

Methods of test for

Soils for civil engineering purposes —

Part 2: Classification tests

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Committees responsible for this British Standard

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- British Civil Engineering Test Equipment Manufacturers' Association
- County Surveyors' Society
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Foreword

This Part of BS 1377 has been prepared under the direction of the Road Engineering Standards Policy Committee. It is a revision of clause 2 of BS 1377:1975 which is superseded by amendment.

BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990:

- *Part 1: General requirements and sample preparation;*
- *Part 2: Classification tests;*
- *Part 3: Chemical and electro-chemical tests;*
- *Part 4: Compaction-related tests;*
- *Part 5: Compressibility, permeability and durability tests;*
- *Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement;*
- *Part 7: Shear strength tests (total stress);*
- *Part 8: Shear strength tests (effective stress);*
- *Part 9: In-situ tests.*

Reference should be made to Part 1 for further information about each of the Parts.

The principal changes to the classification tests as described in the 1975 edition are as follows.

a) *Additions*

- Determination of the saturation moisture content of chalk.
- Determination of the liquid limit by a one-point cone penetration test.
- Determination of shrinkage limit.
- Determination of bulk density by direct measurement of an undisturbed sample.
- Determination of particle density using a large pycnometer (preserving jar).

b) *Deletion*

- The alcohol and sand bath methods for the determination of moisture content.

c) *Significant changes*

- Use of the ISO recommended series of sieve aperture sizes has been introduced as an alternative to existing sieve aperture sizes.

Procedures for fine particle size analysis by sedimentation have been amended. Pretreatment is not now mandatory, and the need for several corrections to test observations has been eliminated.

The term “particle density” replaces “specific gravity”.

For most of the tests the normal requirement is to use the soil in its natural state without the need for drying before testing.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages 1 to 64, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 1377 specifies methods of test for the classification of soil and for the determination of basic physical properties.

Most of these tests are required for the classification of soils in accordance with BS 5930:1981.

Some of the properties determined by these tests are required for tests described in other Parts of this standard.

Reference should be made to Part 1 of this standard for general requirements that are relevant to all Parts of this standard, and for methods of preparation of samples for testing.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1377 the definitions given in BS 1377-1 apply.

3 Determination of moisture content

3.1 General

Water is present in most naturally occurring soils. The amount of water, expressed as a proportion by mass of the dry solid particles, known as the moisture content, has a profound effect on soil behaviour. In this context a soil is “dry” when no further water can be removed at a temperature not exceeding 110 °C.

Moisture content is required as a guide to classification of natural soils and as a control criterion in recompacted soils and is measured on samples used for most field and laboratory tests. The oven-drying method is the definitive procedure used in standard laboratory practice.

NOTE In some situations, for example in the field control of earthworks, a rapid method of measurement of moisture content may be required and a number of rapid methods are available, e.g. the sand bath method, the microwave oven-drying method and the calcium carbide method. It should not be assumed that these methods are appropriate for all soil types and when they are used on a particular soil some tests should also be carried out using the oven-drying method as a check.

A procedure for determining the moisture content at full saturation of chalk is described.

3.2 Oven-drying method

3.2.1 General. This method covers the determination of the moisture content of a specimen of soil as a percentage of its dry mass.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.2.2 Apparatus

3.2.2.1 A *drying oven*, capable of maintaining a temperature of 105 °C to 110 °C.

NOTE A microwave oven should not be used for the determination of moisture content by the definitive method for soils containing clay or organic matter because of the difficulty of ensuring that the temperature of the soil does not exceed 110 °C before all the water is removed. Higher temperatures than this can alter the properties of clay material.

3.2.2.2 For fine-grained soils

3.2.2.2.1 A *glass weighing bottle*, fitted with a ground glass stopper or cap, or a suitable airtight corrosion-resistant metal container.

3.2.2.2.2 A *balance* readable to 0.01 g.

3.2.2.2.3 A *desiccator* containing anhydrous silica gel.

NOTE It is preferable to use self-indicating silica gel as the desiccant. Calcium chloride should not be used as it is known that many clays when oven dry are capable of absorbing water from it.

3.2.2.3 For medium-grained soils

3.2.2.3.1 A *corrosion-resistant container* of about 500 g capacity.

3.2.2.3.2 A *balance* readable to 0.1 g.

3.2.2.3.3 A *scoop* of suitable size.

3.2.2.4 For coarse-grained soils

3.2.2.4.1 A *corrosion-resistant container* of about 4 kg capacity.

3.2.2.4.2 A *balance* readable to 1 g.

3.2.2.4.3 A *scoop* of suitable size.

3.2.3 Procedure

3.2.3.1 For fine-grained soils

3.2.3.1.1 Clean and dry the weighing bottle or metal container and weigh it to the nearest 0.01 g (m_1). Take a sample of at least 30 g of soil, crumble and place loosely in the container or weighing bottle, and replace the lid or stopper. Then weigh the container or bottle and contents to the nearest 0.01 g (m_2).

3.2.3.1.2 Remove the lid or stopper, and place the container or bottle with its lid and contents in the oven and dry at 105 °C to 110 °C. The period required for drying will vary with the type of soil and the size of sample but the sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see **3.2.3.1.3** and **3.2.3.1.4**) at intervals of 4 h do not exceed 0.1 % of the original mass of the sample. Do not replace the lid or stopper while the sample is in the oven.

NOTE 1 Certain soils contain gypsum which on heating loses its water of crystallization. The moisture content determined by this method will be affected by approximately 0.2 % for each 1 % of gypsum. If it is suspected that gypsum is present in the soil the moisture content samples should be dried at no more than 80 °C and possibly for a longer time. The presence of gypsum can be identified by heating a small quantity of soil on a metal plate. Grains of gypsum will turn white within a few minutes, whereas most other mineral grains remain unaltered.

NOTE 2 Between 16 h and 24 h is usually a sufficient length of time for drying most soils, but certain soil types and large or very wet samples will require longer. The drying time will also depend on the amount of material in the oven and may be confirmed by trial tests.

3.2.3.1.3 After drying, remove the container or bottle and contents from the oven and place the whole in the desiccator to cool.

NOTE If the lids of the containers fit well and it is unlikely that the samples are to be left for a considerable time before weighing, the samples need not be placed in the desiccator to cool, unless glass weighing bottles with ground glass stoppers have been used.

3.2.3.1.4 Replace the lid and then weigh the container or bottle and contents to the nearest 0.01 g (m_3).

3.2.3.2 For medium-grained soils

3.2.3.2.1 Clean and dry the container and weigh it to the nearest 0.1 g (m_1). Take a sample of at least 300 g of soil, crumble and place loosely in the container, and replace the lid. Then weigh the container and contents to the nearest 0.1 g (m_2).

3.2.3.2.2 Remove the lid and place the container and contents in the oven and dry at 105 °C to 110 °C (see note 1 to 3.2.3.1.2). The period required for drying will vary with the type of soil, the size of sample and the number of samples in the oven but the sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see 3.2.3.2.3 and 3.2.3.2.4) at intervals of 4 h do not exceed 0.1 % of the original mass of the soil (see note 2 to 3.2.3.1.2). Do not replace the lid while the sample is in the oven.

3.2.3.2.3 After drying, replace the lid and allow the whole to cool.

3.2.3.2.4 Weigh the container and contents to the nearest 0.1 g (m_3).

3.2.3.3 For coarse-grained soils

3.2.3.3.1 Clean and dry the container and weigh it to the nearest 1 g (m_1). Take a sample of at least 3 kg of soil, place loosely in the container and replace the lid. Weigh the container and contents to the nearest 1 g (m_2).

3.2.3.3.2 Remove the lid and place the container and contents in the oven and dry at 105 °C to 110 °C (see note 1 to 3.2.3.1.2). The period for drying will vary with the type of soil and the size of the sample but the sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see 3.2.3.3.3 and 3.2.3.3.4) at intervals of 4 h do not exceed 0.1 % of the original mass of the soil (see note 2 to 3.2.3.1.2). Do not replace the lid while the sample is in the oven.

3.2.3.3.3 After drying, replace the lid and allow the whole to cool.

3.2.3.3.4 Weigh the container and contents to the nearest 1 g (m_3).

3.2.4 Calculations and expression of results (See form 2.A of appendix A.)

Calculate the moisture content of the soil specimen, w , as a percentage of the dry soil mass to the nearest 0.1 %, from the equation:

$$w = \left(\frac{m_2 - m_3}{m_3 - m_1} \right) 100 \text{ (\%)}$$

where

m_1 is the mass of container (in g);

m_2 is the mass of container and wet soil (in g);

m_3 is the mass of container and dry soil (in g).

NOTE 1 If the moisture content is to be related to the Atterberg limits, e.g. for determining the liquidity index, and the soil contains material retained on a 425 µm sieve, the measured moisture content, w (in %), can be corrected to give the equivalent moisture content, w_a (in %), of the fraction passing the 425 µm sieve, using the equation:

$$w_a = w \left(\frac{100}{p_a} \right)$$

where

p_a is the percentage by dry mass of the portion of the soil sample passing the 425 µm test sieve, determined as specified in 4.2.4 and 4.2.5.

If the particles retained on the 425 µm sieve are porous and absorb water, the amount of absorption should be determined and the value of w_a calculated from the equation.

$$w_a = \frac{100}{p_a} w - w_r \left(\frac{100 - p_a}{p_a} \right)$$

where

w_r is the moisture content of the fraction retained on the 425 µm test sieve.

NOTE 2 The presence of dissolved salts in saline water gives an incorrect value of moisture content. For these soils the "fluid content" is more appropriate, i.e. the mass of pore fluid (water plus salts) per unit dry mass of soil particles. This can be calculated from the measured moisture content, w (in %), by the following two ways.

a) If the proportion by mass of salt in the fluid is known (p parts per thousand (ppt), i.e. p in mg of salt per g of fluid), the fluid content, w_f (in %), by mass is calculated from the equation:

$$w_f = \frac{1000}{1000 - p} \frac{w}{\left(1 + \frac{w}{100} \right)}$$

b) If the salt content is known in terms of volume (q in g of salt per litre of fluid), the density of the fluid, ρ_f (in Mg/m³), also needs to be known. The fluid content (in %) by volume can then be calculated from the equation:

$$w_f = \frac{1000}{1000 - \frac{q}{\rho_f}} \frac{w}{\left(1 + \frac{w}{100} \right)}$$

In sea water having a density of 1.024 Mg/m³ and containing a salt concentration of 35 ppt by mass, the difference between the fluid content and the conventional moisture content, expressed as a percentage, is about 3 %. The difference increases with increasing moisture content.

If the salt concentration in the water is not known it can be determined by the method given in clause 8 of BS 1377-3:1990.

Express the moisture content of the soil for values up to 10 % to two significant figures. For moisture contents above 10 % express the result to the nearest whole number.

3.2.5 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall contain the following information:

- a) the method of test used;
- b) the moisture content;
- c) the temperature at which the soil was dried, if less than 105 °C;
- d) the comparison with Atterberg limits, if required (see note 1 to 3.2.4);
- e) the fluid content, if appropriate (see note 2 to 3.2.4);
- f) the information required by clause 9 of BS 1377-1:1990.

3.3 Method for saturation moisture content of chalk

3.3.1 General. The saturation moisture content of intact chalk lumps can be used, together with the chalk crushing value, to classify chalk in relation to its behaviour as a freshly placed fill material. This test is based on the determination of the dry density of the chalk lump, using the "Immersion in water method", and the calculation from it of the potential moisture content at saturation, assuming a value of 2.70 Mg/m³ for the particle density of the chalk solids.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.3.2 Apparatus

3.3.2.1 A metal or plastics watertight container

3.3.2.2 A balance readable to 1 g.

3.3.2.3 A cradle and supporting frame similar in principle to that shown in Figure 8 which, with the frame attached to the scoop or platform of the balance, can support the cradle below the balance.

NOTE The arrangement of the cradle and supporting frame shown in Figure 8 has been found convenient but any other method which enables the specimen to be suspended in water, supported only by the scoop or platform of the balance above, would also be satisfactory. Adequate counterbalance weights should be placed on the supporting battens.

3.3.2.4 Equipment for melting paraffin wax, preferably thermostatically controlled.

3.3.2.5 Apparatus for moisture content determination as specified in 3.2.

3.3.3 Material. Paraffin wax as specified in 5.4.2 of Part 1 of this standard.

3.3.4 Adjustment of apparatus

3.3.4.1 Support the balance with the scoop or platform over the container and with at least 300 mm clear space between the underside of the supports and the top of the container. A suitable arrangement is shown in Figure 8.

3.3.4.2 Fill the container with water to within about 80 mm of the top. Then place it in a position below the balance, and adjust the cradle and supporting frame, so that the cradle is suspended in the water without touching either the bottom or the sides of the container. Ensure that the largest specimen to be tested will be immersed completely when on the cradle.

3.3.4.3 Place a counter-mass on the scale pan to bring the reading on the balance back to zero if necessary.

3.3.5 Procedure

3.3.5.1 Each sample to be tested shall consist of an intact lump of chalk, with a volume between 300 mL and 500 mL. Weigh the sample to the nearest 1 g (m_s).

3.3.5.2 Coat the specimen completely by repeated dipping in molten paraffin wax. Allow the waxed specimen to cool and weigh to the nearest 1 g (m_w).

NOTE 1 Waxing of the specimen should be carried out very carefully. Surface depressions, including cavities left by stones, should be first coated with molten wax applied by brush, and allowed to set before dipping. Ensure that air bubbles are not formed under the wax. Cavities considered to be parts of existing voids, e.g. in compacted soils, due to poor compaction, should be made up with filler before waxing.

NOTE 2 To avoid shrinking and cracking of the wax coating, the wax should be only just molten when applied. In the absence of a thermostatically controlled wax pot, use of a carpenter's glue pot helps to avoid overheating of the wax.

3.3.5.3 Place the waxed specimen in the cradle and suspend the cradle from the supporting frame attached to the scoop or platform of the balance. Record the apparent mass of the specimen while suspended in water to the nearest 1 g (m_g).

NOTE When the specimen is placed in the water, supported by the cradle, care should be taken to see that no air bubbles are trapped underneath the specimen. Also, while measuring the apparent mass when suspended in water, it should be ensured that the specimen is immersed completely. If this is not the case either the level of the water in the container should be raised or the supporting frame should be adjusted until the specimen is immersed completely. The specimen should then be removed from the cradle and the apparatus readjusted as specified in 3.3.4.2 and 3.3.4.3.

3.3.5.4 Remove the specimen from the cradle and carefully remove the paraffin wax. Determine the moisture content of the whole specimen, using the procedure specified in 3.2.

3.3.6 Calculations and expression of results (See form 2.B of appendix A.)

Calculate the volume of the test specimen, V_s (in cm^3), from the equation:

$$V_s = (m_w - m_g) - \frac{(m_w - m_s)}{\rho_p}$$

where

m_w is the mass of specimen and wax coating (in g);

m_g is the apparent mass of specimen and wax coating when suspended in water (in g);

m_s is the mass of the chalk specimen (in g);

ρ_p is the density of paraffin wax (in Mg/m^3).

NOTE The density of the wax can be determined by procedure 1 described in 7.2.

Calculate the bulk density of the specimen, ρ (in Mg/m^3), from the equation:

$$\rho = \frac{m_s}{v_s}$$

Calculate the dry density of the specimen, ρ_d (in Mg/m^3), from the equation:

$$\rho_d = \frac{100 \rho}{100 + w}$$

where

w is the moisture content of the chalk (in %)

Calculate the saturation moisture content, w_s (in %), from the equation:

$$w_s = 100 \left(\frac{1}{\rho_d} - \frac{1}{2.7} \right)$$

where

2.7 is the particle density of the chalk (in Mg/m^3).

Express the saturation moisture content for values up to 10 % to two significant figures. For saturation moisture contents above 10 % express the result to the nearest whole number.

3.3.7 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall contain the following information:

- the method of test used;
- the saturation moisture content;
- the information required by clause 9 of BS 1377-1:1990.

4 Determination of the liquid limit

4.1 General

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state. It provides a means of classifying a soil, especially when the plastic limit (see clause 5) is also known.

Two main types of test are specified. The first is the cone penetrometer method, which is fundamentally more satisfactory than the alternative because it is essentially a static test depending on soil shear strength. It is also easier to perform and gives more reproducible results. The second is the much earlier Casagrande type of test which has been used for many years as a basis for soil classification and correlation of engineering properties. This test introduces dynamic effects and is more susceptible to discrepancies between operators.

For both types of test an alternative rapid "one-point" procedure is given, which may give less accurate results.

The method of sample preparation is the same for all of these tests.

4.2 Sample preparation

4.2.1 General. Wherever possible the test shall be carried out on soil in its natural state. With many clay soils it is practicable and shall be permissible to remove by hand any coarse particles present, i.e. particles retained on a 425 μm test sieve. Otherwise these particles shall be removed by wet sieving as specified in 4.2.4.

In the definitive method the soil shall not be allowed to become dry before testing. Where air drying is required the method used shall be stated. Drying and breaking down procedures shall comply with 7.3.4, 7.3.5 and 7.4.3 of BS 1377-1:1990.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

4.2.2 Apparatus

4.2.2.1 Test sieves, of sizes 425 μm and 2 mm, with receiver.

4.2.2.2 Apparatus for determination of moisture content, as specified in 3.2.2.

4.2.2.3 A sharp knife.

4.2.2.4 An implement for shredding cohesive soil.

4.2.2.5 Two palette knives.

4.2.2.6 A corrosion-resistant airtight container, large enough to take 200 g to 300 g of wet soil.

4.2.2.7 A flat, glass plate, a convenient size being 10 mm thick and about 500 mm square.

4.2.2.8 A wash bottle containing distilled water complying with 5.1 of BS 1377-1:1990.

4.2.2.9 A corrosion-resistant container of 600 mL or 1 000 mL capacity.

4.2.2.10 A glass stirring rod.

4.2.3 Specimen from natural soil

4.2.3.1 From a soil in the natural state containing little or no material retained on a 425 µm test sieve, take a representative sample weighing about 500 g. Cut it into small pieces using a knife or shredder and remove any coarse particles by hand or with tweezers.

4.2.3.2 If coarse particles are present determine their mass and the mass of the sample used.

NOTE These weighings enable the approximate proportion of coarse material to be reported if required.

4.2.3.3 Transfer the soil to a flat glass plate. Add distilled water and mix thoroughly with two palette knives until the mass becomes a thick homogeneous paste.

4.2.3.4 Place the paste in an airtight container and allow to stand for about 24 h or for long enough to enable the water to permeate through the soil.

NOTE A maturing period of about 24 h is recommended for most soils but a shorter time may be acceptable for soils of low clay content. Very silty soils can be tested immediately after mixing.

4.2.4 Sieved specimen

4.2.4.1 Take a sample of the soil of sufficient size to give a test specimen weighing at least 300 g which passes the 425 µm test sieve.

4.2.4.2 From the sample take a representative specimen and determine its moisture content, w_n (in %), as specified in 3.2.

4.2.4.3 Weigh the remainder of the sample to an accuracy of within 0.01 g (m_6).

4.2.4.4 Place the weighed sample in a container under just enough distilled water to submerge it. A dispersant shall not be added. Stir the mixture until it forms a slurry.

4.2.4.5 Pour the slurry through a guard sieve or sieves nested in a 425 µm test sieve nested in a receiver. Use the minimum amount of additional distilled water to wash the fines through into the receiver, or into a large container if necessary, until the water passing the 425 µm test sieve is virtually clear.

4.2.4.6 Collect together the washed material retained on the sieves, dry it at 105 °C to 110 °C and weigh it to an accuracy of within 0.01 g (m_7).

4.2.4.7 Allow the fine soil particles in the wash water to settle and after a suitable interval pour off any clear water above the suspension.

4.2.4.8 Allow the suspension partially to dry in a current of warm air, protected from dust, until it forms a stiff paste. Alternatively, excess water may be removed by filtration under vacuum or pressure.

NOTE A suitable consistency corresponds to not more than 15 mm penetration of the cone penetrometer liquid limit apparatus, or not less than 50 blows of the Casagrande apparatus.

4.2.5 Calculations. For the sieved soil calculate the dry mass, m_d (in g), of the initial sample from the equation:

$$m_d = \left(\frac{100}{100 + w_n} \right) m_6$$

where

w_n is the moisture content (in %);

m_6 is the mass of the sample as determined in 4.2.4.3 (in g).

Calculate the percentage of particles passing the 425 µm test sieve, p_a , from the equation:

$$p_a = \left(\frac{m_d - m_7}{m_d} \right) 100 \%$$

where

m_7 is the mass of the sample as determined in 4.2.4.6 (in g).

4.3 Cone penetrometer method (definitive method)

4.3.1 General. This method covers the determination of the liquid limit of a sample of soil in its natural state, or of a sample of soil from which material retained on a 425 µm test sieve has been removed.

NOTE The method using the cone penetrometer is preferred to that employing the Casagrande apparatus (see 4.5), as the test is both easier to carry out and is capable of giving more reproducible results. The cone penetrometer apparatus is easier to maintain in correct adjustment and the test procedure is less dependent on the judgement of the operator. The results obtained with the cone penetrometer may differ slightly from those with the Casagrande apparatus, but in most cases up to a liquid limit of 100 these differences will not be significant and will be less than the normal variations likely to be obtained using the Casagrande apparatus.

The requirements of Part 1 of this standard, where appropriate shall apply to this test method.

4.3.2 Apparatus

4.3.2.1 A flat, glass plate, of which a convenient size is 10 mm thick and about 500 mm square.

4.3.2.2 Two palette knives or spatulas.

4.3.2.3 A penetrometer as used in bituminous material testing complying with BS 2000-49.

4.3.2.4 A cone of stainless steel or duralumin approximately 35 mm long, with a smooth, polished surface and an angle of $30 \pm 1^\circ$. To ensure that the point remains sufficiently sharp for the purposes of the test, the cone shall be replaced if, after continued use, the point can no longer be felt when brushed lightly with the tip of the finger when the tip of the cone is pushed through a hole 1.5 ± 0.02 mm in diameter, bored through a metal plate 1.75 ± 0.1 mm thick. The mass of the cone together with its sliding shaft shall be 80.00 ± 0.1 g (see Figure 1).

NOTE The effect of surface roughness is more significant than small variations in cone angle or bluntness of the tip.

4.3.2.5 One or more metal cups (55 ± 2) mm in diameter and (40 ± 2) mm deep with the rim parallel to the flat base.

4.3.2.6 An evaporating dish, of about 150 mm diameter.

4.3.2.7 Apparatus for moisture content determination of fine grained soils as specified in 3.2.2.

4.3.2.8 A wash bottle or beaker, containing distilled water complying with 5.1 of Part 1 of this standard.

4.3.2.9 A corrosion-resistant airtight container.

4.3.2.10 A metal straightedge about 100 mm long or a straight-bladed spatula.

4.3.2.11 A stopclock or stopwatch readable to 1 s.

4.3.3 Procedure

4.3.3.1 Take a sample of about 300 g from the soil paste prepared as specified in 4.2.3 (natural condition) or 4.2.4 (sieved soil) and place it on the glass plate.

4.3.3.2 Mix the paste for at least 10 min using the two palette knives. If necessary add more distilled water so that the first cone penetration reading is about 15 mm.

NOTE Some soils, e.g. clays of high plasticity and residual soils, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results. If in doubt comparative tests should be carried out.

4.3.3.3 Push a portion of the mixed soil into the cup with a palette knife taking care not to trap air. Strike off excess soil with the straightedge to give a smooth level surface.

4.3.3.4 With the penetration cone locked in the raised position lower the supporting assembly so that the tip of the cone just touches the surface of the soil. When the cone is in the correct position a slight movement of the cup will just mark the soil surface. Lower the stem of the dial gauge to contact the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm.

4.3.3.5 Release the cone for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device take care not to jerk the apparatus during this operation. After locking the cone in position lower the stem of the dial gauge to contact the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm. Record the difference between the beginning and end of the drop as the cone penetration.

4.3.3.6 Lift out the cone and clean it carefully to avoid scratching.

4.3.3.7 Add a little more wet soil to the cup, taking care not to trap air, make the surface smooth as in 4.3.3.3 and repeat 4.3.3.4 to 4.3.3.6.

4.3.3.8 If the difference between the first and second penetration readings is not more than 0.5 mm record the average of the two penetrations and proceed to 4.3.3.9.

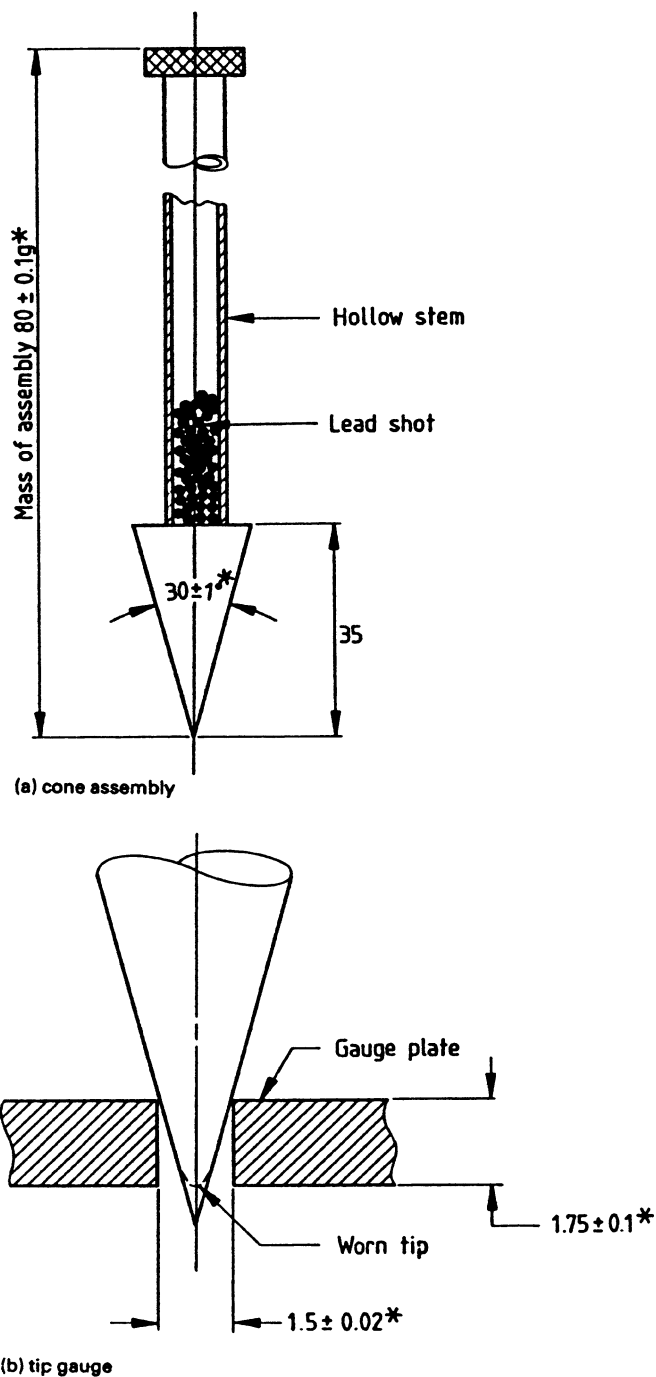
If the second penetration is more than 0.5 mm and less than 1 mm different from the first, carry out a third test. If the overall range is then not more than 1 mm record the average of the three penetrations and proceed to 4.3.3.9.

If the overall range is more than 1 mm remove the soil from the cup, remix and repeat 4.3.3.3 to 4.3.3.8 until consistent results are obtained and then proceed to 4.3.3.9.

4.3.3.9 Take a moisture content sample of about 10 g from the area penetrated by the cone and determine the moisture content as specified in 3.2.

4.3.3.10 Repeat 4.3.3.3 to 4.3.3.9 at least three more times using the same sample of soil to which further increments of distilled water have been added. Proceed from the drier to the wetter condition of the soil. The amount of water added shall be such that a range of penetration values of approximately 15 mm to 25 mm is covered by the four or more test runs and is evenly distributed. Each time soil is removed from the cup for the addition of water, wash and dry the cup.

4.3.3.11 If at any time during the above procedure the soil has to be left for a while on the glass plate cover the soil with the evaporating dish or a damp cloth to prevent the soil drying out.



All dimensions are in millimetres.

Figure 1 — Details of cone for liquid limit test

4.3.4 Calculations and expression of results
(See form 2.C of appendix A).

4.3.4.1 Calculate the moisture content of each test specimen as specified in 3.2.

4.3.4.2 Plot the relationship between moisture content and cone penetration with the percentage moisture contents as abscissae and the cone penetrations as ordinates, both on linear scales.

4.3.4.3 Draw the best straight line fitting the plotted points.

4.3.4.4 From the linear graph read off the moisture content corresponding to a cone penetration of 20 mm to one decimal place.

4.3.4.5 Express the moisture content corresponding to a cone penetration of 20 mm to the nearest whole number and report it as the liquid limit (w_L) of the soil sample.

4.3.4.6 Express the percentage of material passing the 425 μm test sieve correct to the nearest whole number (see 4.2.5).

4.3.5 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall contain the following information:

- a) the method of test used;
- b) the liquid limit;
- c) the percentage of material retained on the 425 μm test sieve;
- d) the history of the material, e.g. whether tested in the natural state, or after wet sieving or after any other process;
- e) the information required by clause 9 of BS 1377-1:1990.

4.4 One-point cone penetrometer method

4.4.1 General. This method enables the liquid limit of a soil sample to be determined from only one measurement of moisture content. This method enables a result to be obtained when only a small amount of soil is available.

NOTE 1 The one-point method using the cone penetrometer is likely to give results that are less reliable than those obtained from the four-point method (see 4.3), and is therefore suitable only where a possibly less accurate result is acceptable.

NOTE 2 If it is suspected that the liquid limit is higher than about 120 % the method specified in 4.3 should be followed using the appropriate size of sample.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

4.4.2 Apparatus. The apparatus shall be the same as that specified in 4.3.2.

4.4.3 Procedure

4.4.3.1 Take a sample of about 100 g from the soil paste prepared as specified in 4.2.3 (natural condition) or 4.2.4 (sieved soil) and place it on the glass plate.

NOTE For many soils the influence of curtailing or omitting the curing time introduces errors that are unlikely to be greater than those inherent in this rapid procedure.

4.4.3.2 Thoroughly mix the paste with distilled water using the two palette knives. Adjust the moisture content to that corresponding to a cone penetration of between 15 mm and 25 mm, and as close as possible to 20 mm. This may be checked with the cone penetrometer device if necessary. Mix for at least 10 min.

NOTE Some soils e.g. clays of high plasticity and residual soils, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results. If in doubt, comparative tests should be carried out.

4.4.3.3 Push a portion of the mixed soil into the cup with a palette knife, taking care not to trap air. Strike off excess soil with the straightedge to give a smooth surface.

4.4.3.4 With the cone locked in the raised position lower the supporting assembly so that the tip of the cone just touches the surface of the soil. When the cone is in the correct position a slight movement of the cup will just mark the soil surface. Record the reading of the dial gauge to the nearest 0.1 mm.

4.4.3.5 Release the cone for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device take care not to jerk the apparatus during this operation. After locking the cone in position lower the dial gauge to the new position of the cone shaft and note the reading to the nearest 0.1 mm. Record the difference between the beginning and end of the drop as the cone penetration.

4.4.3.6 Lift out the cone and clean it carefully to avoid scratching.

4.4.3.7 Add a little more wet soil to the cup, taking care not to trap air, make the surface smooth as specified in 4.4.3.3 and repeat 4.4.3.4 to 4.4.3.6.

4.4.3.8 Repeat 4.4.3.4 to 4.4.3.7 until two consecutive tests give cone penetration readings within 0.5 mm.

4.4.3.9 Remove the bulk of the soil, including the zone penetrated by the cone, from the cup. Place it in a suitable container and determine its moisture content as specified in 3.2.

4.4.4 Calculations and expression of results.

Calculate the moisture content of the test sample as specified in 3.2 and express the result to the first decimal place.

Obtain the factor corresponding to the cone penetration and the moisture content range from Table 1.

Calculate the liquid limit from the equation:

$$\text{liquid limit} = \text{moisture content} \times \text{factor}$$

and express the result to the nearest whole number.

4.4.5 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall contain the following information:

- a) the method of test used;
- b) the value of the liquid limit;
- c) the percentage of material retained on the 425 μm test sieve;

d) the history of the sample, e.g. whether tested in the natural state or after wet sieving or after any other process;

e) the information required by clause 9 of BS 1377-1:1990.

Table 1 — Factors for one-point cone penetrometer liquid limit test^a

Cone penetration mm	Factors for moisture content ranges		
	below 35 %	35 % to 50 %	above 50 %
15	1.057	1.094	1.098
16	1.052	1.076	1.075
17	1.042	1.058	1.055
18	1.030	1.039	1.036
19	1.015	1.020	1.018
20	1.000	1.000	1.000
21	0.984	0.984	0.984
22	0.971	0.968	0.967
23	0.961	0.954	0.949
24	0.955	0.943	0.929
25	0.954	0.934	0.909
Plasticity	low	intermediate	high

^a Reference: Clayton and Jukes, 1978

4.5 Casagrande apparatus method

4.5.1 General. This is an alternative method for the determination of the liquid limit of a sample of natural soil, or of a sample of soil from which material retained on a 425 µm test sieve has been removed.

NOTE The method using the Casagrande apparatus has been the accepted procedure for determining the liquid limit but experience has shown that it is difficult to maintain the apparatus in accordance with the standard and the results are subject to the judgement of the operator. For these reasons the method using the cone penetrometer is to be preferred, but provided that care is taken to ensure that the Casagrande apparatus is correctly maintained and the test procedure is strictly adhered to satisfactory results can be obtained. Results obtained using the Casagrande apparatus may differ slightly from those obtained from the cone method up to a liquid limit of 100 but in most cases these differences will not be significant and will be less than the normal variations likely to be obtained using the Casagrande apparatus. For liquid limits above 100 the cone method appears to give lower values.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

4.5.2 Apparatus

4.5.2.1 A flat, glass plate, of which a convenient size is 10 mm thick and about 500 mm square.

4.5.2.2 Two palette knives or spatulas.

4.5.2.3 A mechanical device complying with the essential details illustrated in Figure 2. The base shall be made of vulcanized rubber of hardness between 84° and 94° IRHD (International Rubber Hardness Scale D) and resilience between 20 % and 35 % at 20 ± 2 °C determined in accordance with BS 903. The formulation of the rubber shall be generally as specified in BS 1154 for type Z compounds but additional fillers, such as phenolic resin, can be used to produce the required hardness and resilience.

The hardness shall be determined at least once every 2 years by use of a hardness tester as specified in BS 903-A26 and the resilience by means of the Lupke pendulum apparatus as specified in BS 903-A8 whilst recognizing that the hardness is greater than 85° IRHD. Each test can be performed either on the full lamination thickness or on the full block thickness.

4.5.2.4 A grooving tool and gauge complying with the essential details illustrated in Figure 3.

NOTE The grooving tool should be withdrawn from use when the tip has worn to a width of 3 mm. It may be found useful to have a standard check gauge of the correct dimension against which the tool can be checked.

4.5.2.5 Apparatus for moisture content determination of fine grained soils as specified in 3.2.2.

4.5.2.6 A wash bottle or beaker, containing distilled water complying with 5.1 of BS 1377-1:1990.

4.5.2.7 A corrosion-resistant airtight container large enough to take 200 g to 250 g of wet soil.

4.5.3 Adjustment of apparatus. Inspect the liquid limit device, ensure that it is clean, dry and in good working order and that the cup falls freely and does not have excessive side play at its hinge. Inspect the grooving tool to ensure that it is clean, dry and that the critical dimensions are as shown in Figure 3 (see note to 4.5.2.4).

Adjust the height to which the cup of the liquid limit device is lifted so that when the cup is raised to its maximum height the 10 mm gauge will just pass between it and the base.

4.5.4 Procedure

4.5.4.1 Take a sample of about 300 g from the soil paste prepared as specified in 4.2.3 (natural condition) or 4.2.4 (sieved soil) and place it on the glass plate.

4.5.4.2 Mix the prepared paste for at least 10 min using the two palette knives. If necessary add more distilled water so that the first blow count (see 4.5.4.5) is about 50 blows.

NOTE Some soils, e.g. clays of high plasticity and residual soils, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results. If in doubt comparative tests should be carried out.

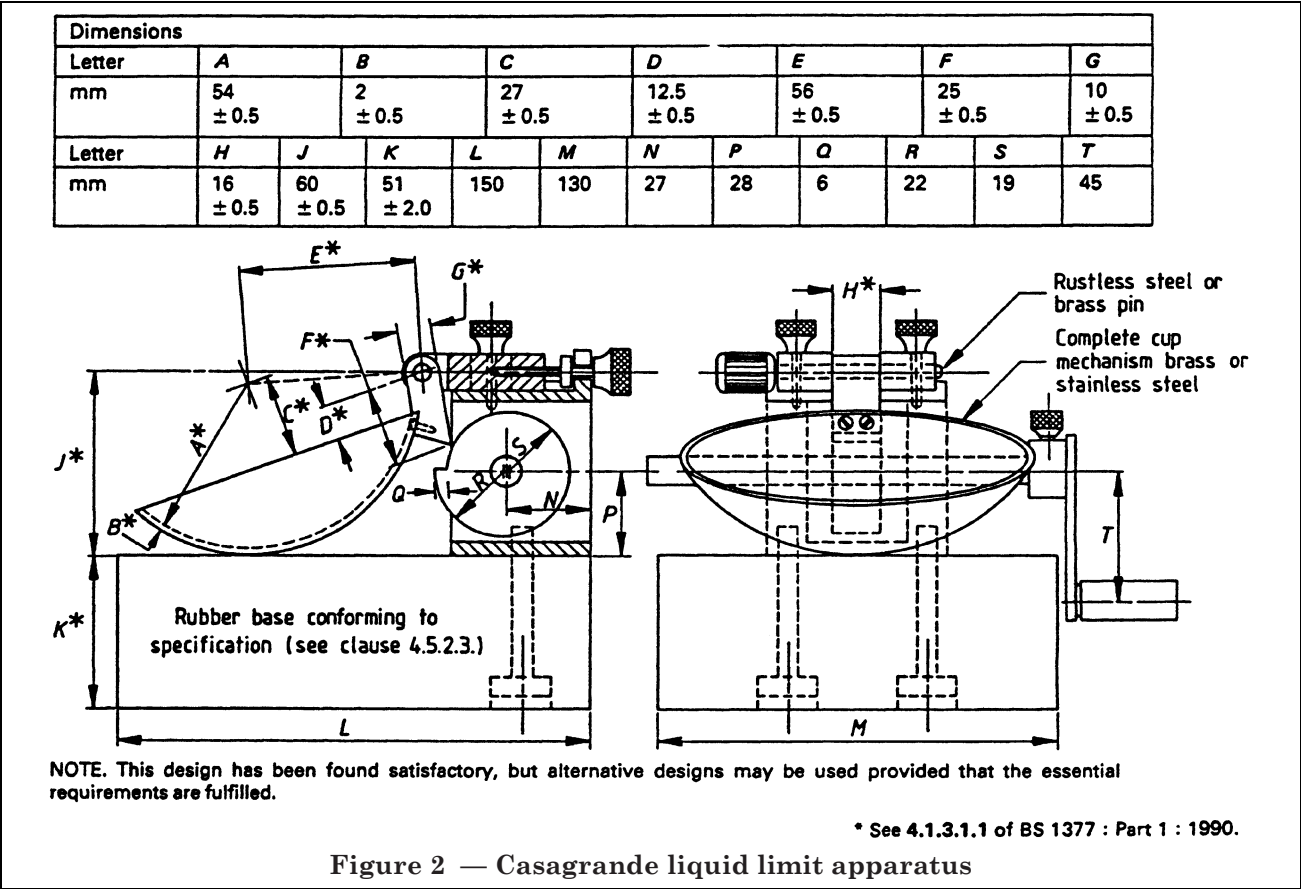


Figure 2 — Casagrande liquid limit apparatus

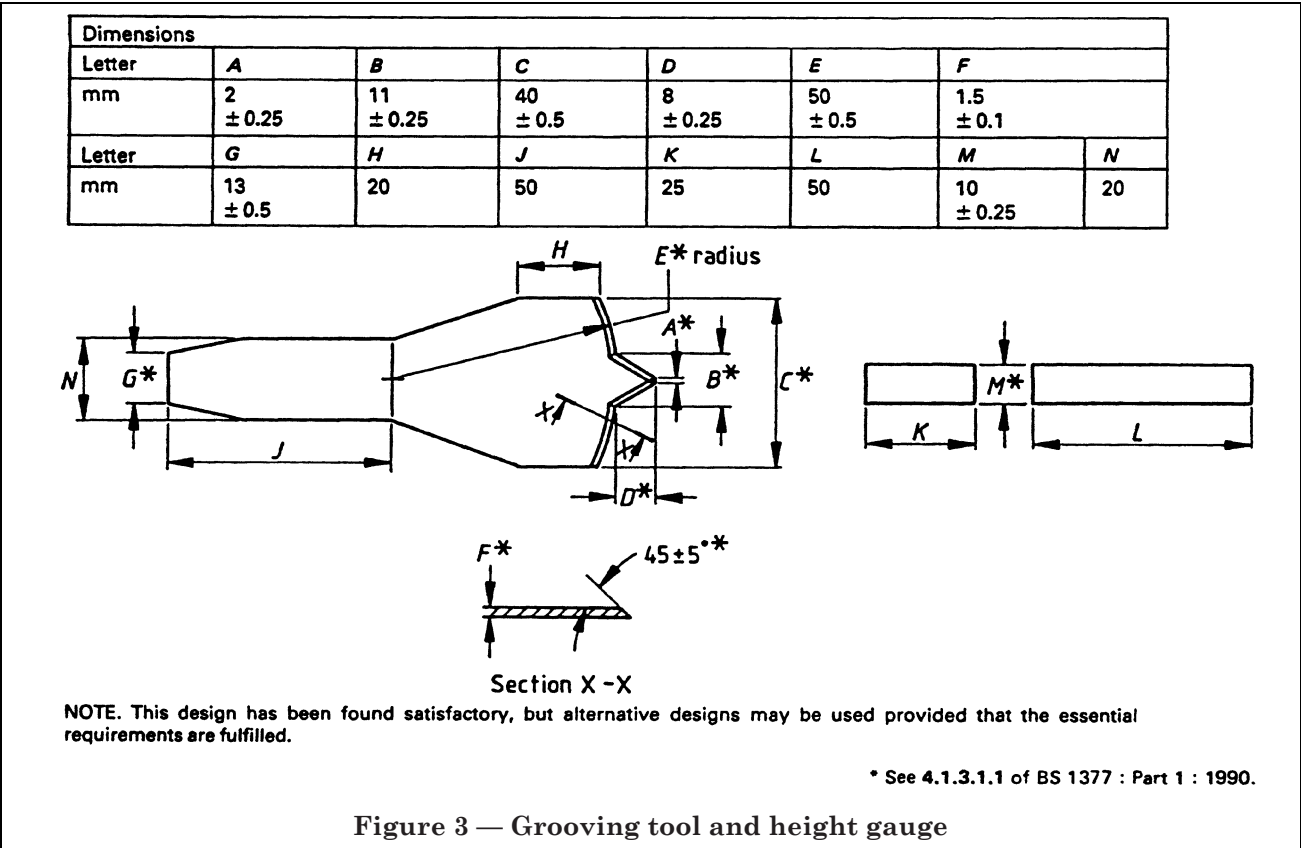


Figure 3 — Grooving tool and height gauge

4.5.4.3 With the cup of the apparatus resting on the base, place a portion of the mixed soil in the cup without entrapping air. Level off the soil surface parallel to the base.

4.5.4.4 Use the grooving tool to divide the soil into two equal parts by drawing the tool from the hinge towards the front in a continuous circular movement. Hold the grooving tool normal to the surface of the cup, with the chamfered edge facing the direction of movement.

NOTE With soils having low plasticity indices it is sometimes difficult to cut a smooth groove in the soil with the grooving tool. However, it does not necessarily follow that because a smooth groove cannot be obtained, the soil is non-plastic, and it should be recorded that the liquid limit could not be obtained by this method. The cone penetrometer method is the only practicable procedure for soils of this type.

4.5.4.5 Turn the crank handle at the rate of 2 r/s so that the cup is lifted and dropped, counting the number of bumps. Continue until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm, measured with the end of the grooving tool or with a ruler. Record the number of bumps at which this occurs.

NOTE Sometimes the soil flows so as to leave a gap between two areas of contact. The test should continue until there is a length of continuous contact for 13 mm.

4.5.4.6 Add a little more of the prepared soil from the glass plate and mix it with the soil in the cup.

4.5.4.7 Repeat **4.5.4.3** to **4.5.4.5** until two consecutive runs give the same number of bumps for closure.

NOTE 1 Some soils tend to slide on the surface of the cup instead of flow taking place within the soil. If this occurs the result should be discarded and the test repeated until flowing does occur. If, after additional increments of water, sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained by this method. The cone penetrometer method (see **4.3**) should be used instead.

NOTE 2 Care should be taken to see that the sample does not dry out between repeat tests as the number of blows for closure will increase gradually as the sample dries.

4.5.4.8 Take about 10 g of soil with a spatula from the portions of the sample that have just flowed together. Place the soil in a suitable container and determine the moisture content as specified in **3.2**.

4.5.4.9 Repeat **4.5.4.3** to **4.5.4.8** at least three more times using the same sample of soil to which further increments of distilled water have been added.

Proceed from the drier to the wetter condition of the soil. The amount of water added shall be such that when the four or more moisture contents are plotted they are evenly distributed over the range between 50 bumps to 10 bumps. Each time the soil is removed from the cup for the addition of water, wash and dry the cup and grooving tool.

4.5.4.10 If at any time during the above procedure the soil has to be left for a while on the glass plate, cover the soil with the evaporating dish or a damp cloth to prevent the soil drying out.

4.5.5 *Calculations and expression of results* (See form 2.D of appendix A.)

Calculate the moisture content of each test sample and express the result as specified in **3.2**.

Plot the relationship between the moisture content and the corresponding number of bumps on a semi-logarithmic chart, with the percentage moisture contents as ordinates on the linear scale and the number of bumps as abscissae on the logarithmic scale.

Draw the best straight line fitting the plotted points (the "flow curve").

From the flow curve read off the moisture content corresponding to the abscissa of 25 blows to the first decimal place.

Express this moisture content to the nearest whole number and report it as the liquid limit.

4.5.6 *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information:

- a) the method of test used;
- b) the value of the liquid limit;
- c) the percentage of material passing the 425 μm test sieve;
- d) the history of the sample, e.g. whether tested in the natural state or after wet sieving or after any other process.
- e) the information required by clause 9 of BS 1377-1:1990.

4.6 One-point Casagrande method

4.6.1 *General.* This method enables the liquid limit of a soil sample to be determined from only one measurement of moisture content. This method enables a result to be obtained when only a small amount of soil is available.

NOTE 1 The one-point method using the Casagrande apparatus is likely to give results that are less reliable than those obtained from the four-point method of **4.5** and is therefore suitable only where a possibly less accurate result is acceptable.

NOTE 2 If it is suspected that the liquid limit is higher than about 120 % the procedure given in **4.3** or **4.5** should be followed using the appropriate size of sample.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

4.6.2 *Apparatus.* The apparatus shall be the same as that specified in **4.5.2**.

4.6.3 *Adjustment of apparatus.* The apparatus shall be adjusted as specified in **4.5.3**.

4.6.4 Procedure

4.6.4.1 Take a sample of about 100 g from the soil paste prepared as specified in **4.2.3** (natural condition) or **4.2.4** (sieved soil) and place it on the glass plate.

NOTE For many soils the influence of curtailing or omitting the curing time introduces errors that are unlikely to be greater than those inherent in this procedure.

4.6.4.2 Thoroughly mix the paste with distilled water using the two palette knives. Adjust the moisture content to that corresponding to the value for between 15 bumps and 35 bumps of the Casagrande machine and as close as possible to 25 bumps. This may be checked with the machine if necessary. Mix for at least 10 min.

NOTE 1 As can be seen from Table 2 the nearer the moisture content is to that at 25 bumps the less is the error due to the variation of the slope of the flow line from the slope of the calculated line obtained from the equation:

$$w_L = w \left(\frac{n}{25} \right)^{\tan B}$$

where

w_L is the liquid limit (in %);

w is the moisture content corresponding to n blows (in %);

$\tan B = 0.092$ (the slope of the calculated flow line relating $\log(w_L)$ to $\log(w)$ for British soils).

NOTE 2 The amount of distilled water added should be such that the number of bumps is less rather than more than 25 because during mixing and placing some moisture tends to evaporate causing the soil to be drier when actually tested.

NOTE 3 Some soils, e.g. clays of high plasticity and residual soils, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results. If in doubt comparative tests should be carried out.

4.6.4.3 With the cup of the apparatus resting on the base, place a portion of the mixed soil in the cup without entrapping air. Level off the soil surface parallel to the base.

4.6.4.4 Use the grooving tool to divide the soil into two equal parts by drawing the tool from the hinge towards the front in a continuous circular movement. Hold the grooving tool normal to the surface of the cup, with the chamfered edge facing the direction of movement.

NOTE With soils having low plasticity indices it is sometimes difficult to cut a smooth groove in the soil with the grooving tool specified. However, it does not necessarily follow that because a smooth groove cannot be obtained the soil is non-plastic, and it should be recorded that the liquid limit could not be obtained by this method. The cone penetrometer method is the only practicable procedure for soils of this type.

4.6.4.5 Turn the crank handle at the rate of 2 r/s so that the cup is lifted and dropped, counting the number of bumps. Continue until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm, measured with the end of the grooving tool or with a ruler. Record the number of bumps at which this occurs. The number shall be between 15 bumps and 35 bumps.

NOTE Sometimes the soil flows so as to leave a gap between two areas of contact. The test should continue until there is a length of continuous contact for 13 mm.

4.6.4.6 Add a little more of the prepared soil from the glass plate and mix it with the soil in the cup.

4.6.4.7 Repeat **4.6.4.3** to **4.6.4.5** until two consecutive runs give the same number of bumps for closure.

NOTE 1 Some soils tend to slide on the surface of the cup instead of flow taking place within the soil. If this occurs the result should be discarded and the test repeated until flowing does occur. If, after additional increments of water, sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained by this method.

NOTE 2 Care should be taken to see that the sample does not dry out between repeat tests as the number of bumps for closure will increase gradually as the sample dries.

4.6.4.8 Remove the bulk of the soil from the cup and place it in a suitable container and determine its moisture content as specified in **3.2**.

4.6.5 Calculations and expression of results.

Calculate the moisture content of the test sample as specified in **3.2** to the first decimal place.

Obtain the factor corresponding to the number of bumps obtained in the test from Table 2.

Calculate the liquid limit from the equation:

Liquid limit = moisture content $\times$ factor
and express the result to the nearest whole percentage number.

4.6.6 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall include the following:

- the method of test used;
- the value of the liquid limit;
- the percentage of material passing the 425 μm test sieve;
- the history of the sample, e.g. whether tested in the natural state, after wet sieving or after any other process;
- the information required by clause 9 of BS 1377-1:1990.

Table 2 — Factors for one-point Casagrande liquid limit test

Number of bumps	Factor	Number of bumps	Factor	Number of bumps	Factor	Number of bumps	Factor
15	0.95	21	0.98	26	1.00	31	1.02
16	0.96	22	0.99	27	1.01	32	1.02
17	0.96	23	0.99	28	1.01	33	1.02
18	0.97	24	0.99	29	1.01	34	1.02
19	0.97	25	1.00	30	1.02	35	1.03
20	0.98						

5 Determination of the plastic limit and plasticity index

5.1 General

The plastic limit is the empirically established moisture content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart (see BS 5930) provides a means of classifying cohesive soils. It is recognized that the results are subject to the judgement of the operator, and that some variability in results will occur.

5.2 Sample preparation

Samples for test shall be prepared as specified in 4.2. The soil shall not be allowed to become dry before testing. Where air drying is required the method used shall be stated. Drying and breaking down procedures shall comply with 7.3.4, 7.3.5 and 7.4.3 of BS 1377-1:1990.

It is convenient to carry out the test on a portion of the material prepared for one of the liquid limit test procedures specified in clause 4.

5.3 Method for plastic limit

5.3.1 General. This method covers the determination of the plastic limit of a soil sample, i.e. the lowest moisture content at which the soil is plastic. The sample shall be of soil in its natural state, or of soil from which material retained on a 425 μm test sieve has been removed.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

5.3.2 Apparatus

5.3.2.1 A flat, glass plate, as specified in 4.3.2.1, on which the soil is mixed.

5.3.2.2 A flat, glass plate, smooth and free from scratches, on which threads are rolled. A convenient size of plate is about 10 mm thick and 300 mm square.

NOTE The condition of the surface of the glass plate affects the behaviour of the rolled threads. Mixing of soil containing silica particles inevitably scratches a glass surface. Use of a separate unscratched glass plate for the rolling operation will reduce discrepancies due to this effect.

5.3.2.3 Two palette knives or spatulas.

5.3.2.4 Apparatus for the moisture content determination of fine-grained soils as specified in 3.2.2.

5.3.2.5 A length of rod, 3 mm in diameter and about 100 mm long.

5.3.3 Procedure

5.3.3.1 Take a sample of about 20 g from the soil paste prepared as specified in 4.2.3 (natural condition) or 4.2.4 (sieved soil) and place it on the glass mixing plate.

5.3.3.2 Allow the soil to dry partially on the plate until it becomes plastic enough to be shaped into a ball.

5.3.3.3 Mould the ball of soil between the fingers and roll it between the palms of the hands until the heat of the hands has dried the soil sufficiently for slight cracks to appear on its surface. Divide this sample into two subsamples of about 10 g each and carry out a separate determination on each portion. Divide each subsample into four more or less equal parts and treat each part as specified in 5.3.3.4 to 5.3.3.8.

5.3.3.4 Mould the soil in the fingers to equalize the distribution of moisture, then form the soil into a thread about 6 mm diameter between the first finger and thumb of each hand.

5.3.3.5 Roll the thread between the fingers, from finger-tip to the second joint, of one hand and the surface of the glass rolling plate. Use enough pressure to reduce the diameter of the thread to about 3 mm in five to 10 complete, forward and back, movements of the hand. Some heavy clays will require 10 to 15 movements when the soil is near the plastic limit because the soil hardens at this stage. It is important to maintain a uniform rolling pressure; do not reduce the pressure as the thread diameter approaches 3 mm.

5.3.3.6 Pick up the soil, mould it between the fingers to dry it further, form it into a thread and roll it out again as specified in **5.3.3.5**.

NOTE Gradually drying of the soil is effected by alternately rolling and moulding, not by continual rolling, either as a ball or as threads, which produces a dried crust.

5.3.3.7 Repeat **5.3.3.6** until the thread shears both longitudinally and transversely when it has been rolled to about 3 mm diameter, as gauged by the rod. Do not gather the pieces of soil together after they have crumbled, in order to reform a thread and to continue rolling; the first crumbling point is the plastic limit.

NOTE With soils that are marginally plastic it is often difficult to obtain the correct crumbling condition.

5.3.3.8 Gather together the portions of the crumbled soil thread, transfer them to a suitable container and replace the lid immediately.

5.3.3.9 Repeat **5.3.3.4** to **5.3.3.8** on the other three portions of soil, placing them all in the same container. Determine the moisture content of the soil in the container as specified in **3.2**.

5.3.3.10 Repeat **5.3.3.3** to **5.3.3.9** on the duplicate sample formed in **5.3.3.3**.

5.3.4 Calculations and expression of results
(Form 2.C or form 2.D of appendix A may be used.)

Calculate the moisture content of both samples by testing in accordance with the method described in **3.2** but utilizing the samples obtained from **5.3.3**.

If the two results differ by more than 0.5 % moisture content, repeat the whole test.

Calculate the average of the two moisture content values and express the value to the nearest whole number. This is the plastic limit.

5.3.5 Test report. The test report shall affirm that the test was carried out in accordance with BS 1377-2:1990 and shall include the following information:

- a) the method of test used;
- b) the plastic limit of the soil sample;
- c) the percentage of material passing the 425 µm test sieve;
- d) the history of the sample, e.g. whether tested in the natural state, or after wet sieving or after any other process;
- e) The information required by clause 9 of BS 1377-1:1990.

If it is not possible to determine the plastic limit this fact shall be reported.

5.4 Derivation of plasticity Index and liquidity Index

5.4.1 General. This method covers the determination of the plasticity index and the liquidity index of a soil.

5.4.2 Procedure. Determine the moisture content, w_a , of the fraction passing a 425 µm test sieve of the sample of soil in its natural condition by one of the procedures specified in clause 3. (See note to **3.2.4**.)

Determine the liquid limit, w_L , by one of the procedures specified in clause 4, and the plastic limit, w_p , by the procedure specified in **5.3**.

5.4.3 Calculations. Calculate the plasticity index, I_p , from the equation:

$$I_p = w_L - w_p$$

Calculate the liquidity index, I_L , from the equation:

$$I_L = \frac{w_a - w_p}{I_p}$$

6 Determination of shrinkage characteristics

6.1 General

6.1.1 Objective. Shrinkage due to drying is significant in clays but less so in silts and sands. These tests enable the shrinkage limit, w_s , of clays to be determined, i.e. the moisture content below which a clay ceases to shrink. They also provide ways of quantifying the amount of shrinkage likely to be experienced by clays, in terms of the shrinkage ratio, volumetric shrinkage and linear shrinkage.

These factors are also relevant to the converse condition of expansion due to wetting.

6.1.2 Types of test. Three types of test are specified. The first is the definitive method in which volumetric measurements are made on a cylindrical specimen, usually of undisturbed soil, as it is allowed to dry. The second is the subsidiary method, in which disturbed soil is mixed to a paste with water to form a small pat for the same purpose. Both procedures enable the shrinkage limit of the soil, the shrinkage ratio, and the volumetric shrinkage for a given change of moisture content, to be determined. In the third test only the total linear shrinkage of a soil paste is measured.

The second and third procedures are carried out on the fraction of the soil sample passing a 425 µm test sieve.

6.2 Sample preparation

The cylindrical specimen for the test specified in **6.3** shall be prepared by one of the procedures specified in clause 7 of BS 1377-1:1990 depending on whether the specimen is to be of undisturbed, remoulded or compacted soil, and the type or size of the original sample.

Samples for the tests specified in 6.4 and 6.5 shall be prepared in the same way as specified in 4.2. Wherever possible, soil in the natural state shall be used and particles larger than 425 μm shall be removed by hand.

In the definitive method the soil shall not be allowed to become dry before testing. Where air drying is required the method used shall be stated. Drying and breaking down procedures shall comply with 7.3.4, 7.3.5 and 7.4.3 of BS 1377-1:1990.

6.3 Volumetric shrinkage (definitive method)

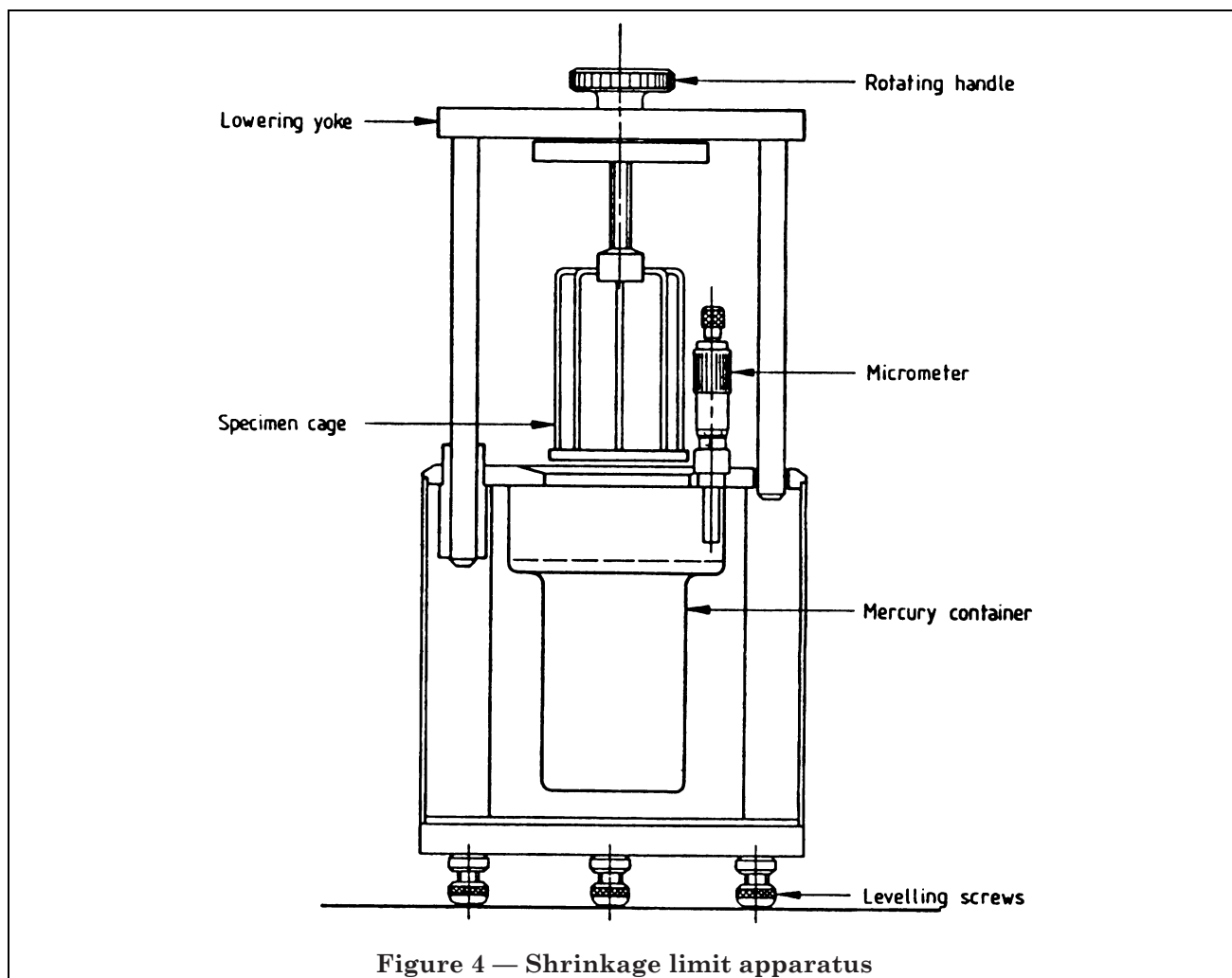
6.3.1 General. This test covers the determination of the shrinkage limit of a cylindrical specimen of undisturbed or remoulded soil by measuring its volume as its moisture content decreases from the initial value and plotting the shrinkage curve. The soil specimen is ideally of 38 mm to 51 mm diameter, with a length of between 1 diameter and 2 diameters.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

6.3.2 Apparatus

6.3.2.1 Shrinkage limit apparatus, of the type shown in Figure 4. The essential features are as follows:

- immersion tank for containing mercury;
- wire cage for enclosing the specimen;
- micrometer measuring device, readable to 0.01 mm, complying with 4.2.1.3 of BS 1377-1:1990.
- electrical circuit with battery, indicator lamp and platinum contact mounted on the tip of the micrometer stem, such that contact with the mercury surface completes the circuit and lights the lamp;
- circuit test switch;
- levelling screws on the base, and circular levelling bubble;
- dished top surface, to allow spilt droplets of mercury to run back into the tank.



6.3.2.2 Mercury metal, sufficient to fill the tank of the apparatus to the required level.

WARNING: Mercury is a hazardous substance and the appropriate precautionary measures should be taken when using it. Reference should be made to current Government regulations and to Guidance Note MS 12, Health & Safety Executive: Mercury — medical surveillance (HMSO, June 1979). Operations involving the use of mercury should be carried out in a fume cupboard or in the vicinity of an air-extractor fan so that any mercury vapour can be removed immediately.

Adequate provision should be made for the removal of vapour from the drying oven.

6.3.2.3 Tray containing a little water, on which to stand the apparatus so that any spilled mercury can be retained.

6.3.2.4 Balance readable to 0.01 g.

6.3.2.5 Watch glass.

6.3.2.6 Tongs for lifting the specimen.

6.3.2.7 Small brush, for brushing droplets of mercury.

6.3.2.8 Apparatus for determination of moisture content as specified in 3.2.

6.3.2.9 Mould or tube for forming the test specimen, and suitable cutting and trimming tools, as specified in 8.2.1 and 8.2.3 of BS 1377-1:1990.

6.3.2.10 Rubber gloves.

6.3.3 Preparation of apparatus

6.3.3.1 Determine the internal diameter, D , of the mercury tank to 0.1 mm.

6.3.3.2 Place the apparatus on a firm bench, situated in a fume cupboard or in the vicinity of an air-extractor fan.

6.3.3.3 Level the apparatus by means of the base adjusting screws.

6.3.3.4 Add mercury carefully to the tank, to the required depth.

6.3.3.5 Readjust the apparatus if necessary to ensure that it remains level.

6.3.3.6 Use the test switch to check the electrical circuit.

6.3.3.7 Lower the cage into the mercury tank until it is completely submerged, and rotate it a few times to dislodge any air bubbles.

6.3.3.8 Adjust the micrometer until the platinum contact just touches the surface of the mercury, as indicated by the indicator lamp.

6.3.3.9 Record the reading of the micrometer as the zero reading, M_0 (in mm).

6.3.3.10 Raise the cage out of the tank and raise the micrometer adjustment.

6.3.4 Preparation of the specimen. Prepare the cylindrical specimen by one of the methods specified in clause 8 of BS 1377-1:1990.

Measure the initial length and diameter of the specimen to the nearest 0.01 mm, as specified in 7.2.4. Record the average values of length, L_1 , and diameter, D_1 .

NOTE These measurements provide a check on the volume measurements obtained from the shrinkage limit apparatus, but are not essential.

Weigh the specimen to 0.01 g, and record it as the initial mass, m_1 .

6.3.5 Test procedure

6.3.5.1 Place the soil specimen in the cage of the shrinkage limit apparatus and lower the cage until it is completely immersed in the mercury. Rotate the cage a few times to dislodge any air bubbles.

6.3.5.2 Adjust the micrometer so that contact with the mercury is just made, lighting the lamp.

6.3.5.3 Record the micrometer reading, M (in mm), and calculate the difference between M and the zero reading, M_0 .

6.3.5.4 Raise the cage, remove the specimen and carefully brush off any droplet of mercury back into the tank.

6.3.5.5 Weigh the specimen immediately to 0.01 g (m).

6.3.5.6 Place the specimen on a watch glass and leave it standing exposed to the air at room temperature for about 2 h so as to dry partially.

6.3.5.7 Repeat 6.3.5.1 to 6.3.5.6, determining the zero reading each time as described in 6.3.3.7 to 6.3.3.10, and obtain sets of micrometer readings and the corresponding mass. Continue until three successive differences in micrometer readings show no change with reducing mass.

NOTE 1 At this point the soil will normally take on a lighter colour.

NOTE 2 The drying process may take several days. It should not be hurried, e.g. by oven drying, otherwise cracks may develop in the specimen. Mercury may not fully penetrate very fine cracks, which would give a false reading of volume. Wider cracks may fill with mercury which could remain entrapped, giving a false mass.

NOTE 3 If necessary cover the specimen with a damp cloth under a polyethelene sheet to prevent too much loss of moisture overnight.

6.3.5.8 When no further shrinkage is taking place, dry the specimen to constant mass at 105 °C to 110 °C.

NOTE The oven and its surroundings should be adequately ventilated to eliminate any mercury vapour.

6.3.5.9 Cool the dried specimen in a desiccator and weigh it to 0.01 g (m_d).

6.3.5.10 Immerse the dry specimen in the mercury tank and determine the micrometer reading, M_d , as specified in 6.3.5.1 to 6.3.5.4.