TECHNICAL GUIDE
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Laboratory compaction of road construction materials

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Preface

Compaction testing in the laboratory is conducted for various reasons, but generally is it to determine for a pavement or earthwork material sample the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) or Maximum Wet Density (MWD). These tests are generally referred to as Proctor tests.

Compaction of a soil is achieved by reducing the air voids in the soil with little or no reduction of the water content. Compaction of soil using mechanical means packs the soil particles more closely and increases the dry density.

This guide note covers the following test methods:

- T111 - Dry density/moisture relationship of road construction materials
- T112 - Dry density/moisture relationship of road construction materials (Modified compaction)
- T130 - Dry Density/Moisture Relationship of Road Construction Materials (Blended in the Laboratory with Cementitious Binders)
- T162 - Compaction control test (rapid method).

1. Introduction

The general principal with any compaction test is that for the same compactive effort, increases in moisture content increases density until the optimum moisture content is reached, and subsequently the density decreases with increasing moisture content as shown in Figure 1. All materials behave slightly different and each material will have different MDD and OMC values, depending on their particle size distribution, particle density and plasticity.

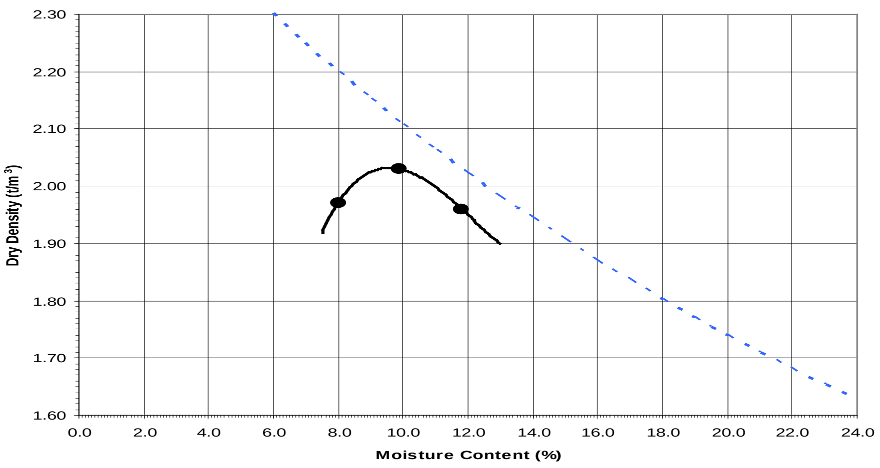

Figure 1: Compaction curve with zero air voids line

The three points shown in Figure 1 on the compaction curve are the individual points compacted in the laboratory. A minimum of three points are required to produce a viable curve and these points must straddle the peak of the curve. Straddling has been achieved when:

- Three moisture contents lie between OMC - 2.5% and OMC + 2.0% with one result below OMC and one result exceeding OMC.
- The increments between the moisture contents should not be more than 2.5%.

There are various mathematical means to produce a parabolic type curve to determine maximum density and OMC, and these formulas will give slightly differing answers but the difference is not considered significant. The industry accepted preferred formula is the cubic spline as the cubic spline smoothes out a curved line between the three individual compaction points.

2. Definitions and abbreviations

MDD – Maximum Dry Density.

MWD – Maximum Wet Density.

OMC – Optimum moisture Content.

CBR – California Bearing Ratio

UCS – Unconfined Compressive Strength

FDD – Field Dry Density

FWD – Field Wet Density.

Zero Air Voids - is the relationship between dry density and corresponding moisture contents, for a specific particle density, assuming that all of the voids are completely filled with water. The default density for soil testing is 2.67 t/m^3, but should be checked if anomalies are suspected.

Constant mass - Constant mass is defined as that stage in the drying process where the loss in mass of the material between successive dryings is less than 0.1%

3. Compaction equipment

Compaction requires material to be compacted in a mould (of known volume) with a rammer using a specific compactive effort. There are two different types of compaction methods are (refer to Table 1):

- Standard compaction based on a compactive effort with energy input of 596 kJ/m^3
- Modified compaction based on a compactive effort with energy input of 2703 kJ/m^3.

Table 1: Differences between standard and modified compaction methods

Item	Standard Compaction	Modified Compaction
Number of layers	3	5 for 1 litre mould 3 for the 2 litre mould
Rammer drop mass (kg)	2.7 ± 0.01	4.9 ± 0.01
Height of drop (mm)	300 ± 2.0	450 ± 2.0
Number of uniformly distributed blows per layer	25 for the one litre mould 50 for the two litre mould	25 for the one litre mould 83 for the two litre mould

The selection of either standard or modified compaction depends on the specification and generally standard compaction is more commonly used.

Test methods permit one or two litre moulds for compaction. The selection of moulds depends on the particle size distribution of the material, such as:

- if all the material passes the 19 mm sieve a 1 L mould is used
- if more than 5% of the material is retained on the 19 mm sieve the 2 L mould must be used
- if some material (<5%) is retained on the 19 mm sieve this material can be discarded and a 1 L or a 2 L mould used.

The exception to this rule is when the MDD and OMC data is to be used for other tests, such as Unconfined Compressive Strength (UCS) and Californian Bearing Ratios (CBR), and in these cases standard compaction using a 1 L mould is to be used. For the UCS and CBR tests all the +19 mm material is taken out of the sample at the preparation stage and not used in the tests with a requirement for the percentage of material collected on +19 mm to be measured and reported.

Figure 2: View of the one (left) and two litre moulds.

The compaction applied to the sample is by the use of a rammer with:

- Standard compaction has a drop mass of 2.7 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 300 ± 2.0 mm
- Modified compaction has a drop mass of 4.9 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 450 ± 2.0 mm.

In both cases the rammer must be constructed of metal with a 50 ± 0.4 mm face diameter as shown in Figure 3. The rammers are used by hand and mechanical rammers can be used provided the essential dimensions are adhered consistent. Mechanical rammers (see Figure 4) reduce muscle strain from long repetitive work and also provide consistent results for the same material.

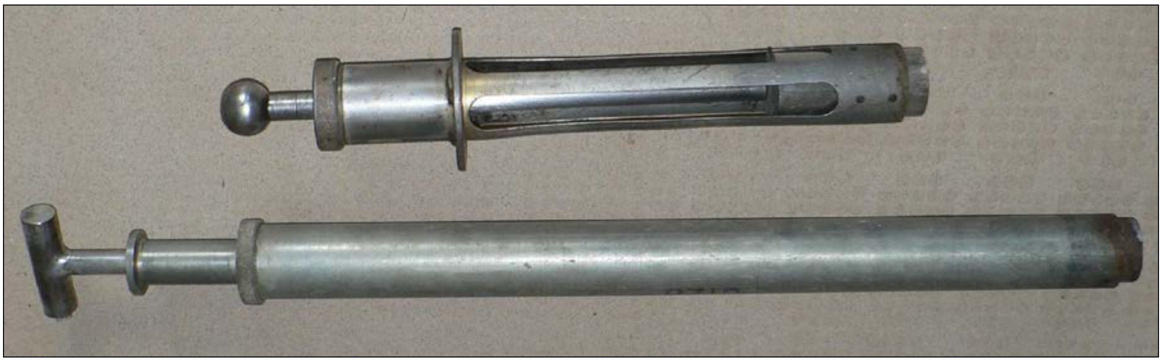

Figure 3: Standard rammer (top) and a modified rammer.

Figure 4: A typical mechanical rammer

4. Compaction process

The sample collected from the field must be divided into the required mass for the test (refer to T105), and the sample division must be carried out to test method T105 (A3) to provide four essentially identical test portions of which three for the test and one reserve portion.

To conduct the test successfully and produce a compaction curve (see Figure 1) that provides the maximum density and OMC results, a minimum of three points at different moisture contents must be compacted as previously noted.

If the sample is well below optimum, additional water may need to be added so the first point is approximately 2 percent below optimum and then the next 2 points straddle the OMC. It is important that water is thoroughly mixed into the sample for the three moisture increments and at each addition of water the operator must allow, the material to be cured. Curing allows the moisture to permeate evenly throughout the material. As a general rule, sandy materials may be satisfactorily cured in one hour and heavy clays make take several days. It is good laboratory practice to remix the material after curing and prior to conducting the test.

The material is compacted into the relevant mould using the compactive effort as specified in Table 1. Care must be taken during compaction so that layers do not vary in height by more than 5 mm (ie the specified tolerance in the test method). Figure 5 shows the sample extracted from the mould and the 3 equal layers of compaction.

Figure 5: An extruded compaction specimen and another broken to show three equal layers.

After the material is compacted at the third layer, the material is allowed to overfill the mould by no more than 5 mm and not allowed to under fill the mould at all. If this criterion is not met the sub-sample must be rejected and the test repeated with a new portion of material. This small amount of over fill is cut off the top of the mould with a straightedge and any holes in the surface must be patched to produce a level surface.

Material that has been previously compacted cannot be used again as compaction has the potential to breakdown the material to the extent it is not representative of the original sample.

The mass of the mould and material is recorded, and then the material is extruded from the mould. A sample must be taken to determine the moisture content at compaction. The moulded material is broken in such a manner to provide a representative sample for moisture content determination that meets the minimum mass requirement for the moisture content test method T120.

To successfully produce a compaction curve the three sub-samples must be at different moisture contents that straddle OMC. The differences in moisture contents must not be greater than 2.5% and all three points must be between OMC -2.5% and OMC +2.0%. A wider spread of results will give a less accurate determination of MDD and OMC.

The Zero Air Voids line is the relationship between dry unit mass and the corresponding moisture contents, assuming that all of the voids are completely filled with water. The blue curved dotted line in Figure 1 is the zero air voids line and any compaction curve should never pass over this line. Other air void lines, such as the 5% line, can be used but the zero line takes precedence.

If the compaction curve crosses the zero air voids line the compaction process should be checked for possible errors or the default particle density may be incorrect.

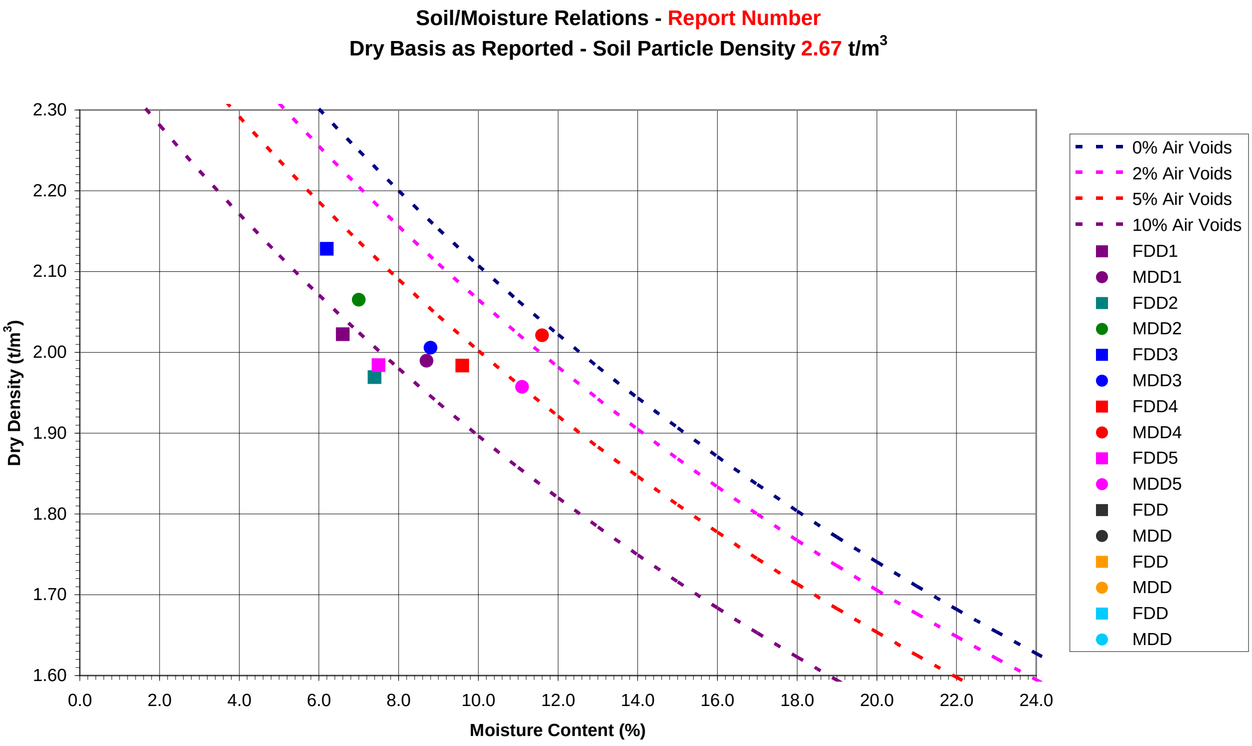

Figure 7: Zero air voids line with all MDD and FDD for a lot.

T166 requires the graph in Figure 7 as part of the reporting requirements. Figure 7 shows plots of the field dry density against the field moisture content (square symbols). In addition it shows plots of the laboratory maximum dry density and optimum moisture content (round symbols) for each sample tested in the Lot. The field wet densities are converted to field dry densities from the field moisture content. The maximum dry density, optimum moisture content (T111, T112) or the maximum converted dry density, optimum moisture content or the maximum dry bulk density, adjusted optimum moisture content as calculated in T166 must be plotted.

The points in Figure 7 show the signatory that results #1, #2, #3 and #5 are valid for that specific Lot. The MDD of sample #4 is very close to the Zero Air Voids line and the result should be investigated prior to signing the report. The actual compaction test may not have been conducted properly or the particle density may be different for that particular sample.

In test method T105 A13 has a formula for the Zero Air Voids line and this formula is based on a particle density of 2.67 t/m^3 which is the common density for materials derived from rock types like granites and sandstone. Materials which have a different density, such as basalts, should use test method T127 to assess the particle density and redraw the graph with the appropriate particle density inserted in the Zero Air Voids formula.

5. Test Methods

5.1 T111 – Dry density/moisture relationship of road construction materials

This test method is the most commonly used test method to provide MDD and OMC data.

5.2 T112 – Dry density/moisture relationship of road construction materials (Modified compaction)

Modified compaction is specified for some heavy duty flexible pavements. This method is identical to T111 except the larger rammer (see Table 1) is used to compact at a higher rate of compactive effort than standard compactions.

It is generally accepted that modified compaction will give a higher MDD and a lower OMC than standard compaction for the same material. The modified OMC is generally about 2% lower than in standard compaction but this rule of thumb is not consistent for all materials.

5.3 T130 - Dry Density/Moisture Relationship of Road Construction Materials (Blended in the Laboratory with Cementitious Binders)

When stabilising roads the Californian Bearing Ratio or the Unconfined Compressive Strength is used to assess the quantity of binder required with the material. Prior to conducting the CBR or UCS test the MDD and OMC must be determined for this stabilised material. As the cementitious binder generates a chemical reaction the time restraints to conduct the test method must be adhered to by the operator.

Table 2: Time constraints for compaction for different test methods

Test Method/ Steps	Description	Time constraint	
		Fast Setting Binder (Working time < 4 hrs)	Slow Setting Binder (Working time > 6 hrs)
T130 5.2(b) or 5.3(a) or 5.4(a)	Incorporate binder into each sample	Start of timing	Start of timing
T130 5.2(b) or 5.3(a) or 5.4(a)	Curing period.	Approximately 15 mins after incorporating binder	Approximately 1 hr after incorporating binder
T111 5.2(f)	Completion of moulding each sub-sample.	Within approximately 30 mins after incorporating binder	Within approximately 1¼ hrs after incorporating binder

Generally fast setting binders are GP cement and the slow setting binders are cement blends with slag. T147 is the test method to be used to determine the actual Working Time of any binder.

It is preferable that the binders used in this test come from the same supplier as the binders that will be used on the road. Even though binders may meet the minimum specified active constituents, their active constituents vary from one source to another.

5.4 T162 – Compaction control test (rapid method)

This test is commonly used in road works for determining the density of materials to ensure the specified compaction is achieved.

As the test method title indicates the test is a rapid method for determining the maximum density of a material, but instead of determining the Maximum Dry Density this method calculates the Maximum Wet Density of the material.

The test is related to the initial moisture content of the sample and this is usually the moisture content as taken from insitu density tests. It is very important that this initial moisture content is preserved. Increments of water are added as a percentage of the wet weight of each sample compaction point and it is very important that these increments are mixed into the sample until the moisture content is uniform.

The Zero Air Voids line does not work with wet densities, but the Maximum Wet Density can be converted to a dry density using the initial (field) moisture content.

All the principals in the previous tests must be adhered to in this test except no moisture contents need be taken from the compaction points. The OMC determined in this test is an apparent optimum which is related to the initial moisture content.

This compaction method is most commonly used for field compaction assessment work. The field wet density is determined followed by the material being tested to T162 to give a maximum wet density. A comparison of the two values for the relative compaction (T166) is assessed according to the relevant specification.

It is important when taking a sample from the T173 site for T162 testing that the material is representative. An excavation is made of roughly the size of the nuclear density gauge footprint and to the exact same depth tested by T173. If the sample is not taken from the correct depth and a moisture gradient exists then the resultant T166 result can be incorrect.

6. Checklist

A bulk sample must be reduced by a recognised method so that the portions for testing have identical properties as the original sample. This is achieved by:

- Moisture content samples must be dried to constant mass prior to their mass being recorded. This requires recording two or more dry mass values on the worksheet to prove the oven has dried the material properly.
- Moisture contents are generally dried in an oven at a temperature range of 105 º to 110ºC. The worksheet must show traceability to the oven that was used for drying. If using a lower temperature to dry samples the times between weighing must be calculated as per the requirements test method T120.

When observing the compaction process, ensure the:

- compacted layers in the mould are even (±5 mm)
- mould is overfilled by no more than 5 mm
- mould is not under filled at all
- mould assembly is firmly secured to a rigid foundation.

If the mould is not firmly secured the bouncing of the mould negates some of the compactive effort resulting in lower MDD's.

7. Conclusions

Some of the problems in compaction testing result when the following occurs:

- The bulk sample has not been divided properly into equal portions as simply scooping out of a mass of material is not appropriate sample division. A bulk sample must be reduced by a recognised method so that the portions for testing have identical properties as the original sample (refer to T105, A3 – Sample Division).
- Moisture is not uniformly mixed into the material at each moisture increment.
- Compacted layers are not even in the mould and do not meet tolerances (± 5 mm).
- After compaction the mould is either under-filled or has an excess of material of more than 5 mm.
- Equipment is not calibrated properly or has been subjected to excessive wearing without parts being replaced.
- When hand compacting there can be a tendency to throw the rammer rather than allowing it to free fall – this will result in a higher density.
- When hand compacting there can also be a tendency to not raise the rammer to the correct free fall height, especially if the technician has been continually compacting for a long time - this will result in a lower density.

Generally the higher the plasticity the lower the MDD and the higher the OMC. For example, a crushed rock of zero plasticity may give a MDD of 2.22 t/m^3 at 6.3% OMC, where a clayey material may have a MDD of 1.85 t/m^3 at 14.8%. Conversely, the rockier the material the higher the MDD and the lower the OMC.

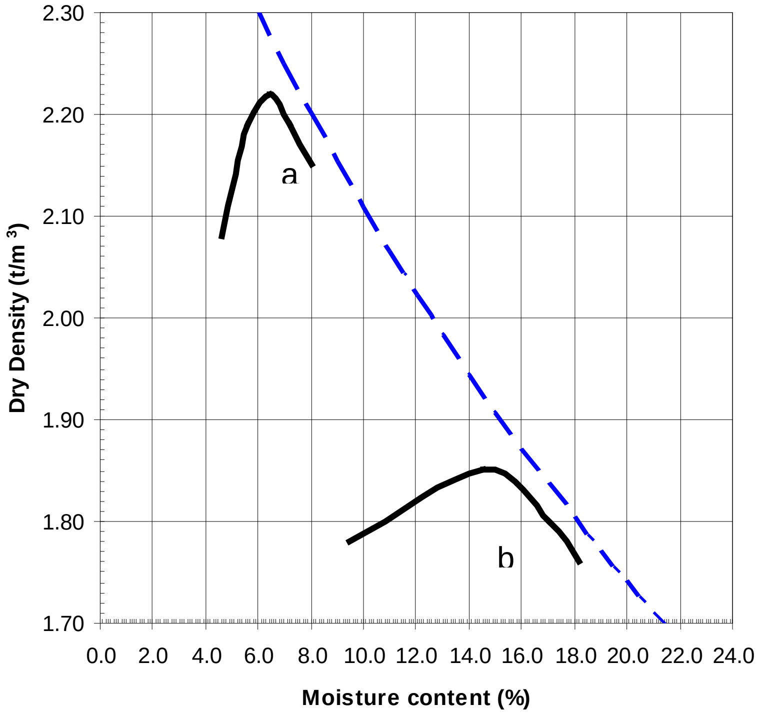

Figure 8: Examples of compaction curves for gravely (a) and clayey (b) materials

The shape of the MDD graph can give an indication of the material's sensitivity to moisture. Figure 8 shows a gravelly material which has a reasonably steep curve compared to material with a large percentage of clayey fines which has a much flatter curve. Comparing the difference in density at OMC and at OMC -2% the curve in Figure 8 shows that the:

- gravelly material has a far greater difference in density for a 2% change in moisture content, and
- gravelly material is far more moisture sensitive than the clayey material.

8. References

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