NZTA T28: 2025

Test Method for the Determination of the Dry Density and Water Content Relationship of Aggregate

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1 Scope

This method covers the determination of the maximum dry density and optimum water content for an aggregate. The fraction passing a 26.5mm test sieve is compacted by an electrically operated vibrating hammer compactor over a range of water contents and the dry density determined. The dry density for the whole material is corrected to allow for any material coarser than 26.5mm.

2 Related Documents

(a) Standards New Zealand NZS 4402 Methods of Testing Soil for Civil Engineering Purposes.
(b) Standards New Zealand NZS 4407 Methods of Sampling and Testing Road Aggregates.
(c) ASTM International ASTM D4718 Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

3 Sampling

Obtain a representative field sample of the aggregate using the procedure of NZS 4407 section 2, sub-method 2.4.6.3.2 or 2.4.6.4 as appropriate to the stockpile construction, or sub-method 2.4.7 if samples are obtained from freshly spread layers, or sub-method 2.4.8 if samples are obtained from road pavements.

4 Apparatus

The following apparatus is required:

(a) A non-corrodible cylindrical metal mould complying with the requirements of NZS 4407 test 3.15 (figure 16), adjusted if necessary by the use of an appropriate spacer, to give a specimen height of 125mm to 127mm. The mould shall be provided with a perforated metal baseplate and a metal extension collar of nominal depth 60mm.

Note: A split mould shall not be used.

Determine the internal diameter of the mould to 0.5mm or better by taking at least four measurements evenly spaced around the mould circumference. Calculate the mean internal diameter of the mould over the portion to be occupied by the specimen, and record (d).

Place a straight edge across the top of the extension collar. Measure the depth from the straight edge to the surface of the spacer to 0.5mm (or base of mould if the spacer is not used) and record. Take at least 6 readings around the mould; calculate the mean height and record (h_1).

(b) If required, a metal spacer 150mm +0mm, -0.5mm diameter of thickness appropriate to give the required specimen height, with a detachable handle. Refer to NZS 4407 test 3.15 (figure 16) for a drawing of the spacer.

Note: The spacer is required for use in a CBR mould so that the specimen height is 125mm to 127mm after compaction. If a 127mm height mould is used the spacer is not needed.

(c) A Hikoki H60MC electric vibrating hammer. It shall be fitted with an hour meter that records the total working hours of the hammer. The hammer shall be discarded and replaced after 250 hours operation.
(d) A loading frame to support the apparatus and provide a vertical static downward mass of 35kg ± 1kg, including the clamp assembly, vibrating hammer and tamper.

The loading frame shall consist of a metal clamp assembly to firmly hold the vibrating hammer. The clamp assembly shall be supported by two parallel guide rods perpendicular to the base plate and move freely without any appreciable binding. The loading frame shall be designed to securely hold the clamp assembly and vibrating hammer to allow insertion and removal of the mould prior to, and following specimen compaction. See Figure 2 and Figure 3.

Note: Traditional cantilever-type loading frames such as in NZS 4402 test 4.1.3 figure 4.1.4 are not compliant with this test method.

The loading frame shall have a steel baseplate at least 10mm thick and clamping arrangements for the mould such that it is rigidly coupled to the baseplate throughout the test. The loading frame shall hold the vibrating hammer perpendicular to the test specimen at all times during the test.

The steel baseplate shall be level and rigidly fastened to a concrete pedestal at least 150mm thick and both wider and deeper than the baseplate or a building concrete floor slab.

(e) A steel tamper with a circular foot with a diameter of 148mm ± 2mm. The shaft of the tamper must fit the vibrating hammer tool socket. See Figure 4.
(f) A balance readable and accurate to 1g or better.
(g) A timing device readable and accurate to 1s.
(h) 26.5mm and 9.50mm test sieves and receiver.
(i) A large tray (a convenient size is 600mm x 500mm x 80mm).
(j) At least 6 small trays (a convenient size is 300mm x 300mm x 80mm).
(k) At least 8 heavy grade plastics bags or other suitable air-tight, non-corrodible containers.
(l) Heavy grade plastic discs cut to accurately fit within the cylindrical mould. Plastic thickness of 0.125mm has been found to be satisfactory.
(m) A steel rule readable and accurate to 0.5mm.
(n) A straight-edge.
(o) Apparatus for water content determination as specified in NZS 4407 Test 3.1.

5 Procedure

5.1 Particle Size Distribution

Obtain a representative test sample from the field sample and determine the particle size distribution using the method of NZS 4407 Test 3.8.1. Determine the percentage passing the 26.5mm test sieve, P_f.

The maximum dry density and optimum water content testing is conditional on the particle size distribution compliance with the relevant standard. Do not continue if the aggregate is not compliant.

5.2 Aggregate Solid Density

Obtain a representative test sample from the field sample and determine the aggregate solid density using the method of NZS 4407 Test 3.7, as follows:

(a) Sieve the test sample over the 26.5mm test sieve.
(b) Determine the solid density of the aggregate fraction retained on the 26.5mm sieve, the "coarse aggregate fraction" ρ_{sdc} using the method of NZS 4407 Test 3.7.2.
(c) Determine the solid density of the aggregate fraction passing the 26.5mm sieve, the "fine aggregate fraction" ρ_{sdf} using the method of NZS 4407 Test 3.7.1.
(d) Calculate the combined solid density ρ_s of the aggregate using the formula:

$$\rho_s = \frac{1}{\frac{P_c}{\rho_{sdc}} + \frac{P_f}{\rho_{sdf}}} \quad (t/m^3)$$

Where: ρ_{sdc} = the solid density of the coarse aggregate fraction (t/m³)
P_c = the percentage retained on the 26.5mm test sieve expressed as a decimal
ρ_{sdf} = the solid density of the fine aggregate fraction (t/m³)
P_f = the percentage passing the 26.5mm test sieve expressed as a decimal.

5.3 Dry Density and Water Content Relationship

5.3.1 Sample Preparation

(a) Obtain a representative sub-sample from the field sample. Sieve the sub-sample over the 26.5mm test sieve. At least 80kg of aggregate passing the 26.5mm sieve will be required.

(b) Take a representative test sample of the aggregate retained on the 26.5mm test sieve and determine the water content w_c using the method of NZS 4407 test 3.1.
(c) Take a representative test sample of the aggregate passing the 26.5mm test sieve and determine the water content w_f using the method of NZS 4407 test 3.1.
(d) Thoroughly mix the aggregate fraction passing the 26.5mm sieve in the large tray. Break down aggregations of material so that, with the exception of individual particles, all material would pass a 9.50mm test sieve.

Lumps of cohesive materials may require cutting or breaking up by hand. Take care during sample preparation to minimise drying. Maintain the material as close as possible to the natural water content.

(e) Representatively divide the aggregate fraction into test samples of sufficient volume for the test. It is recommended that 8 test samples are prepared to allow for repeat testing.
(f) Assess the range of water contents required for the test. Within this range, adjust the water content of the individual test samples by removing or adding water to provide a series of samples at different water content which span the estimated optimum water content (OWC). Make at least two test samples wetter than OWC and at least three test samples drier than OWC.

The material, when received, may be at a water content above or below the optimum value. Aggregates with a water content greater than the optimum value shall be carefully dried to the desired water content. Control of water loss can be achieved by comparative weighing during drying. Drying may be accomplished with a current of warm air, but whatever method is used, regular stirring is essential to prevent over-drying of any part of the surface of the aggregate. Do not use a drying oven to reduce the water content.

A sample, any part of which has been accidentally over-dried, must not be used unless it can be shown that such drying has no effect on its compaction characteristics.

Aggregates with a water content less than the optimum will require water to be added. Add water as a fine spray to each sample and thoroughly mix. Control of the amount of water to be added can be achieved by comparative weighing during wetting.

Place each test sample in a heavy grade plastics bag or airtight container, seal to minimise the air space between the container and the aggregate (see Note (a)).

(g) For natural aggregate materials containing no stabilising binder subject to curing, cure overnight (at least 12 hours) in a cool place. For aggregate materials containing a stabilising binder compact the test specimens immediately.

5.3.2 Test Procedure

(a) Check that the test mould assembly is clean and dry and that the parts fit together properly. Lightly oil the inside of the mould, baseplate and spacer, and fit the spacer (if used) inside the mould with the lifting handle socket downwards. Place a plastic disc in the base of the mould.
(b) Weigh the mould, extension collar, baseplate, plastic disc and spacer to 1g and record (M_1).
(c) Clamp the assembled mould on the baseplate of the loading frame with the vibrating hammer withdrawn to allow free access to the mould.
(d) Take one of the test samples, thoroughly mix and take enough of the test sample to half fill the mould when compacted and reseal the bag or container. Take care to minimise segregation of the aggregate while filling the mould. Level the surface and place one or two plastic discs on top of the specimen.
(e) Assemble the vibrating hammer with the tamper inside the mould so that the vibrating hammer is in a position for operation. Operate the hammer for 180 ± 10 seconds. Remove the vibrating hammer and tamper from the mould. The height of the aggregate in the mould should be within ± 2mm of half the mould height (i.e. 63mm ± 2mm).
(f) Remove the plastic discs and add more aggregate so that when compacted the specimen just protrudes into the extension collar. Level the surface, place one (or two) plastic discs on top of the specimen and repeat step (e).
(g) Remove the mould assembly from the loading frame and clean any aggregate from the outside of the mould. Remove the plastic discs from the upper surface of the specimen. Scrape any fine aggregate slurry within the mould back on to the test specimen.

(h) Place a straight-edge across the top of the extension collar, measure the depth from the straight-edge to the surface of the specimen to 0.5mm and record. Take at least 6 readings around the mould, all at least 15mm from the side of the mould. Record the 6 readings and calculate the mean depth and record (h_2).
(i) Weigh the mould assembly, complete with sample, to 1g and record (M_2).
(j) Remove all of the compacted aggregate from the mould and place it on a tray and determine the water content using NZS 4407 test 3.1. Record the water content as (w_f).
(k) Treat each of the remaining test samples as specified in (d) to (j) inclusive above.

6 Calculations

(a) Calculate the bulk density (wet) ρ_{fw} of each compacted specimen of the aggregate fine fraction using the formula:

$$\rho_{fw} = \frac{4000(M_2 - M_1)}{\pi d^2 (h_1 - h_2)} \quad (t/m^3)$$

Where:
M_1 = mass of the mould, collar, spacer and baseplate (g)
M_2 = mass of the mould, collar, spacer, baseplate and soil (g)
d = mean internal diameter of the mould (mm)
h_1 = mean height from the top of the mould base (or top of the spacer if used) to the top of the collar (mm)
h_2 = mean depth from the top of the soil to the top of the collar (mm)

(b) Calculate the dry density for the aggregate fraction passing 26.5mm ρ_f from the formula:

$$\rho_f = \frac{\rho_{fw}}{1 + w_f} \quad (t/m^3)$$

Where: w_f = water content of the fine aggregate fraction expressed as a decimal.

(c) Calculate the corrected water content for the aggregate (combined coarse and fine fractions) using the following formula:

$$w_{corr} = \left((w_c P_c) + (w_f P_f)\right) \text{x } 100 \quad (\%)$$

Where:
w_{corr} = corrected water content of combined coarse and fine aggregate fractions (%)
w_c = water content of coarse aggregate fraction expressed as a decimal
w_f = water content of fine aggregate fraction expressed as a decimal
P_c = percentage of aggregate retained on the 26.5mm sieve as determined by the particle size distribution test expressed as a decimal
P_f = percentage of aggregate passing the 26.5mm sieve as determined by the particle size distribution test expressed as a decimal.

(d) Calculate the corrected dry density for the aggregate ρ_{corr} (combined coarse and fine fractions) using the following formula:

$$\rho_{corr} = \frac{\rho_f \rho_{sdc} \rho_{water}}{(\rho_f P_c) + (\rho_{sdc} \rho_{water} P_f)} \quad (t/m^3)$$

Where:
ρ_{water} = is the density of water and may be assumed to be 1.00.
P_c = percentage of aggregate retained on the 26.5mm sieve as determined by the particle size distribution test expressed as a decimal
P_f = percentage of aggregate passing the 26.5mm sieve as determined by the particle size distribution test expressed as a decimal.

(e) Plot the corrected dry densities (ρ_{corr}) obtained in the series of determinations against the corresponding water contents (w). Draw a smooth curve fitting the resulting points and determine the position of the maximum (ρ_{dmax}) on this curve.

(f) Calculate the maximum dry density as a percentage of the solid density using the following formula:

$$R = \frac{\rho_{dmax}}{\rho_s} \times 100 \quad (\%)$$

(g) Plot the air voids lines at 0%, 5% and 10% using the formula below to calculate the density water content relationship for the various air voids contents (see note (b)).

$$\rho_d = \frac{1 - V_a}{\frac{1}{\rho_s} + \frac{w}{\rho_w}} \quad (t/m^3)$$

Where:

ρ_d	=	dry density of aggregate (t/m³)
ρ_{water}	=	density of water (t/m³), and may be assumed to be 1.00
V_a	=	volume of air voids in the aggregate, expressed as decimal
ρ_s	=	solid density of aggregate (t/m³)
w	=	water content expressed as a decimal.

7 Reporting of results

Report the following:

(a) The solid density of the aggregate ρ_s in t/m³ to the nearest 0.01t/m³.

(b) The maximum dry density (the dry density corresponding to the maximum point on the water content/dry density curve) ρ_{dmax} in t/m³ to the nearest 0.01t/m³.

(c) The dry density and air voids curves.

(d) The maximum dry density as a percentage of the solid density, *R*.

(e) The optimum water content (the water content corresponding to the maximum dry density on the water content/dry density curve) (%) to the nearest 0.2% for values below 5%, to the nearest 0.5% for values from 5% to 10%, and to the nearest whole number for values exceeding 10%.

Note: If the values of maximum dry density and optimum water content cannot be clearly determined from the curve, this fact shall be reported.

(f) State the history of the sample, for example, natural state, air-dried, oven-dried, or unknown.

8 Precision and Bias

8.1 Precision

The repeatability standard deviation has not been determined under laboratory conditions with the same test method in the same laboratory by the same operator with the same equipment in the shortest practical period of time using test specimens taken at random from a single quantity of source material.

8.2 Bias

There are presently no accepted reference values for this test method, therefore, bias cannot be determined.

9 Notes

(a) When the aggregate is stored in sealed containers water may condense on the container walls. The aggregate sub-samples shall be packed tightly into the container to minimize air space and reduce the problem of condensation.

(b) The zero air voids line is a valuable aid to the correct drawing of the compaction curve. At water contents above optimum water content, the compaction curve should asymptotically approach the zero air voids line but should never cross it. Should any of the plotted dry density/ water content values be to the right of the zero air voids line, an error has occurred, either in the value of the solid density used, or in the compaction test. The 5% and 10% air voids lines can enable estimation of the air voids present in the compacted soil.

Figure 1: Example of a Dry Density, Water Content Curve with Air Voids Curves Included

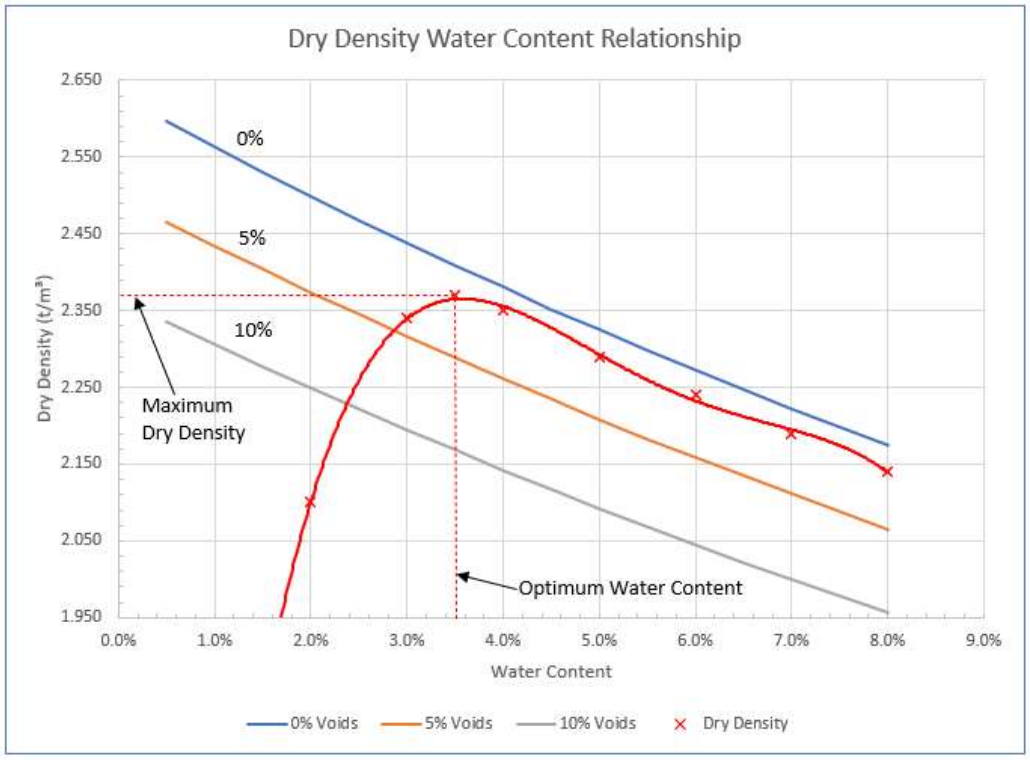

Figure 2: Vibrating Hammer and Loading Frame

Figure 3: Loading Frame General Arrangement

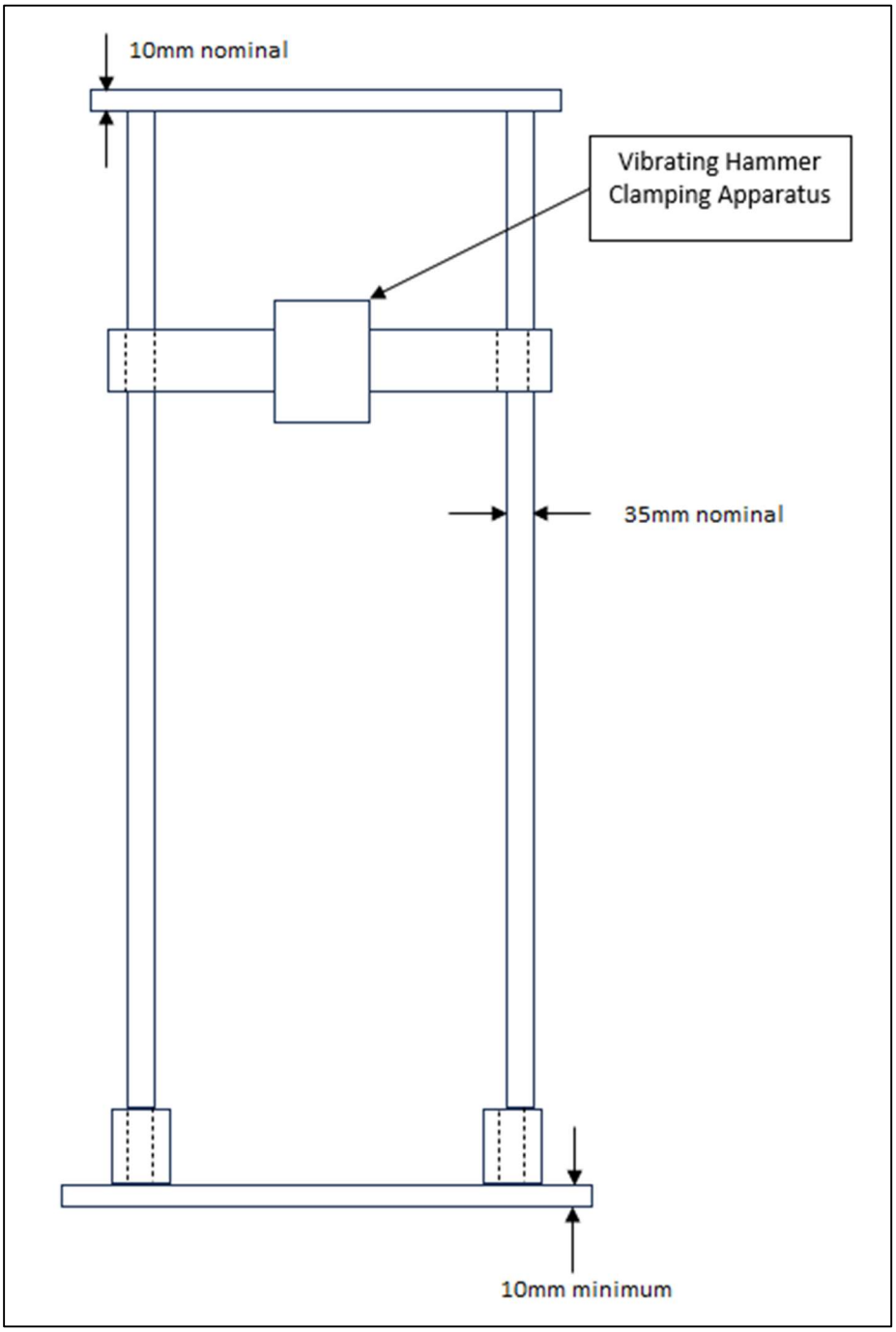

Figure 4: Tamper for the Vibrating Hammer Compaction Test