NEW ZEALAND STANDARD

METHODS OF TESTING SOILS FOR CIVIL ENGINEERING PURPOSES

Part 5
Soil density tests

5.1
DETERMINATION OF THE DENSITY OF SOIL

TEST 5.1.1
Sand replacement method for the determination of the *in situ* density

5.1.1.1
Scope
This method covers the determination *in situ* of the density of undisturbed or compacted soils. For medium and fine soils within a depth of 150 mm from the working surface either the small pouring cylinder or the large pouring cylinder may be used. For coarse soils, or for depths exceeding 150 mm but not exceeding 250 mm from the working surface, the large pouring cylinder shall be used (see Note (1)).

5.1.1.2
Related documents
The provisions of Part 1 of this Standard are applicable to, and shall be read in conjunction with, this method of test. Reference is made to Test 2.1 of this Standard.

5.1.1.3
Apparatus
(a) A pouring cylinder of appropriate size as shown in fig. 5.1.1.
(b) A cylindrical metal calibrating container of appropriate size as shown in fig. 5.1.1.
(c) A balance readable and accurate to 5 g (see Note (2)).
(d) A glass plate. (A convenient size is 10 mm thick by 600 mm square).
(e) A rigid metal digging tray of appropriate size, together with 3 or more spikes or pegs for securely fixing the tray in place on the ground. A suitable apparatus is shown in fig. 5.1.1.
(f) Suitable tools for preparing the site and excavating a hole in the soil, for example, spade, trowel, large screwdriver, bent spoon, ladle; dibber and scraper as shown in fig. 5.1.2.
(g) A suitable non-corrodible, air-tight container, or heavy grade plastics bag for the excavated sample.
(h) A non-corrodible rigid cylindrical sampling tube bevelled at one end to provide a cutting edge at the inner surface. A suitable design is shown in fig. 5.1.3. The hammer, dolly and guide rod shown in the figure are not required for this test.
(j) A linear measuring device such as a vernier caliper having a range of at least 250 mm readable and accurate to 0.1 mm.
(k) Apparatus for water content determination as specified in Test 2.1.

5.1.1.4
Material
The sand used in the test shall be clean washed sand passing the 600 μm and retained on the 300 μm test sieve and free from organic matter. The sand shall be oven-dried and then stored for a suitable period to allow its water content to reach equilibrium with atmospheric humidity (see Notes (3) and (4)).

5.1.1.5
Calibration of apparatus

5.1.1.5.1
Determination of the mass of sand in the cone of the pouring cylinder:
(a) With the shutter closed, place the pouring cylinder on a firm level surface and fill with sand to within about 15 mm of the top. Use this height of sand as the constant starting point each time the cylinder is used. It is essential that the pouring cylinder shall not be jarred or vibrated during the filling, weighing and discharge stages.

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(b) Place the appropriate calibrating container on a firm level surface. Support the pouring cylinder above the container and by opening the shutter discharge enough sand to just fill the container. Close the shutter.
(c) Place the pouring cylinder on the centre of the glass plate which is in turn on a firm level bench. Open the shutter of the pouring cylinder and allow sand to run out until no further movement takes place. Close the shutter and carefully remove the pouring cylinder to avoid any loss of sand off the glass plate.
(d) Collect all of the sand discharged onto the glass plate, weigh to 5 g, and record (M_1).
(e) Repeat steps (a) to (d) 3 times and calculate the mean mass of sand held on the glass plate (M_2).
(f) Measure the diameter and height of the hole in the digging tray and calculate the volume (V_2) to an accuracy of 1 %.

5.1.1.5.2
Determination of the bulk density of the sand:
(a) Determine the internal volume (V_1) of the calibrating container to be used from the volume of water required to fill it (see Note (5)).
(b) Fill the pouring cylinder with sand to the same height as in 5.1.1.5.1 (a). Weigh the cylinder plus sand to 5 g and record (M_3) (see Note (2)). Place the calibrating container on a firm level surface and then place the pouring cylinder concentrically over it. Open the shutter and allow sand to run out until no further movement occurs. Do not tap or vibrate the cylinder or container during this period. Close the shutter, remove the pouring cylinder, and weigh it plus the retained sand to 5 g, and record (M_4).
(c) Repeat step (b) 3 times. Calculate the mean value of $M_3 - M_4$ and record (M_5). (See Note (6)).

5.1.1.6
Measurement of soil density

5.1.1.6.1
Preparation of site:
(a) Prepare the test site, approximately 450 mm x 450 mm for the small cylinder or 600 mm x 600 mm for the large cylinder, by removing loose soil and trimming to give a level bedding surface.
(b) Bed the digging tray on the prepared surface and securely fix it in position using the spikes or pegs. If the use of spikes or pegs is impracticable, other means such as sandbags must be used to fix the tray. Any gap between the inside edge of the digging tray and the soil surface must be filled with plasticine or similar material.
(c) For fine cohesionless soils the following alternative method to step (b) may be used (see Note (7)). Place the sampling tube at the centre of the prepared area and press it evenly into the soil until the top edge is slightly below the levelled surface. Trim the surface until it is flush with the top edge of the sampling tube. Place the small cylinder digging tray concentrically over the sampling tube and securely fix it in position using the spikes or pegs.

5.1.1.6.2
Initial reading
(a) Fill the appropriate pouring cylinder with sand to the same height as in 5.1.1.5.1 (a). Weigh the pouring cylinder plus sand to 5 g and record (M_6) (see Note (2)).
(b) Carefully place the pouring cylinder on the digging tray concentrically over the hole in the tray. Open the shutter and allow sand to run out until no further movement occurs. Do not tap or vibrate the pouring cylinder and surrounding ground during this period. Close the shutter, remove the pouring cylinder and weigh it and the retained sand to 5 g and record (M_7) (see Note (2)).
(c) Empty the pouring cylinder and carefully remove the sand from the digging tray and surface of the soil. Take care not to disturb the digging tray. (See Note (8)).

NOTE – If the nature of the soil under test permits a true level bedding surface to be prepared, or if the sampling tube method of 5.1.1.6.1 (c) is used, the initial reading may be omitted and the alternative formulae given in 5.1.1.7 (b) used to calculate the bulk density of the soil.

5.1.1.6.3
Final reading
(a) Working through the hole in the digging tray excavate a test hole in the soil approximately the same diameter as the central hole in the digging tray (see Note (9)). For the small cylinder the depth of the hole shall be equal to the thickness of the layer being tested or approximately 150 mm whichever is the less. For the large cylinder the depth of the hole shall be equal to the thickness of the layer being tested, or approximately 250 mm, whichever is the less (see Note (10)). If the sampling tube of 5.1.1.6.1 (c) is used the soil should be excavated from within the tube to a depth of approximately 120 mm. Take care to remove all loose or disturbed soil from the sides and base of the hole. Put all soil removed from the hole into the air-tight container or plastics bag and immediately seal to preserve the *in situ* water content of the soil (see Note (11)). Weigh the excavated soil to 5 g and record (M_8).
(b) Fill the appropriate pouring cylinder with sand to the same height as in 5.1.1.5.1 (a). Weigh the cylinder plus sand to 5 g, and

record (M_9) (see Note (2)). Carefully place the pouring cylinder on the digging tray concentrically over the excavated hole. Open the shutter and allow sand to run out until no further movement occurs. Do not tap or vibrate the pouring cylinder and surrounding ground during this period. Close the shutter, remove the pouring cylinder, and weigh it and the retained sand to 5 g, and record (M_{10}).

(c) Take a representative portion of the excavated soil and determine its water content as specified in Test 2.1 and record (w).

(d) If the initial reading has been omitted, calculate the volume of the hole in the digging plate from its dimensions, to the nearest ml, and record (V_2).

5.1.1.7
Calculations
(see Form 4.4):

(a) Calculate the bulk density of the sand (ϱ_r) from the formula:

$$\varrho_r = \frac{M_5 - M_2}{V_1} \quad \text{..... t/m}^3$$

where M_2 = mean mass of sand in cone (g).
M_5 = mean value of $M_3 - M_4$ (g).
V_1 = volume of the calibrating container (ml).

(b) Calculate the bulk density of the soil (ϱ) from the formula:

$$\varrho = \frac{M_8}{\left(\frac{M_9 - M_{10}}{\varrho_r}\right) - \left(\frac{M_6 - M_7}{\varrho_r}\right)} \quad \text{..... t/m}^3$$

where M_6 = mass of cylinder and sand before the initial reading (g)
M_7 = mass of cylinder and sand after the initial reading (g)
M_8 = mass of excavated soil (g).
M_9 = mass of cylinder and sand before the final reading (g).
M_{10} = mass of cylinder and sand after the final reading (g).

Alternatively, if the initial reading has been omitted, calculate the bulk density of the soil (ϱ) from the formula:

$$\varrho = \frac{M_8}{\left(\frac{M_9 - M_{10}}{\varrho_r}\right) - \left(\frac{M_2}{\varrho_r} + V_2\right)} \quad \text{..... t/m}^3$$

where V_2 = volume of the hole in the digging plate (ml).

(c) Calculate the dry density of the soil (ϱ_d) from the formula:

$$\varrho_d = \frac{100\varrho}{100 + w} \quad \text{..... t/m}^3$$

where w = water content of the soil (%)

(d) Calculate the air voids (V_a) from the formula:

$$V_a = \left(1 - \frac{\varrho_d}{\varrho_s} - \frac{w\varrho_d}{100\varrho_w}\right) \times 100 \quad \text{..... \%}$$

where ϱ_d = dry density of soil (t/m^3)
ϱ_s = solid density of soil particles (t/m^3).
ϱ_w = density of water (t/m^3).

5.1.1.8
Reporting of results

5.1.1.8.1
Report the following values:

(a) The bulk density of the soil *in situ* (t/m^3) to the nearest 0.02.

(b) The dry density of the soil *in situ* (t/m^3) to the nearest 0.02.

(c) The water content of the soil (%).

(d) The air voids of the soil (%) to 2 significant figures.

5.1.1.8.2
State the history of the sample, for example, undisturbed or compacted, and whether the solid density of the soil particles was measured or assumed.

5.1.1.8.3
State that the result was obtained in accordance with this Standard Test Method.

NOTES ON TEST 5.1.1

NOTE (1). With granular materials having little or no cohesion particularly when they are wet, there is a danger of errors in the measurement of dry density by this method. These errors are caused by the 'slumping' of the sides of the excavated density hole and always result in an over-estimation of the density. Where these soils are tested the sampling tube should be used (see 4.4.6.1 (c)) (see Note (7)).

NOTE (2). Where the large pouring cylinder is used, the total mass of the pouring cylinder and sand may be too large for the balance specified. If so the suggested method for determining the mass of the full cylinder is to divide the sand into several portions, weigh each portion and the empty cylinder to the required accuracy, tip each portion into the pouring cylinder, and sum the several weighings.

NOTE (3). Generally a storage period, after oven-drying, of about 7 days is sufficient for the water content of the sand to reach equilibrium with the atmospheric humidity. The sand shall not be stored in air-tight containers and shall be thoroughly mixed before use. If sand is salvaged after being used in the field, it is advisable to sieve, dry and store this sand again before it is used in further sand-replacement tests.

NOTE (4). Granular materials other than sand may be used in this test provided that the material is closely graded and gives a consistent bulk density when calibrated in the manner described in the test. The pouring characteristics of the material shall not be more sensitive than the sand to changes in atmospheric humidity.

NOTE (5). The following method for determining the volume of the calibrating container has been found both convenient and accurate:

For calibrating the small container a balance readable and accurate to 1 g shall be used.

For calibrating the large container a balance readable and accurate to 5 g may be used.

Place the empty container on the flat pan of the balance, ensuring that the upper rim of the container is horizontal, if necessary by embedding the base in plasticine (or similar material). Determine the mass of the container, together

with any plasticine, and record (M_{11}). Pour water into the calibrating container until it is almost filled. Place a straight-edge across the top of the container and add water carefully by means of a dropping rod until the water just touches the straight-edge. Remove the straight-edge and determine the mass of the container plus water and record. Repeat the measurement a number of times to obtain an accurate mean value (M_{12}). For the repeat tests it is only necessary to remove a small amount of water by means of the dropping rod, and to refill the container to the level of the straight-edge. The volume of the calibrating container (V_1) is given by:

$$V_1 = \frac{M_{12} - M_{11}}{\varrho_W} \quad \text{..... ml}$$

NOTE (6). Since variations in atmospheric humidity affect the water content of the sand, and hence its bulk density, the calibration shall be made (or at least checked) during each day's work. To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch shall be sampled and calibrated.

NOTE (7). The procedure described in 5.1.1.6.1 (c) shall be employed only when the fine-grained cohesionless soil is in such a condition that a satisfactory hole cannot be formed because of the instability of the sides of the hole. The use of the core cutter will produce some disturbance in the soil, and where this procedure is necessary due allowance shall be made for a lower standard of accuracy than would normally be expected with the sand-replacement method.

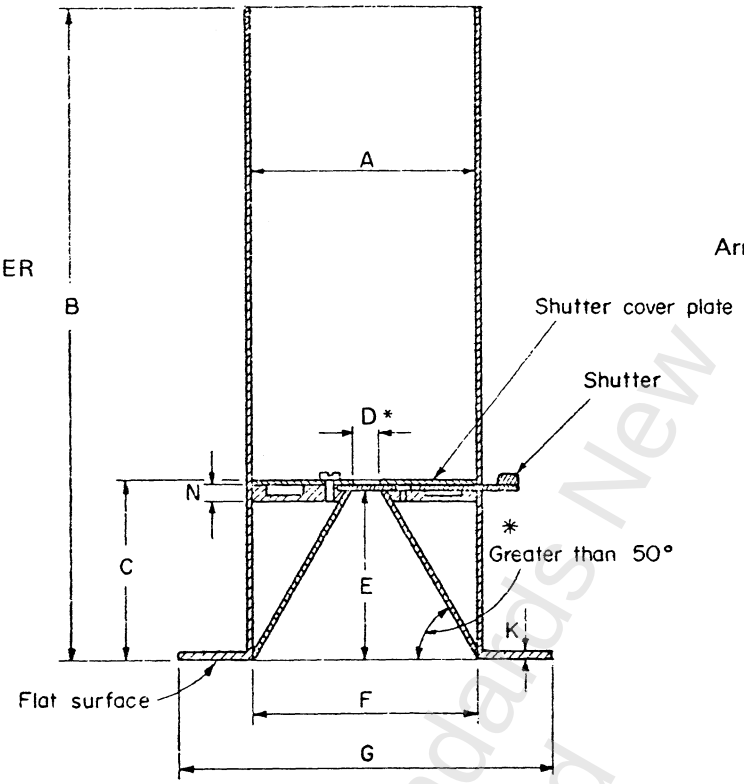
NOTE (8). If the soil under test is granular, care must be taken to ensure that particles of soil are not removed with the sand. If conditions are such that this is not possible, place a sheet of damp wet-strength tissue paper on the surface of the soil before placing the digging tray in position. Remove the paper after removing the sand.

NOTE (9). Take care in excavating the hole not to enlarge it by levering against the side, as this will result in lower densities being recorded.

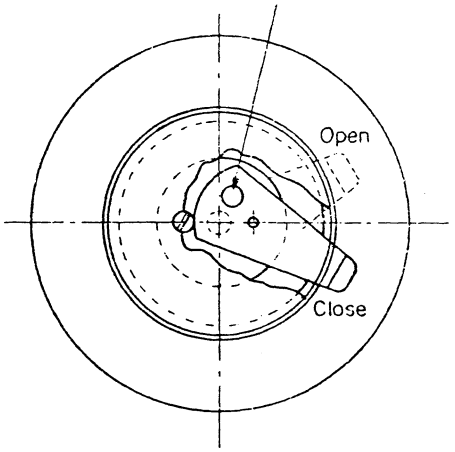
NOTE (10). The depth of hole excavated should be as large as possible within the limits stated. If for any reason it is necessary to excavate holes to depths other than 150 mm for the small pouring cylinder, or 250 mm for the large pouring cylinder the calibrating container must be replaced by one with a depth similar to that of the hole excavated, or the effective depth of the calibrating container must be reduced to about that of the hole excavated.

NOTE (11). Carefully save all the materials from the test hole and immediately transfer to the airtight container. In conditions of hot sun or drying winds, significant amounts of water may be lost from the material during the time taken to excavate the hole.

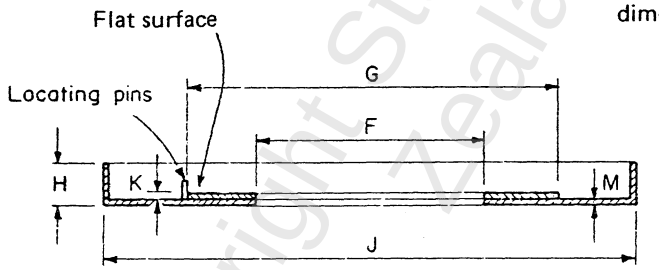
POURING CYLINDER



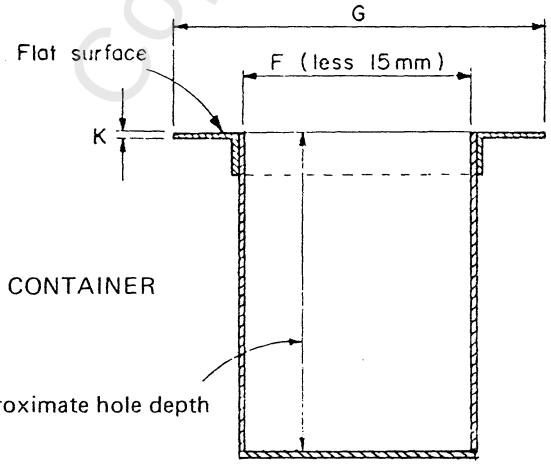
Arrangement of shutter with D* dia. hole



NOTE — This design has been found satisfactory but alternative designs may be employed provided the essential requirements are fulfilled. (Essential dimensions indicated by an asterisk.)



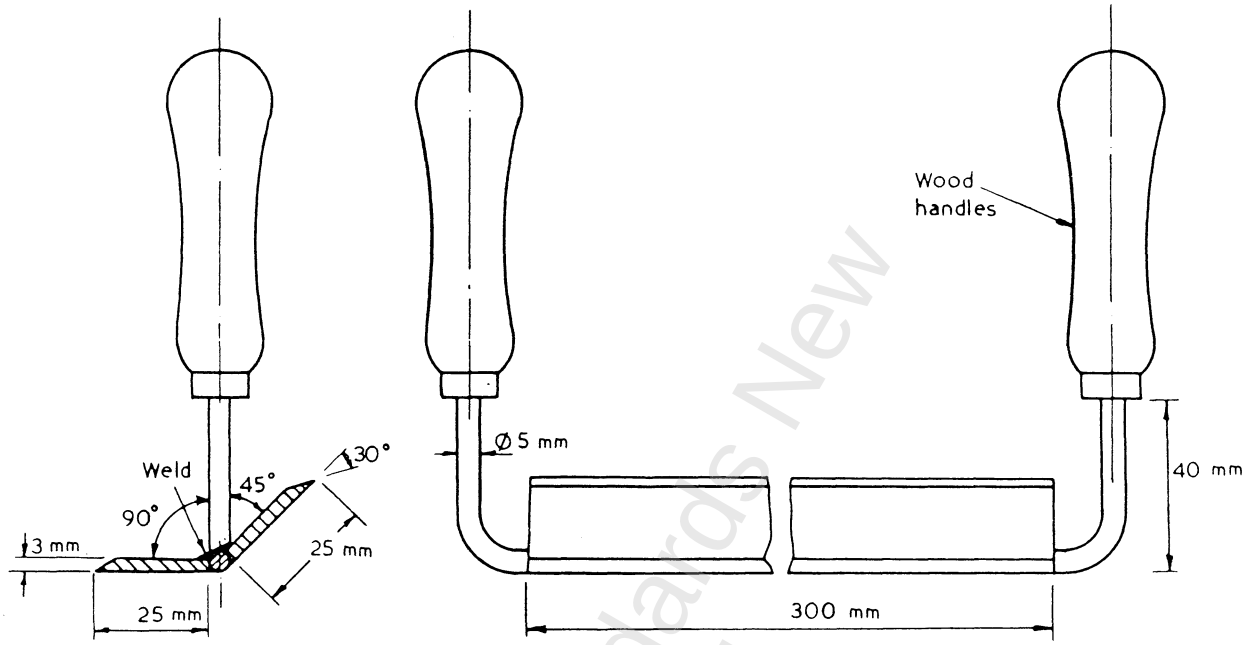
SQUARE RIGID METAL DIGGING TRAY



CALIBRATING CONTAINER

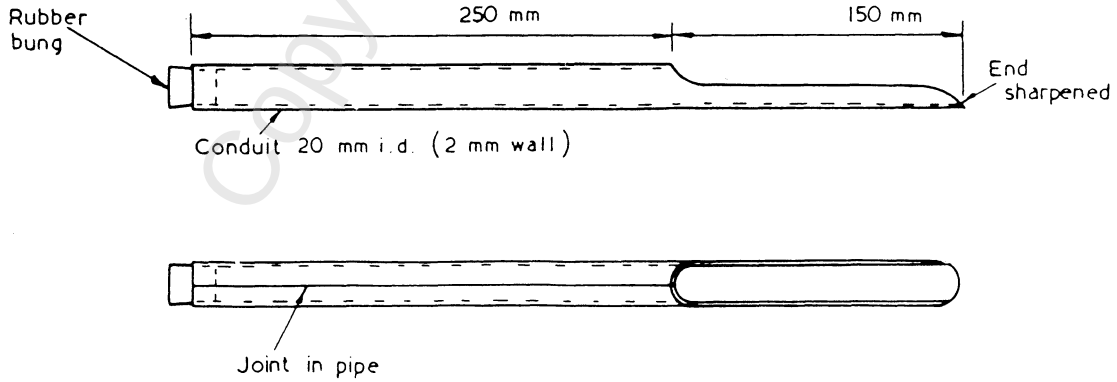
KEY	Large pouring cylinder (mm)	Small pouring cylinder (mm)
A (internal diam.)	215	115
B	610	380
C	165	85
D (diam.)	25 + 1, − 0*	15 + 1, − 0*
E	160	80
F (diam.)	215	115
G (diam.)	350	200
H	40	40
J	500 x 500	300 x 300
K	5	5
M	3.5	3.5
N	10	10

Fig. 5.1.1
POURING CYLINDER, DIGGING TRAY AND CALIBRATING CONTAINER



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled.

Scraper for levelling surface of soil



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled.

Dibber for digging holes for soil density determinations

Fig. 5.1.2
SCRAPER AND DIBBER FOR SOIL SURFACE AND HOLE EXCAVATION, SOIL DENSITY DETERMINATIONS

This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled.

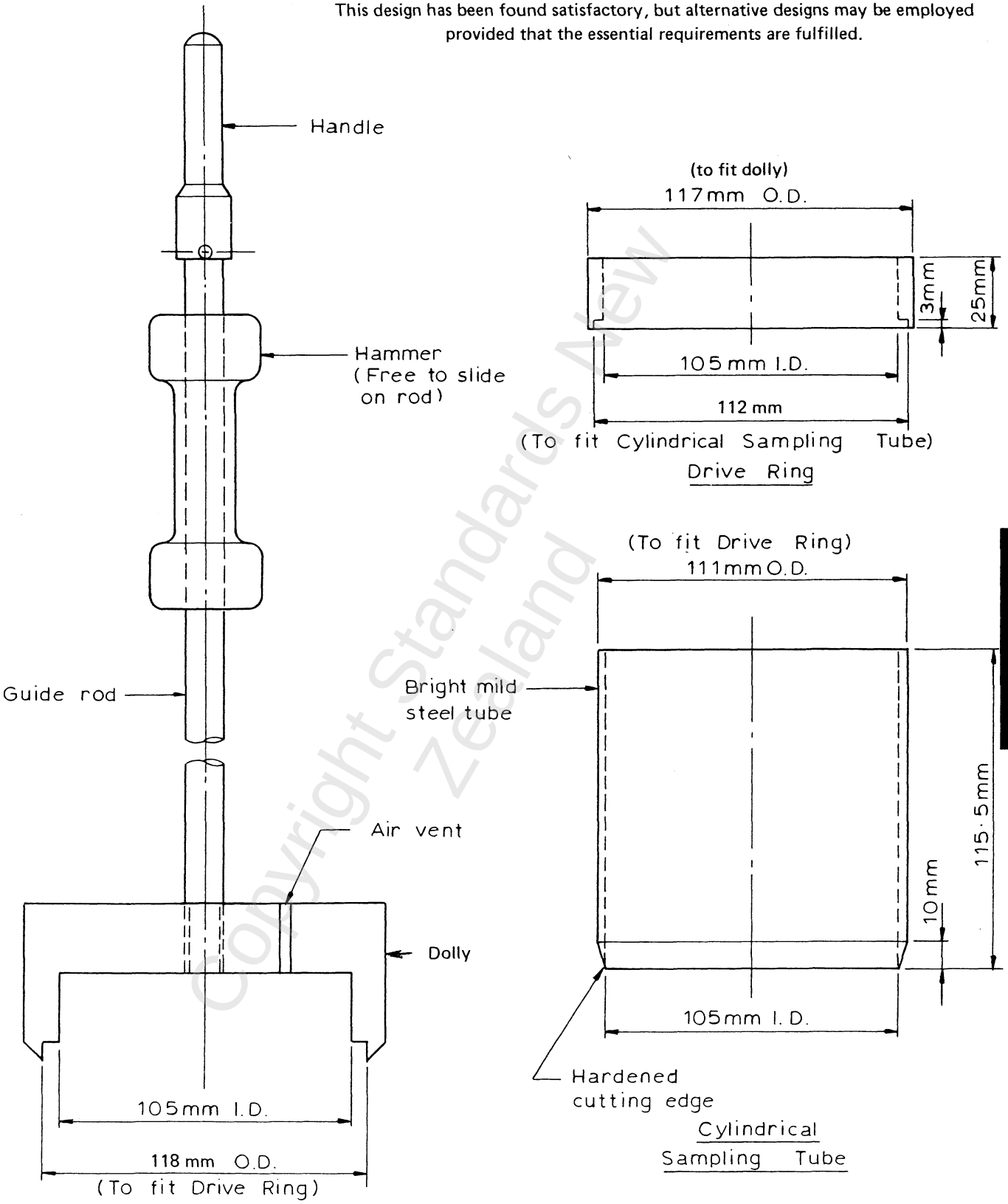


Fig. 5.1.3
CORE CUTTER APPARATUS FOR SOIL DENSITY DETERMINATION

Form 5.1.1
(Sheet 1)
DETERMINATION OF THE IN SITU DENSITY – SAND REPLACEMENT METHOD
(Test 5.1.1)

Job: Test no(s):
Location: Tested by:
Test details:* Date:
Soil description: Checked by:
Undisturbed/compacted/unknown Date:
Solid density of soil particles (ϱ_s): ..... t/m³, measured/assumed.

Calibration of sand						
Calibration run no.			1	2	3	4
Mass of sand in cone of pouring cylinder		M_1 g				
Mean value of M_1		M_2 g				
Mass of cylinder	cylinder	g				
plus sand before	portion of sand	g				
pouring into	portion of sand	g				
calibrating container	portion of sand	g				
Total mass before pouring		M_3 g				
Mass of cylinder plus sand after pouring		M_4 g				
Mass of sand to fill cone + container		$M_3 - M_4$				
Mean value of $M_3 - M_4$		M_5 g				
Internal volume of calibrating container		V_1 ml				
Bulk density of sand $\varrho_r = \frac{M_5 - M_2}{V_1}$		t/m³				

Determination of bulk density of soil						
Test no.			1	2	3	4
Initial reading (if ground surface is irregular)						
Mass of cylinder	cylinder	g				
plus sand before	portion of sand	g				
initial reading	portion of sand	g				
	portion of sand	g				
Total mass before pouring		M_6 g				
Mass of cylinder	cylinder	g				
plus sand after	portion of sand	g				
initial reading	portion of sand	g				
	portion of sand	g				
Total mass after pouring		M_7 g				
Volume of hole in digging tray $V_2 = \frac{M_6 - M_7 - M_2}{\varrho_r}$		ml				

* Delete inappropriate words.

Form 5.1.1
(Sheet 2)

Mass of wet soil excavated from hole		M_8 g				
Final reading						
Mass of cylinder	cylinder	g				
plus sand	portion of sand	g				
before pouring	portion of sand	g				
into hole	portion of sand	g				
Total mass		M_9 g				
Mass of cylinder plus sand after pouring		M_{10} g				
Volume of hole in digging tray		V_2 ml				
Volume of sand poured $V_3 = \frac{M_9 - M_{10} - M_2}{\varrho_r}$		ml				
Bulk density of soil $\varrho = \frac{M_8}{V_3 - V_2}$		t/m³				
Determination of water content Container no.						
Mass of container and wet soil		M g				
Mass of container and dried soil		M_S g				
Mass of container		M_C g				
Mass of water		$M - M_S$ g				
Mass of dried soil		$M_S - M_C$ g				
Water content $w = \frac{M - M_S}{M_S - M_C} \times 100$		%				
Dry density $\varrho_d = \frac{100\varrho}{100 + w}$		t/m³				
Percentage air voids $V_a = 100\left(1 - \frac{\varrho_d}{\varrho_s} - \frac{w\varrho_d}{100\varrho_w}\right)$		%				