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USE OF PROCTOR COMPACTION TESTING FOR DEEP FILL CONSTRUCTION USING IMPACT ROLLERS

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Rolling Dynamic Compaction (RDC) is a generic term associated with densifying ground using non-circular (impact) rollers. RDC is suited to deep fill applications because of the ability to compact ground efficiently by means of its faster operating speed (10-12 km/h) and greater depth of influence when compared to conventional circular rollers. Whilst conventional circular rollers are able to compact layer thicknesses typically in the range of 200-500 mm, thicker layers are able to be compacted using RDC. This paper discusses performance based specifications and the applicability of both the Standard and Modified Proctor compaction tests to RDC. For projects where impact rollers are used, the Modified Proctor test is strongly recommended as the energy imparted onto the soil is more representative than the Standard test.

Keywords: Proctor, compaction, impact, roller

1 Introduction

This paper is concerned with a specific type of dynamic compaction, known as rolling dynamic compaction (RDC), which involves densifying the ground using heavy (6 to 12 tonne) non-circular modules (of three, four or five sides), that rotates about a corner as they are towed, causing the module to fall to the ground and compact it dynamically. Examples of these are shown in Figure 1. Due to the combination of kinetic and potential energies, and the relatively large mass of the module, RDC is able to compact the ground to greater depths than its static and vibrating roller counterparts, and more efficiently because of its greater speed – 12 km/h compared with 4 km/h using traditional rollers (Pinard 1999).

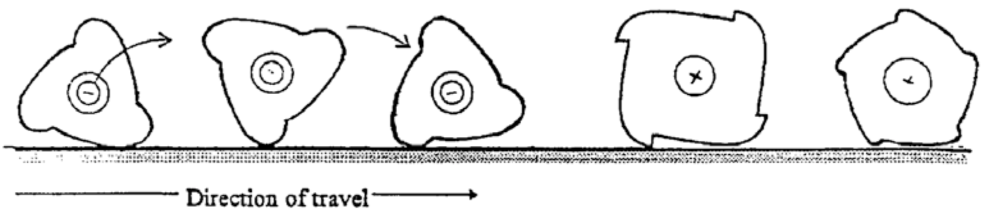

Figure 1. RDC modules: 3-, 4- and 5-sided.

2 Compaction of deep filling

Deep fills have been traditionally constructed by compacting soil in thin layers using relatively small particle sizes placed in a highly controlled manner. Field density tests are typically undertaken in each layer to confirm performance specifications of the placed fill. The determination of field density testing using a nuclear density gauge (Standards Australia 2007), is the current industry standard, and involves determining the in situ density at discrete locations within the top 300 mm from the surface. This method ideally suited for the verification of fill density that has been placed in relatively thin layers (lifts) using conventional static or vibrating drum rollers (where thin layers comparable to the influence depth of the nuclear density gauge are generally adopted). However, in RDC applications involving thicker lifts, verification using field density testing typically requires excavation through compacted material down to targeted bench levels to verify fill density. The ability of an impact roller to compact material in larger quantities is an obvious advantage over compacting fill in thin layers; however, as noted by Avalle (2007) there are challenges associated with verification. This paper discusses performance based specifications that are based on field density test results and discusses the applicability of both the Standard Proctor (Standards Australia 2003a) and Modified Proctor (Standards Australia 2003b) compaction tests to RDC.

3 Standard and Modified Proctor Compaction Tests

In order to determine the suitability of Standard and Modified Proctor Compaction tests to RDC, it is pertinent to highlight the difference in the imparted energy between the two test methods. As noted in Table 1, the Modified test (2703 kJ/m^3) imparts approximately 4.5 times the energy per unit volume as the Standard test (596 kJ/m^3).

Table 1. Comparison of imparted energy for Standard and Modified Proctor tests.

Test	Standard Proctor	Modified Proctor
Hammer weight	2.7 kg	4.9 kg
Drop height	300 mm	450 mm
Energy imparted per blow	7.94 J	21.62 J
No. of soil layers	3	5
No. of blows per layer	25	25
Energy imparted per unit volume	596 kJ/m^3	2703 kJ/m^3

As detailed in Coduto et al (2011), the Standard test was developed by R. R. Proctor in the 1930s as a means for modelling and assessing compacted fills using compaction equipment of that era. During the 1940s and 1950s, fills compacted using the Standard test no longer provided adequate support for trucks and aircraft traffic that were increasing in both size and frequency. To address this issue, the U.S. Army Corps of Engineers developed the Modified test in 1958 that used a higher compactive effort to better model heavier compaction equipment that was then needed to compact fills to support heavier and more frequent trucks and aircraft traffic. Since 1958, increases in the size and frequency of trucks and aircraft traffic have continued; compaction equipment has also evolved with larger and heavier rollers used today compared to over 50 years ago, yet the Modified test has continued to stand the test of time. Of greater interest (or concern) however, is that the Standard test as developed by R. R. Proctor approximately 80 years ago, continues to be widely referred to, despite much of today's modern compaction equipment bearing little resemblance (in terms of energy imparted per unit volume) to that used during the 1930s.

Whether the performance criteria for a particular project are a function of the Standard or Modified Proctor compaction test is often dictated by what is written in the project specification, a decision usually made at the discretion of the project engineer. It is commonly accepted that the Modified test is used where fills involving heavy compaction equipment will be require in order to support large loads, such as roads and runways; with the Standard test used for fills involving other applications where lower loads are expected and hence, lower dry unit weights are required. It is the experience of the authors that a number of specifications written around the use of heavy compaction equipment (such as impact rollers) commonly refer to key performance criteria relative to the Standard Proctor test. Virtually all compaction specifications include the criterion of achieving a minimum dry unit weight; in some instances the moisture content is also specified within a certain range. In cases where both dry unit weight and moisture content are used as specification criteria, it is critical to understand what laboratory baseline test (Modified or Standard) is more representative of the field compactive effort, which is a function of the weight and type of roller, number of passes and lift thickness that is used.

Figure 2 shows the particle size distribution for a soil sample that was subjected to both laboratory test methods. A comparison of Standard and Modified Proctor test results on the same soil are shown in Figure 3. For this example (hereby referred to as Site A) the materials consisted of fine to medium grained sand (containing 3% clay sized, 96% sand sized and 1% gravel sized particles). It can be observed that the 'maximum dry unit weight' for the Modified test is slightly higher (~1.5%) than that resulting from the Standard test, which corresponds to a lower optimum moisture content. A summary of the test results for Site A are included in Table 2.

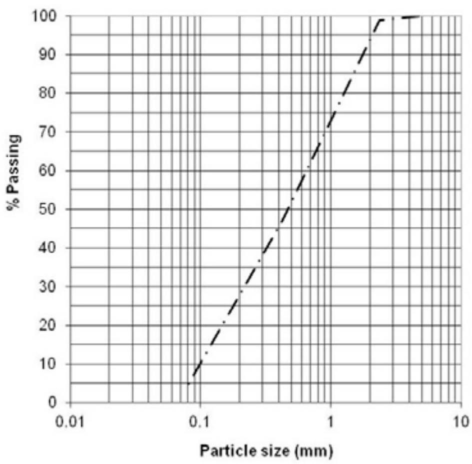

Figure 2. Particle size distribution for Site A

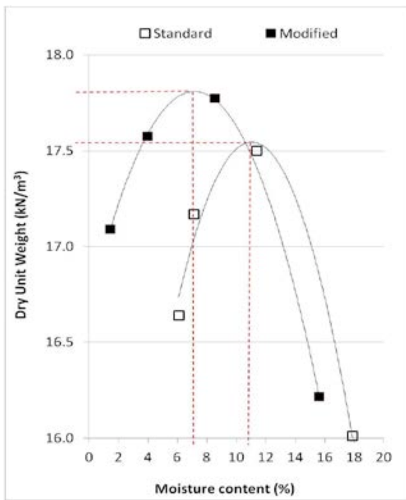

Figure 3. Comparison of Standard and Modified Proctor test results for Site A

Table 2. Comparison of Standard and Modified Proctor test results for Site A.

Test	Standard Proctor	Modified Proctor
Maximum dry unit weight	17.55 kN/m^3	17.8 kN/m^3
Optimum moisture content	~ 11%	~ 7%

Figure 4 shows the particle size distribution for a different material taken from Site B; a comparison of Standard and Modified Proctor test results are shown in Figure 5. At this site, the material consisted of iron tailings (containing 6% clay sized, 80% sand sized and 14% gravel sized particles); it can be observed that the 'maximum dry unit weight' for the Modified test is approximately 8% higher than that resulting from the Standard test; with the optimum moisture content for the Modified test slightly slower than that from the Standard test. A summary of the test results are included in Table 3.

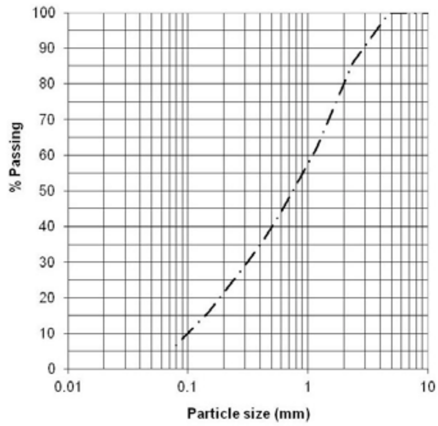

Figure 4. Particle size distribution for Site B

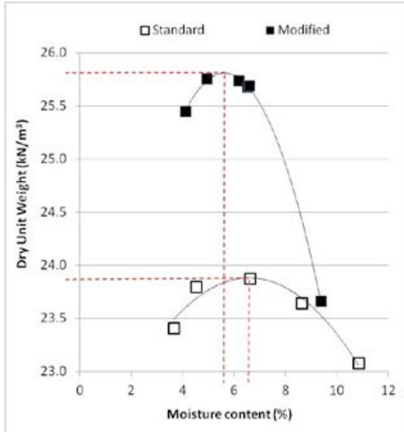

Figure 5. Comparison of Standard and Modified Proctor test results for Site B

Table 3. Comparison of Standard and Modified Proctor test results for Site B.

Test	Standard Proctor	Modified Proctor
Maximum dry unit weight	23.9 kN/m^3	25.8 kN/m^3
Optimum moisture content	~ 6.5%	~ 5.6%

For both Sites A and B, two values for 'maximum dry unit weight' were presented in Tables 2 and 3, respectively; as Coduto et al (2011) explain this term is somewhat misleading, because the Standard and Modified tests have two different 'maximums'. However, as they describe, this term can best be thought of as 'the greatest dry unit weight that can be achieved for that particular compactive effort'. As the two examples in this paper show (on different materials that have somewhat comparable particle size distributions but obvious differences in mineral composition and specific gravity) changes in field compactive effort can significantly change the relationship between moisture content and dry unit weight. Additionally, there is no magic relationship that converts Standard and Modified compaction results, as the relationship between the two is unique for each soil type.

For the purposes of comparison, Table 4 determines the target moisture content range for Sites A and B assuming specification criteria of at least 98% of SMDD (maximum dry density with respect to the Standard Proctor compaction test); with Table assuming specification criteria of at least 95% of MMDD (maximum dry density with respect to the Modified Proctor compaction test). It can be observed from Tables 4 and 5 that for the case of Site B, minimal change in target moisture content would have resulted, however; the target moisture range for Site A was significantly different depending on which laboratory baseline test was used. It must be stressed at this point that both Sites A and B consist of coarse grained soils that contain minimal fines content, so they are less moisture sensitive to changes in moisture content and can be compacted over a wider moisture range than fine grained soils (beyond the scope of this paper due to space restrictions).

Table 4. Specification of 98% of Maximum Standard Dry Unit Weight for Sites A and B.

	Site A	Site B
Maximum dry unit weight	17.55 kN/m^3	23.9 kN/m^3
Target dry unit weight (98% SMDD)	17.2 kN/m^3	23.4 kN/m^3
Corresponding (target) moisture range	7 – 15%	~3 – 10%

Table 5. Specification of 95% of Maximum Modified Dry Unit Weight for Sites A and B.

	Site A	Site B
Maximum dry unit weight	17.8 kN/m^3	25.8 kN/m^3
Target dry unit weight (95% MMDD)	16.9 kN/m3	24.5 kN/m3
Corresponding (target) moisture range	~2 – 14%	~3 – 9%

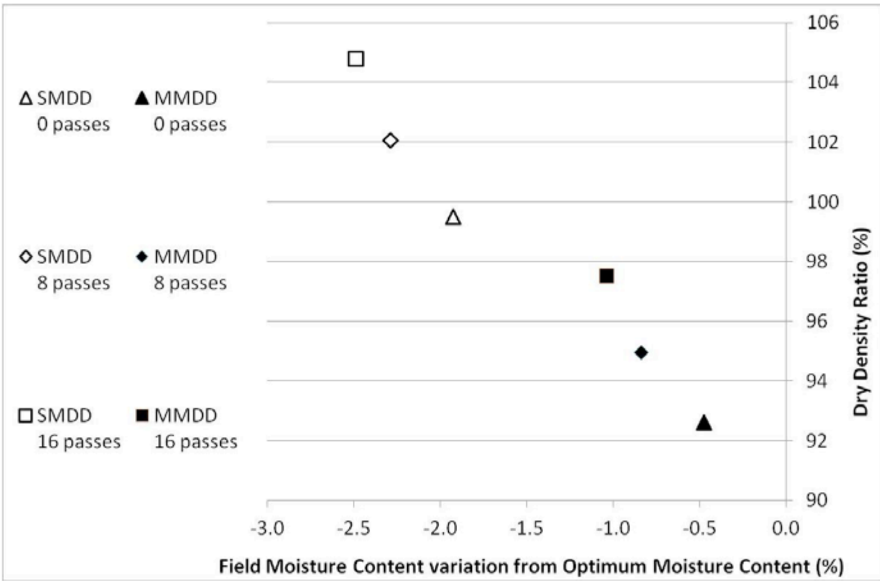

Figure 6. Dry density ratio versus moisture content for increasing compactive effort at Site B.

The authors' past experience has shown that for cases where the Standard test is used, impact rollers are likely to achieve the desired dry unit weight criterion in thick lifts (depending on the soil type adequate dry unit weights may be achieved in layer thicknesses up to 1500 mm). If an additional moisture range is also included as part of a project specification (e.g. in the case of deep fills where hydro-compression is of concern) then consideration needs to be given as to how representative the baseline laboratory test chosen will be of impact rolling. The contractor will inevitably use the test results to optimize the site compaction by selecting an optimal combination of both compactive effort and moisture content range, bearing in mind that the contractor will also be optimizing against a third criteria (cost), thereby avoiding increased compactive effort and the need for additional moisture wherever possible.

Figure 6 shows an example of field density measurements taken after 0, 8 and 16 passes of an impact roller at Site B compared against both Standard and Modified Proctor compaction tests, expressed as a ratio of maximum dry density. This figure shows that with increasing passes of the roller, the dry density ratio increases; corresponding to a reduced field moisture content. The difference in field moisture content compared to the optimal moisture content obtained from both test methods clearly shows that the Modified test better models the density versus moisture content relationship, as it is more representative of the compactive effort being imparted into the ground than the Standard test.

4 Conclusions

RDC is unique in that it is able to compact large volumes effectively and efficiently. The ability to compact material in thicker lifts and at lower moisture contents (when compared to the optimum) has the potential for significant time and cost advantages. When determining which Proctor compaction test method to use, it is important to understand which laboratory test is more representative to the field compactive effort that is proposed; a decision often based on the loads to be supported, which in turn affects the compaction equipment to be used to ensure adequate dry unit weights will be achieved. In the case where impact rollers are proposed, use of the Modified test is strongly recommended as the energy imparted onto the soil is more representative than the Standard test.

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