Transport
Roads & Maritime Services

Guide Note

Particle size distribution in road construction materials

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Revision Summary

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Note that Roads and Maritime Services is hereafter referred to as 'RMS'.

The most recent revision to this Guide Note (other than minor editorial changes) is indicated by a vertical line in the margin as shown here.

Guide Note

Particle size distribution in road construction materials

PREFACE

This guide note covers RMS test methods T105, T106, T107, T190, T201 and T203.

1. INTRODUCTION

Road construction materials consist of a range of particle sizes and these are grouped into ranges to determine the proportions of each size range by dry mass. Figure 1 clearly shows how the particle size varies in a sample and this is commonly referred to as ‘grading’.

Figure 1 All pavement and earthwork materials can be grouped into particle size ranges.

The particle size distribution is one of the most important physical characteristics of a soil or pavement material as it is the main basis for classification. Many geotechnical and geophysical properties of a soil are related to the particle size distribution and Table 1 lists the particle size range for various gravels and soils.

Table 1 Common particle description and size range (AS 1726).

	Particle Description	Particle Size Range
	Boulder	> 200 mm
	Cobble	63 – 200 mm
Gravels	Coarse Gravel	20 – 63 mm
	Medium Gravel	6 – 20 mm
	Fine Gravel	2.36 – 6 mm
Sands	Coarse Sand	0.6 – 2.36 mm
	Medium Sand	0.2 – 0.6 mm
	Fine Sand	0.075 (75µm) – 0.2 mm
	Silt	2 µm – 75 µm
	Clay	< 2 µm

RMS specifications detail the required percentage in each group, generally these specifications have an upper and lower limit, which is commonly called the 'grading envelope'. To conform to the specification the material must fit the grading envelope. Grading envelopes have been designed to provide a balance between coarse and fine particles, coarse particles give the material strength, while the fines fill the voids thus providing mechanical interlock, improved workability and reduced permeability. Without this balance, material with too much coarse material could easily fall apart and materials with an excess of fines are likely to move and rut under traffic.

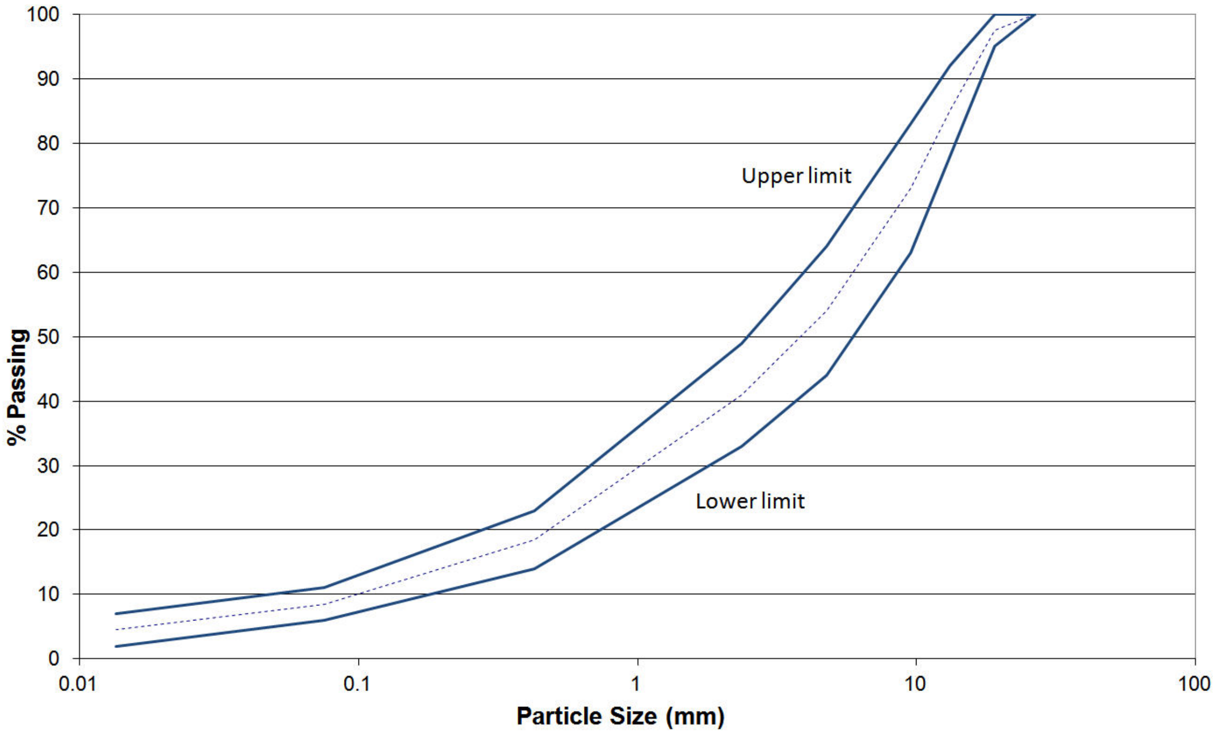

Figure 3 Grading envelope showing a material (dotted line) that fits the requirements for DGB20 in RMS Specification 3051.

The various test methods used by RMS to determine the particle size distribution (PSD) of earthworks and pavement materials are listed as follows:

- T105 – Preparation of samples for testing (soils).
- T106 - Coarse particle size distribution of road construction materials (by dry sieving).
- T107 - Fine particle size distribution of road construction materials
- T190 – Fine particle distribution by Hydrometer
- T201 - Particle distribution of aggregates (by washing)
- T203 – Particle distribution of aggregates finer than 75µm (by washing)

Details of each test method are covered in Section 3.

Common terms and definitions used in this guide note are listed in Section 5.

2. Sieves

2.1 General

The determination of the mass in each distribution range is referred to as sieving (also called screening) and this process of separating in particle size groups is by the use of test sieves. The main test methods for determining the PSD of materials are:

- T106 (soils & gravels) and
- T201 (aggregates)

Where both methods use a 'nest' of sieves where the material is passed over sieves fitted together in various aperture sizes in descending order (see Figure 4). The nest of sieves will have a receiver pan on the bottom and a lid on top to prevent the loss of any material, especially fines, during the sieving process.

Figure 4 Typical nests of sieves.

RMS test methods T106 and T201 generally determine the coarse and medium particle size distribution, and other test methods, such as T107, T190 and T203, can be used to define the distribution of finer particles.

2.2 Sieve types

Generally sieves are of two different types as shown in Figure 5. Perforated plate sieves, where the aperture has been punched from a flat metal plate, are of a size greater than 2.36 mm. Woven wire sieves, as the name suggests are constructed of woven wire, usually 2.36 mm and smaller.

Figure 5 View of perforated plate (left) and woven wire sieves.

Sieving is complete when no more than 1% of the material retained on the sieve passes through the apertures in one minute. It is very important to comply with this requirement to obtain an accurate calculation of the grading.

2.3 Calibration

A calibration check of sieves is important. Sieves should not be used until they have been checked and found to conform to AS 1152. Perforated plate sieves can be checked using Go/No-Go Gauges or vernier calipers. UKAS Lab 22 is a British standard accepted by NATA as the best procedure to complete a detailed calibration check on woven wire sieves. This calibration check involves using glass beads (usually boron silicate) of various sizes to check that sieve apertures have not been damaged or worn.

Laboratories must have records of regular calibration checks available in their facility, these records should show conformance with the sieve requirements. There are other processes to check sieve calibrations but those mentioned above are the most commonly used. Sieves that are damaged should be discarded and noted on file.

2.4 Mass limits per sieve

During all sieving processes it is important that individual sieves are not overloaded and Table 2 details the maximum allowable mass on any one sieve after the sieving has been complete. An overloaded sieve will not work properly and fine material that should pass through the sieve apertures will remain, leading to erroneous results. In addition, overloading of sieves can also cause damage to sieves and again resulting in erroneous results.

Note that RMS Test Method T201 uses a similar table but there are slight differences in the allowable masses.

Table 2 Maximum mass of material to be retained on various sieves at the completion of screening (T105).

Sieve Size (mm)	200 mm diameter sieve(g)	300 mm diameter sieve(g)	450 mm diameter sieve(g)
75.0	1000	3000	6000
53.0	1000	2750	5500
37.5	1000	2200	5000
26.5	800	1800	4000
19.0	600	1200	3000
13.2	400	900	2000
9.5	250	600	1500
6.7	225	500	1250
4.75	200	400	1000
3.35	180	350	800
2.36	150	300	600
1.70	125	250	500
1.18	100	200	400
0.700	90	170	-
0.600	75	150	-
0.425	60	120	-
0.300	50	100	-
0.150	35	-	-
0.075	25	-	-

2.5 Mechanical versus hand sieving

Most laboratories use mechanical sieve shakers to improve efficiency and reduce repetitive strain injury with staff carrying out the same task all day (see Figure 6). Mechanical sieve shakers are frequently used to pass the bulk of the sample through the sieves, but hand sieving must always be used to finalise the process. Mechanical sieving should be limited to no more than 10 minutes as longer periods of sieving can break down the material giving a finer result.

Figure 6 Typical mechanical sieve shakers used by laboratories.

With all gradings, a sieve one size greater than the one that retains the coarsest particles must be used. When a PSD is reported the first sieve used must show 100% passing.

2.6 Before sieving

The grading test requires the sample to be dried, soils/gravels must have the portion passing the 19 mm sieve dried to constant mass as are all aggregates. The initial mass of the dry sample is recorded and then the portions retained on each sieve are also weighed. The calculation determines the percentage of material retained on each sieve but then this is converted to a cumulative percent passing for reporting purposes. All specifications are based on percentage passing.

3. COMMON GRADING TEST METHODS

3.1 T106 - Coarse particle size distribution of road construction materials (by dry sieving)

This test method is the usual test method to determine the PSD of soils and gravels, but only to the 2.36 mm sieve and T107 can then be used to determine the finer fractions of the material. Preparation for this test is detailed in T105, which stipulates the minimum amount of material required for the test. This minimum mass depends on the nominal size of the material.

The first stage of the preparation stage is to dry the sample sufficiently for the material to be crumbled, crumbling enables aggregations of material to be broken down easily so they can pass through the sieves. If these aggregations are dry and hard a mortar and rubber pestle may be required to facilitate this break down of the aggregations.

Figure 7 Mortar and rubber pestle.

Next the sample must be divided down to an amount that meets the specified minimum mass, sample division can be done using a riffle box or by cone and quartering. This sample division reduces the size of the sample so that the sub-sample is representative of the original bulk sample. It is very important that reducing the sample size is done correctly or the results will be meaningless.

Now that we have a sub-sample that is representative of the whole, is of the required mass and dry enough to be crumbled, the material is weighed then sieved over the coarse sieves, 19 mm and larger. To ensure that only discrete particles are retained on sieves, material on each sieve should be tested for breakdown of any material aggregations in the mortar with a rubber pestle, then placed back over the same sieve.

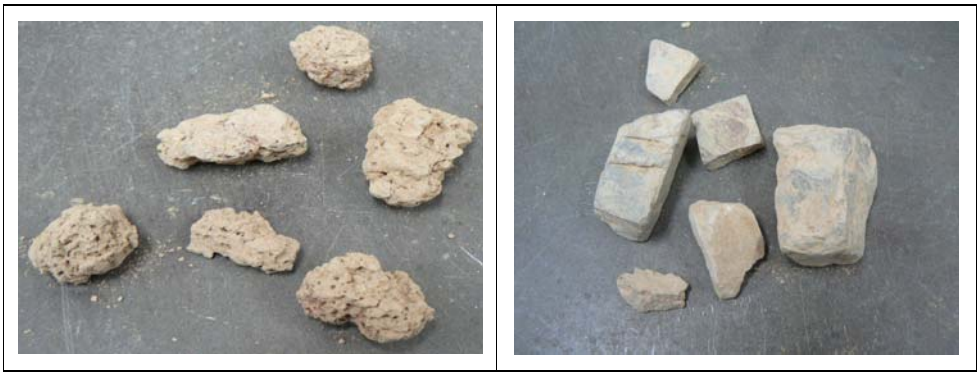

Figure 8 Aggregations of particles (left) and discrete particles.

After the operator is sure that only discrete particles are retained on each sieve these fractions are weighed and recorded.

The material passing the 19 mm sieve must be dried to constant mass before any more sieving can occur. This dry material is then placed through the intermediate sieves for further sieving. The material retained on each sieve must be ground on the mortar and rubber pestle to break down any aggregations. After sieving is complete:

- all fractions are weighed and recorded,
- calculations work out the percentage passing through each sieve use, and
- reporting is to the nearest whole number.

The test method does not mandate production of a graph (as per Figure 3), but this can be very useful and together with the specification limits any deficiencies in the grading can be immediately seen.

3.2 T107 - Fine particle size distribution of road construction materials

This test is the next step after T106 is completed and is used to determine the finer fractions of the sample and in conjunction with T106 gives a full grading of the material. The test determines the percentages passing the 425 µm, 75 µm and 13.5 µm.

This method uses sedimentation and decantation as the means for determining the percent passing 13.5 µm. It is noted that a 13.5 µm sieve would have very small apertures and would be very easily damaged.

Decantation is based on Stokes' Law, (refer to Table 3) which determines the rate of settlement acted upon by gravity of a specific sized particle in a fluid.

Table 3 Stokes' Law converted for this specific application.

Temperature of water (ºC)	Settling time (Minutes)
39	5.5
34	6.0
30	6.5
27	7.0
24	7.5
21	8.0
19	8.5
16.5	9.0
14.5	9.5
12.5	10.0
10.5	10.5
9	11.0
7	11.5
6	12.0
4	12.5

The test is based on the -2.36 mm fraction, and from T106 the material must be dried to constant mass. A portion of approximately 50 g is divided from the fraction and the mass is recorded.

The portion is placed in a beaker, a one litre beaker with marks at 30 mm and 110 mm from the bottom (see Figure 9). At least half a litre of water is added and brought to the boil. The material is boiled for one hour, every ten minutes the beaker must be stirred briskly (using a rubber tipped glass stirring rod to avoid breaking the beaker) to stop the material baking on the bottom. The rubber tip on the stirring rod must be sealed so that material is not picked up inside the rubber. This boiling process breaks down any aggregations of material that exist in the sample and failure to boil properly will result in erroneous answers.

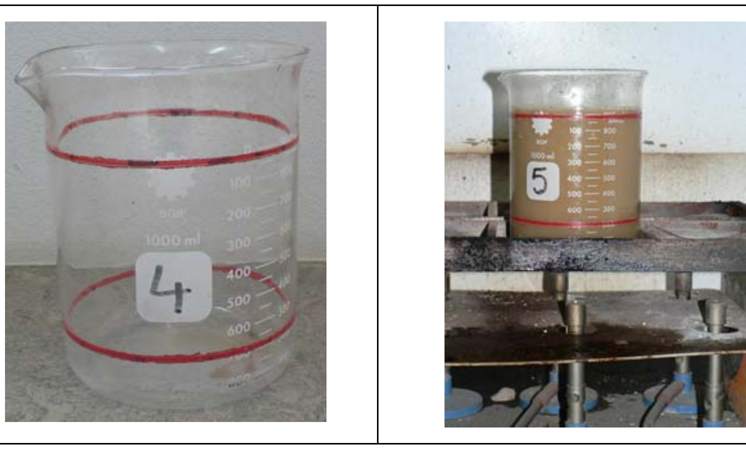

Figure 9 Beaker showing 30 mm and 110 mm marks (left) and material being boiled.

After boiling, the beaker is topped up with cool water to the top (110 mm) mark, a thermometer inserted to determine the water temperature so that the settling time from Stokes' Law can be used. Next step is for the material to be stirred and this stirring should use a figure eight action so currents that could artificially suspend material in the beaker are not formed. Generally the stirring is for 20 seconds, this is 10 seconds of figure eight stirring followed by 10 seconds of carefully moving the material towards the front of the beaker. The 20 seconds of stirring equals the 20 seconds of pouring after the settling period, this also helps the timing when several samples are tested together.

Although not mentioned in the test method it is good laboratory practise not to pour the water off down to the 30 mm line for the first couple of pours. A lot of particles are jostling together in the water and Stokes' Law assumes that particles do not interfere with each other.

The stirring suspends the material in the water allowing Stokes' Law to take effect. When pouring off water from the beaker 'underwater splashing' is a possibility, this can happen when the beaker is tipped up to pour and material on the bottom slides toward the front of the beaker causing a 'splash' which can put coarse material into suspension. This is the reason material is brought toward the front of the beaker during the 20 seconds of stirring.

After stirring, the beaker is allowed to stand undisturbed for the settling period, determined by the water temperature and Stokes' Law. Then the water and suspended material are gently poured off to the 30 mm line on the beaker. The water temperature is taken after topping up the beaker until the temperature stabilises during the entire pouring procedure. This process of topping up the beaker with water, stirring, settling and pouring continues until the dispersion is complete, ie the water becomes clear. If after 16 pours the dispersion has not been completed (water remains cloudy) the test is discontinued and repeated with an alternative dispersion agent or reported as incomplete dispersion.

At the end of the decantation process the beaker is allowed to stand for five minutes and then the water is poured off taking care not to pour off any of the sediment. The beaker is then placed in a hot oven (105 - 110ºC) until dry (typically left overnight in the oven). The material is then weighed and sieved on the finer sieves, 425 µm and 75 µm. Material retained on each sieve is carefully weighed and recorded, then calculated as a full grading for the material being tested. Reporting is to the nearest 1%.

3.3 T201 - Particle distribution of aggregates (by washing)

This test methods refers directly to the Australian Standard's test method; AS 1141.11.1, which requires the sample to be washed over a 75 µm sieve prior to grading the aggregate on the larger sieves. As with most testing the bulk sample has to be reduced to a portion that complies with the minimum mass required, sample division is usually done using a riffle box or cone and quartering.

Figure 10 Aggregate showing the particle size groups after sieving.

Table 4 Minimum mass of test portion for sieving (AS 1141.11.1).

Nominal size (mm)	75	40	28	20	14	10	7	5	Fine aggreg.	Fillers
Graded Aggregate	30 kg	15 kg	5 kg	3 kg	1.5 kg	800 g	500 g	300 g	150 g	25 g
One-sized aggregate	25 kg	10 kg	4 kg	1.5 kg	700 g	500 g	300 g	200 g	100 g	-

For the purposes of RMS testing, aggregates are considered to be 'one-sized'.
After the sample is reduced to the required mass the material is dried (105 - 110ºC oven) to constant mass and this mass is recorded, the test portion is placed in a dish or pan and clean water is added so that the material is completely covered. The contents are vigorously agitated until the fine material is taken into suspension, then immediately poured over the sieve. To protect the fine fabric of the 75 µm sieve a guard sieve of (usually) 1.18 mm is used.

This process of covering with water, agitating and decanting is repeated until the wash water has become clear. The aggregate is then dried to constant mass and recorded. The difference between the initial mass and the dried mass is the -75 µm material.

Now that the fines have been taken out of the material it must be sieved on the required sieves as per the sieving processes as detailed in T106 above, except the mortar and pestle are not required.

Calculations will then determine the percentages passing each sieve, the accuracy of reporting is to the nearest whole number, except the percent passing the 75 µm sieve is reported to 0.1%.

3.4 T203 – Particle distribution of aggregates finer than 75 µm (by washing)

This test method specifically determines the percentage of -75 µm material in a sample and refers directly to the Australian Standard's test method AS 1141.12, which is identical to the washing process in T201 above.

3.5 T190 – Fine particle distribution by Hydrometer.

This test method refers directly to the Australian Standards test method; AS 1289.3.6.3.

This test is not commonly used but can set out the quantitative determination of the particle size distribution in a soil from a coarse sand size down, using a hydrometer for particles finer than the 75 µm sieve.

The test is very involved and should not be attempted by an inexperienced technician without adequate supervision.

3.6 Other methods

Other test methods incorporate detection systems using x-rays, laser beams, and density measurements and particle counters can by used but are not covered under these test methods.

4. REFERENCES

Australian Standards

AS 1141.12 - Methods for sampling and testing of aggregates – Material finer than 75 micrometre in aggregates (by washing),

AS 1152 – Specification for test sieves.

AS 1289.3.6.3 – Methods of testing soils for engineering purposes – Soil classification tests – Determination of the particle size distribution of a soil – Standard method of fine analysis using a hydrometer.

AS 1726 – Geotechnical Site Investigation.

HB 160 – Soil Testing Handbook.

RMS Test Methods

T105 – Preparation of samples for testing (soils).

T106 - Coarse particle size distribution of road construction materials (by dry sieving).

T107 - Fine particle size distribution of road construction materials

T190 – Fine particle distribution by Hydrometer

T201 - Particle distribution of aggregates (by washing)

T203 – Particle distribution of aggregates finer than 75µm (by washing)

5. DEFINITIONS

The following list of definitions are used in this guide note and does not represent a complete list of soil testing definitions.

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%.

Final sieving - Sieving is complete when no more than 1% of the material retained on the sieve passes through the apertures in one minute.

Fraction – The material derived from a sample that is;

(i) retained on a specific sieve; or

(ii) passes a specific sieve; or

(iii) is retained between two specific sieves.

Graded aggregate - An aggregate of which more than 15% (by mass) of the total material is retained on at least three consecutive sieves.

Nominal size – The nominal size is expressed as a whole number above the smallest sieve aperture size through which at least 90% of the material passes.

One-sized aggregate - An aggregate of which at least 60% of the mass of the total material passes a sieve which is immediately less than the nominal size of the aggregate and is retained on the sieve immediately following the selected sieve in the series.

Portion - The material derived from a sample after screening and/or division for a specific test.

PSD – Particle size distribution.

Sample – The bulk sample prior to any testing.

RMS/Pub 12.181