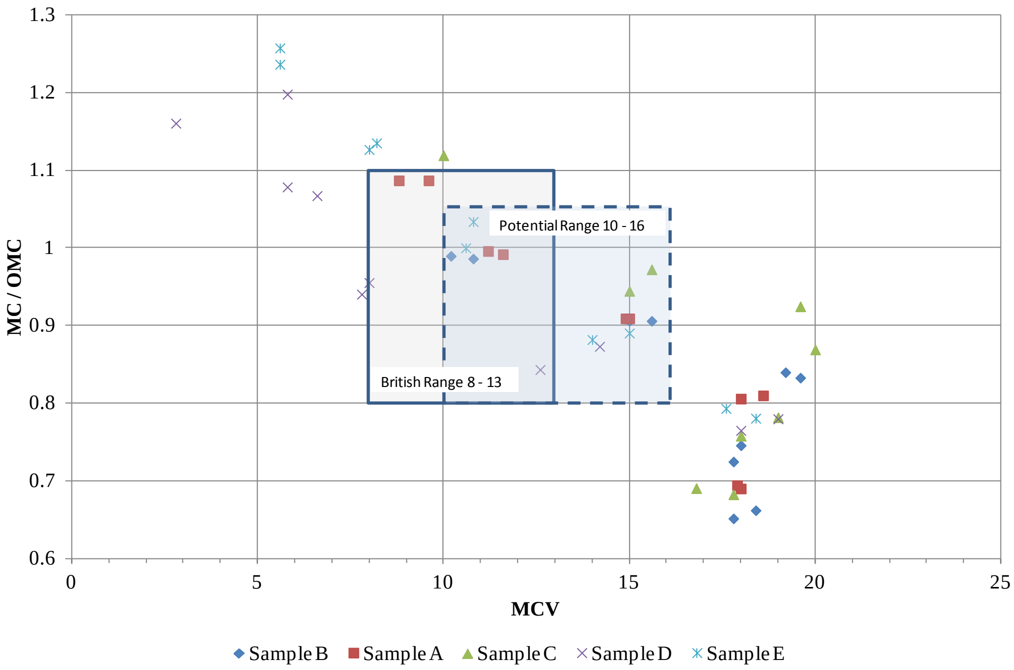


Figure 9: MCV results from tests on high plasticity clay

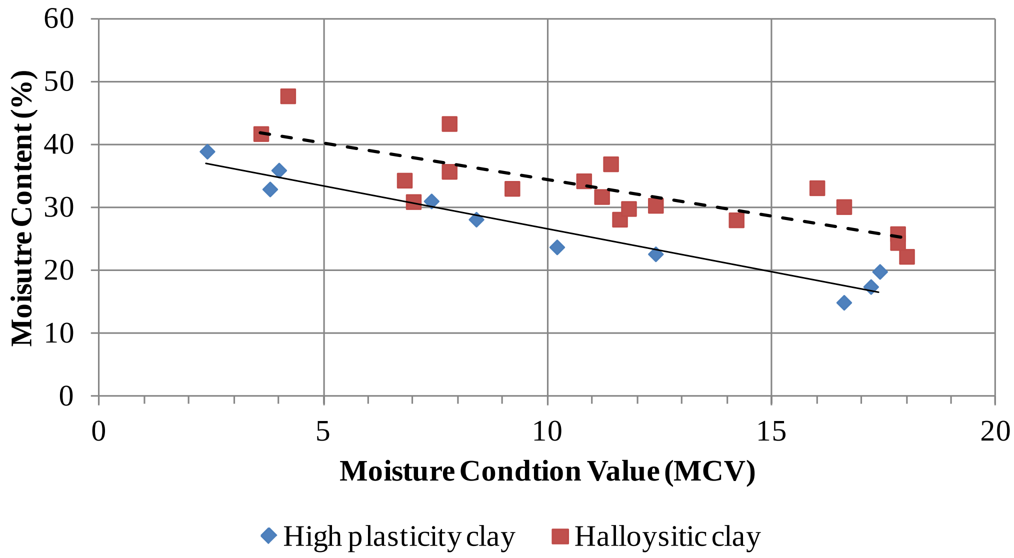


Figure 10: Data from Halloysitic Clay air dried

4 AN ALTERNATIVE CONSTRUCTION PROCESS FROM SITE INVESTIGATION TO VERIFICATION

British Standard BS1377-4:1990 describes a process for earthworks compliance testing using the MCV and field density tests. The process starts during the site investigation phase when the MCV is calibrated to Proctor tests to assess whether material is suitable for compaction and to develop a relationship(s) between MCV and moisture content. Samples are tested in the field for compliance with approved MCV at time of compaction. The MCV recorded also gives an indicative moisture content (from previously calibrated tests) and the wet density measured by nuclear densometer can be converted to dry density. The lot is then provisionally released, although subject to recall, while conformance tests are carried out in the site laboratory to give a true moisture content and actual dry density. Laboratory moisture content tests are made less frequent as surety is gained in the accuracy of the MCV calibration and effectively becomes an audit procedure.

Periodic calibrations to Proctor tests occur during construction to ensure that compliance testing is representative of the placed fill. As this test has yet to be used in Australia, parallel testing with currently accepted processes will be required to develop confidence in the alternative approach. A procedure for incorporating the MCV into earthworks is summarised as follows:

1. Material is sampled in advance of the earthworks operations (typically during site investigation) at varying depths to represent source material from each of the cuts. These will undergo a range of testing to determine the indicative qualities of the material at varying depths for each cut. Samples are air dried, if Halloysitic, to determine the optimum, and source field moisture content;
2. A relationship between moisture content and MCV is determined as per Figures 3.2 and 3.5 for each material type;
3. Proctor tests are then performed on the same sample to determine the OMC. MCV corresponding to the range of moisture ratios required in the specification are determined and this range forms the suitability criterion for fill placement;
4. During construction, samples are taken at the point of fill placement and tested in the field using the moisture condition apparatus prior to compaction. The field MCV is compared with the suitability criterion previously developed. If the MCV is within the acceptable range the lot will be compacted and works will continue;
5. If the 'at time of compaction' field MCV is less than the minimum value, then the lot is dried back, reworked and then resubmitted for the Contractor site control testing. If the field MCV is greater than the maximum value then the lot is reworked with the addition of water and then resubmitted for the Contractor site control testing;
6. Only lots that lie within the permitted range of MCV are considered acceptable for compaction;
7. The nuclear densometer (ND) test is then used to assess field bulk density and
8. Dry density is inferred from bulk density via a moisture content inferred from the MCV. If the test data shows that the field bulk density is above a target value determined from the Proctor tests then the lot is accepted. Statistical methods to ensure uniformity of compaction within the lot would still apply.

Where the MCV is incorporated into the conformance process, the testing would be performed by an independent laboratory. The MCV test can also be performed by the contractor to enable appropriate moisture conditioning of the soil prior to compaction.

5 CONCLUSIONS

High plasticity and halloysitic clays can cause standard test methods to be unrepresentative of material behaviour. The MCV test is used in the UK and Europe as part of an earthworks conformance process that does not require field moisture content to be measured. The MCV data predicts that these clays are compactable when moisture contents are in the range of 80% to 105% of standard optimum moisture content, which agrees well with construction experience. Adoption of the MCV as part of an earthworks conformance process has the potential to de-risk construction in areas subject to significant weather delays because it is possible to place and conform multiple layers of fill in a single day. The process also has the potential to increase production in areas not prone to wet weather with consequent cost savings to the client.

6 ACKNOWLEDGEMENTS

The authors would like to thank the Roads and Maritime Authority of New South Wales for use of the data. The authors also acknowledge Aurecon for permission to reprint the SEM data.

7 REFERENCES

Aurecon, Pacific Highway Upgrade – *Tintenbar to Ewingsdale Geotechnical Interpretation and Design Report*, (2011)

Belloni, L., Morris, D., Bellingeri, G.A. and Purwoko, I, Compaction and strength characteristics of a residual clay from Bali, Indonesia, Proc. 2nd Int. Conf. Geomechanics in Tropical Soils, Singapore, Vol.1, pp343-349

British Standards Institution, BS1377 "Methods of test for soils for civil engineering purposes, 1990, BSI, London

BS EN 13286-46:2003 Unbound and hydraulically bound mixtures. Test method for the determination of the moisture condition value

Parsons, A.W. *The rapid measurement of moisture condition of earthwork material.* Transport and Road Research Laboratory report TRRL 750, 1996