Geospec 3

Model Specification for Soil Testing

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Foreword

This Geospec presents the recommended standard methods for testing of soils in Hong Kong for civil engineering purposes.

Since 1992, the Geotechnical Engineering Office (GEO) has carried out a two-phase review of the soil testing methods with the aim to produce standard methods for testing of soils in Hong Kong for civil engineering purposes. The first phase of the review covered the soil classification and compaction tests (the Phase I tests) and was published in GEO Report No. 36 in 1994. The second phase of the review covered the soil shear strength and compressibility tests (the Phase II Tests), as well as additional tests akin to the Phase I tests. The review has now been completed. The recommended standard methods for all Phase I and Phase II tests are included in this Geospec, which supersedes GEO Report No. 36.

This Geospec is divided into three parts. Part I gives general and technical guidance on planning and supervising laboratory tests, to ensure that quality test results are obtained. Part II and Part III provide detailed technical procedures for individual tests.

The technical standards presented in this Geospec are mainly based on BS 1377 (BSI, 1990). With the permission of the British Standards Institute, extracts from BS 1377 (BSI, 1990) and other British Standards have been incorporated into this Geospec.

To ensure that this Geospec would be considered as a consensus document in Hong Kong, a draft version of this Geospec was widely circulated to interested parties and experts both locally and overseas. Many useful comments were received, and they have been taken into account in finalising the Geospec. All contributions are gratefully acknowledged.

This document was prepared largely by Ir Philip W K Chung, Ir Dr Richard P L Pang and Ir C K Cheung. Editing of the document was assisted by Ir B N Leung and Dr L S Cheung in the early stage, and was later taken over by Ir Jenny F Yeung and Ir M Y Ho. Ir Y C Chan provided general supervision during the final stage of the document preparation.

Practitioners are encouraged to comment at any time to the GEO on the contents of this Geospec, so that improvements can be made to future editions.

R.K.S. Chan
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Part I

1 Introduction

1.1 Background

The current international standards for soil testing are based on classical soil mechanics, which has been developed mainly for sedimentary, transported and re-deposited soils. Modifications of these standards are needed for use on tropical soils formed by in-situ weathering of rock.

In the early 1990s, the Geotechnical Engineering Office (GEO) embarked on a study of BS 1377 : 1990 (BSI, 1990), with a view to adapting it for use in Hong Kong. As a result, GEO Report No. 36 (GEO, 1996), which describes recommended procedures for nineteen “Phase I soil tests”, was issued.

GEO Report No. 36 (GEO, 1996) subsequently became the standard reference specified by the Works Bureau (Hong Kong Government, 1994) and the Building Department (Hong Kong Government, 1996). The document has also been adopted by the Hong Kong Accreditation Service (HKAS) for laboratory accreditation of the Phase I soil tests under the Hong Kong Laboratory Accreditation Scheme (HOKLAS).

In response to the need of the profession for a standard reference that can cover a comprehensive range of soil tests, in the late 1990s GEO carried out a second phase of study to expand the scope of the Phase I soil tests and to include the soil shear strength and compressibility tests (viz. the “Phase II soil tests”).

This Geospec contains thirty-two standard procedures for Phase I tests and seven standard procedures for Phase II tests. The standard test procedures mainly follow BS 1377 : 1990 (BSI, 1990), modified for use in Hong Kong. The objective of this Geospec is to give guidance on good practice and complete description of the modified procedures of soil testing.

Laboratories may seek HOKLAS accreditation from HKAS on the Phase I and Phase II soil tests in accordance with this Geospec. Specifiers may specify modifications to these standard procedures in order to suit his own design or research needs. However, the resulting non-standard procedures are unlikely to be readily accepted by the relevant authorities. HKAS may accredit non-standard test methods provided that they are verified and validated in accordance with Clause 5.4.4 of HOKLAS 003 (HKAS, 2000).

1.2 Definitions and Terminology

Unless otherwise specified, British Standards referred to in this document are the latest version issued by the British Standards Institute (BSI); the terminology for the soil description shall follow Geoguide 3: Guide to Rock and Soil Descriptions (GCO, 1988). Other terms used in this Geospec are defined as follows:

AS-RECEIVED STATE of a soil sample is the state of the sample when the laboratory first receives it. The sample must be stored in such a way that it preserves the as-received state as far as possible before tested in the laboratory.

COARSE-GRAINED SOILS are soils for which more than 10% by weight are retained on a 20 mm test sieve, but not more than 10% by weight are retained on a 37.5 mm test sieve. Soils with more than 10% of materials retained on a 37.5 mm test sieve cannot be meaningfully tested by the methods described in this Geospec. MEDIUM-GRAINED SOILS are soils of particles not larger than 37.5 mm, more than 10% by weight are retained on a 2 mm test sieve but not more than 10% by weight are retained on a 20 mm test sieve. FINE-GRAINED SOILS are soils of particles not larger than 20 mm, and not more than 10% by weight are retained on a 2 mm test sieve.

COHESIVE SOILS are soils that will form a coherent mass at suitable moisture contents by virtue of their fine-grained content, e.g. clays. COHESIONLESS or GRANULAR SOILS are soils consisting of particles that can be identified individually by the naked eye or with the aid of a hand lens, e.g. gravels and sands.

DRYING means

(a) drying to a constant mass in an oven maintained at a temperature of 45 ± 5°C, or

(b) drying to a constant mass in an oven maintained at a temperature of 105 ± 5°C, or

(c) air-drying at room temperature or oven drying at a temperature ≤ 50°C.

SAMPLE refers to a portion of the materials to be tested, taken as being representative of the material. SPECIMEN refers to a portion of a sample on which a test is carried out.

SAPROLITIC SOILS or SAPROLITES are soils derived from in-situ weathering of rock, and which retain the original texture, fabric and structure of the parent rock. RESIDUAL SOILS are soils derived from in-situ weathering of rock, and which do not contain any traces of the original texture, fabric and structure of the parent rock. COLLUVIAL SOILS or COLLUVIUM are formed by slipping, flowing or rolling of earth materials down slopes under the action of gravity.

SPECIFIERS are the persons or parties who request laboratory tests. HOKLAS 003 (HKAS, 2000) uses the term clients instead of Specifiers, the two terms are synonymous in this Geospec.

2 General Guidance to Specifiers

2.1 General

This Clause provides general guidance to the Specifiers who may find it useful to read the Clause carefully before ordering any soil tests from a laboratory.

2.2 Planning for Testing during Ground Investigation

Modern civil and geotechnical engineering projects rely upon the use of standard tests to determine the engineering properties of soils. Soil classification, compaction, consolidation and shear strength tests are often specified as part of the ground investigation for these projects. It is therefore a good practice to plan for the soil testing early as part of the planning for the ground investigation. This would assist in ensuring that sufficient soil sample of suitable quality is collected and that sufficient time is allowed for the soil testing.

When planning for soil testing, it is useful to carry out a preliminary analysis of the problem at hand, so as to determine the scope and quantity of the testing. It would be useful for the Specifier to consider carefully the nature and type of projects in terms of their importance or the consequence of a failure or non-performance. Further guidance can be found in Part 1 of Eurocode 7 (Eurocode, 1994), which describes three geotechnical categories structures. Part 2 of Eurocode 7 (Eurocode, 1999) provides further guidance on the quantity of the testing required.

In general, more tests should be carried out where the test results are sensitive to the problem and the ground is variable. On the other hand, when the ground is uniform, the scope of testing can be reduced by making good use of index tests. For example, if the soil compressibility and shear strength parameters can be correlated to classification test results, consolidation and strength tests may be carried out only on selected representative samples, while classification tests are carried out to assess soil variability.

Cost consideration should always be a secondary factor in determining the scope of soil testing. Usually, the cost of testing is relatively small compared to that of a ground investigation, which in turn is relatively small compared to that of a project. Nevertheless, avoiding excessive and unnecessary tests ensures the effective use of resources. This may be achieved by systematically considering how the results of each test will be used in the design. Readily available test results on similar soils help to reduce the scope of testing. In particular, use of correlations or data from adjacent sites may provide additional information. For large projects which requires detailed investigation of a number of sites in the same area, an integrated approach is recommended.

Where soil testing is justified for a project, sufficient tests for each type of soil should be ordered. The soil parameters obtained from a test are relevant to the soil specimens tested only. To carry out a quantitative assessment of the in-situ behaviour of the ground mass, testing of sufficient numbers of representative samples from each of the significant geological units is needed to provide relevant parameters for analysis. The zoning of the ground mass for characterisation and for selection of representative samples may depend on the thickness of the geological units, stress range, initial consistency and density and other environmental variability. It is a good practice to take additional samples for duplicate tests on similar materials to check the consistency of test results.

In specifying the sampling methods during ground investigation, the quality of samples and the size of test specimens required for the laboratory tests should be considered. The accuracy of Phase II test results depends critically on the sample quality. Reference should be made to Tables 8 and 9 of Geoguide 2 (GCO, 1987) on expected sample quality for different sampling procedures and materials. Full-time supervision during sampling is recommended.

The Specifiers are recommended to review their soil testing plan after examination of the soils retrieved from the ground. It is important to check that the samples retrieved will allow good quality test specimens that are representative of the soils to be prepared. Additional tests should be ordered if high variability of the ground mass is revealed by the ground investigation. If the test results turn out to be inadequate, the designer may have to adopt conservative assumptions to minimise the risk of uncertainties in the design, which could result in higher construction costs for the project.

Adequate time should be allowed for soil testing in project planning. Phase II soil tests normally take longer time to complete, especially for soils of low permeability.

In general, planning for soil testing requires geotechnical knowledge and judgement and should be carried out by a qualified professional geotechnical engineer or engineering geologist.

2.3 Selection of Laboratories

In Hong Kong, the technical competence of laboratories may be assessed by the Hong Kong Accreditation Service (HKAS) under the Hong Kong Laboratory Accreditation Scheme (HOKLAS). HOKLAS accredits a laboratory for performing a test after an assessment that confirms the laboratory has a quality management system that meets international or national (or government specified) standards, and that it has the technical capability of conducting the test to obtain accurate and reliable results. Accreditation is on a test-by-test basis: a laboratory accredited to carry out Test A may not be accredited to carry out Test B.

A laboratory accredited to carry out a particular test can issue a HOKLAS endorsed test report only when the test has been performed in accordance with the terms and conditions of the accreditation. Specifiers should order tests from laboratories accredited for the tests, where such laboratories are available, and require HOKLAS-endorsed test reports to be issued for the tests.

Sometimes, it may not be possible to identify a laboratory which is accredited for all the tests requested. In such cases, it is preferred to use a laboratory accredited for most of the soil tests required. The Specifiers may request the laboratory to make available the documents listed in (a) and (b) below for the Specifiers' inspection at the laboratory and provide the information listed in (c) below for the Specifiers' assessment:

(a) quality manual and test procedures manuals (which should contain details of testing equipment, sample preparation and testing procedures, as well as worksheet and test report formats used by the laboratory),

(b) copies of calibration certificates for major equipment and measuring instruments to be used, and

(c) details of the person who will be supervising the tests and certifying the test reports including name, designation, qualifications and experience in testing.

Other related obligations of HOKLAS accredited laboratories are described in Section 5 of HOKLAS 002 (HKAS, 1998) and Section 4.7 of HOKLAS 003 (HKAS, 2000).

2.4 Specifying Test Requirements

Specifiers are responsible for providing the testing laboratory with detailed requirements of testing. The following general information is usually required by the laboratory for carrying out a test and preparing a test report:

(a) project title and number,

(b) ground investigation title and job number,

(c) reference numbers and locations of the ground investigation stations (e.g. borehole or trial pit numbers),

(d) sample depth and its identification/reference number (e.g. BH1/1), which has to be unique for each sample,

(e) sample type (e.g. a block, bulk, Mazier, piston, U76/U100 or vibrocore sample),

(f) orientation of the sample for undisturbed samples (e.g. a label to indicate the top and preferably also the bottom of a block or tube sample),

(g) soil description for each sample in accordance with Geoguide 3 (GCO, 1988), possible geological origin of the soil, and whether the soil particles are susceptible to crushing,

(h) sample recovery (for tube samples only),

(i) number of test specimens to be prepared from each sample,

(j) version of the testing standard to be used (including the year of issue and any amendments),

(k) the testing method and procedures,

(l) general testing conditions which include:

- the method of specimen preparation,
- the method and temperature for drying the soil and for moisture content determination (either Test Method 5.1 or 5.2),

  Note: Where necessary, the Specifiers may separately request the initial moisture content of the soil to be determined from separate portions in the sample to Test Method 5.3 for comparison. The results would enable the Specifiers to decide on the correct temperature to be used for the drying of the specimen in this test.

- whether dispersant is to be used (e.g. no dispersant should be used where the tests are for filter design), and
- whether particle density is to be assumed or determined (if assumed, a default value of 2.65 Mg/m^3 is to be used unless otherwise specified), and

  Note: For Phase II soil tests, the particle density shall be determined in accordance with Test Method 7.1 or 7.2, as appropriate.

(m) specific testing conditions (if any, see Clause 3).

Note: The testing conditions specified should correspond as closely as possible to those that will exist in the field for the design situation being considered. Not all testing conditions needed to be specified. Some testing conditions for standard tests are fixed (e.g. back pressure used for saturating soil specimen in a triaxial compression test).

When requesting Phase II tests, the Specifiers should also provide the following information:

(n) for remoulded samples, the target density and moisture content, the sizes of large particles to be excluded, and the method and temperature of drying, and

Note: The sample will be oven-dried at the same temperature as that adopted for the determination of moisture content if not specifically requested otherwise.

(o) for undisturbed samples, the location and orientation (if other than vertical) of test specimens within the original sample, whether the specimens were selected by the Specifiers or the laboratory, and the name, designation and affiliation of the person who selected the specimens.

In specifying tests, samples of the various materials or geological units (or sub-units) should be grouped for testing. The initial state of the samples as well as the state of the soils in the final construction should be taken into account.

Each testing request should be vetted by a professionally qualified geotechnical engineer or engineering geologist to ensure that the tests ordered are appropriate and adequate for the project in hand.

2.5 Selection of Samples and Minimum Sample Mass

2.5.1 Disturbed Samples

The Specifiers should select only those samples that are representative of the unit of ground mass under investigation.

An adequate amount of disturbed soil sample should be obtained for a test. This is to ensure that a representative specimen is prepared for the test. The minimum masses of disturbed soil samples that are required for the Phase I tests, after allowing for drying, wastage and removal of any over-sized particles, are given in Table 2.1.

2.5.2 Undisturbed Samples

The Specifiers should select only those samples that are of adequate quality for laboratory testing. The requirement for quality soil samples for Phase II tests is necessarily stringent for producing meaningful test results. The Specifiers should request the appropriate sampling technique to be used during ground investigation for the laboratory tests ordered. For example, driven tube samples are often not of adequate quality for strength testing because a loose soil is likely to be densified during the sampling process.

More guidance on the effect of ground conditions on the selection of soil sampling methods is given in Section 12 of Geoguide 2 (GCO, 1987).

In addition, the Specifiers should select the representative portion of a sample for the preparation of test specimens. For instance, the ends of open tube samples usually contains some disturbed material, due to heaving resulting from stress relief and inadequate cleaning of the hole prior to sampling. Specimens for testing should be taken away from the zone of disturbance.

Laboratory preparation of test specimens from the initially ‘undisturbed’ soil samples would inevitably disturb the soil. For some soils, this disturbance may be so large as to render the test results meaningless. For example, laboratory strength tests on ‘undisturbed’ tube samples of very soft clays and cohesionless sands are unlikely to produce meaningful results of in-situ strength.

The total mass of undisturbed soil samples, such as samples retrieved using a Mazier sampler, is limited for investigative testing. Account should also be taken of the sample recovery for tube samples. For samples of 74 mm to 76 mm diameter by 1 m long, three triaxial specimens can sometimes be prepared from each sample with the remaining soil to be used for classification tests. However, for medium-grained soils which contain particles up to about 10 mm, there may not be sufficient material in the same tube sample for classification tests if three specimens are to be taken for triaxial tests. When the mass of the remaining soil to be used for classification tests is less than that obtained using Table 2.1, the tests can only be carried out provided that the minimum specimen masses specified in the corresponding test methods are achieved.

Table 2.1 Minimum Mass of a Disturbed Soil Sample Required for Each Phase I Soil Test

Type of Test	Test		Soil Group		
			Fine-grained	**Medium-grained**	**Coarse-grained**
Moisture Content	5.1	Determination of Moisture Content by Oven-drying at 45 ± 5°C	50 g	350 g	4 kg
	5.2	Determination of Moisture Content by Oven-drying at 105 ± 5°C			
	5.3	Comparative Test for Determination of Moisture Content by Oven-drying			
Liquid and Plastic Limits	6.1	Determination of Liquid Limit, Plastic Limit and Plasticity Index	550 g	1.1 kg	2.2 kg
Particle Density	7.1	Determination of Particle Density by Gas Jar Method	1 kg 100 g	1 kg 100 g	1 kg 100 g
	7.2	Determination of Particle Density by Small Pyknometer Method			
Particle Size Distribution (Sieving)	8.1	Determination of Particle Size Distribution by Wet sieving (with Dispersant)	150 g	2.5 kg	17 kg
	8.2	Determination of Particle Size Distribution by Wet sieving (without Dispersant)			
Particle Size Distribution (Sedimentation)	8.3	Determination of Particle Size Distribution by Pipette Method (with Dispersant)	100 g	100 g+	100 g+
	8.4	Determination of Particle Size Distribution by Pipette Method (without Dispersant)			
	8.5	Determination of Particle Size Distribution by Hydrometer Method (with Dispersant)	250 g	250 g+	250 g+
	8.6	Determination of Particle Size Distribution by Hydrometer Method (without Dispersant)			
Chemical Tests	9.1	Determination of Organic Matter Content	150 g	600 g	3.5 kg
	9.2	Determination of Mass Loss on Ignition	150 g	600 g	3.5 kg
	9.3	Determination of Total Sulphate Content of Soil and Sulphate Content of Groundwater and of Aqueous Soil Extracts by Gravimetric Method	150 g	600 g	3.5 kg
	9.4	Determination of Water-soluble Chloride Content	750 g	1.5 kg	3.5 kg
	9.5	Determination of pH Value	150 g	600 g	3.5 kg
Compaction Tests	10.1/ 10.5	Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which are Not Susceptible to Crushing (Using 1000 cc Mould and 2.5/4.5 kg Rammer)	10 kg	10 kg	10 kg
	10.2/ 10.6	Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which are Susceptible to Crushing (Using 1000 cc Mould and 2.5/4.5 kg Rammer)	25 kg	25 kg	25 kg
	10.3/ 10.7	Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which are Not Susceptible to Crushing (Using CBR Mould and 2.5/4.5 kg Rammer)	50 kg	50 kg	50 kg
	10.4/ 10.8	Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which are Susceptible to Crushing (Using CBR Mould and 2.5/4.5 kg Rammer)	80 kg	80 kg	80 kg
California Bearing Ratio	12	Determination of California Bearing Ratio (CBR)	6 kg	6 kg	12 kg

Note: + denotes sufficient to give the stated mass of fine-grained materials.

2.6 Handling of Samples

Samples should be handled carefully at all time such that the natural states of soil samples can be retained as far as possible. Samples should be transported upright, packed and cushioned against jolting and vibration. Particular care should be taken for high quality samples of soft soils.

Undisturbed soil samples such as block samples and open tube samples should be tested as soon as possible after they are retrieved from the ground to minimise time-dependent deterioration in sample quality. Wherever possible, samples should be transported within two weeks of sampling to a laboratory for testing. If storage is necessary, the samples should be well sealed and stored at a location that is not subjected to vibration and significant temperature and humidity variations. Where necessary, ordering of tests at a laboratory should be done in phases to reduce the period of sample storage.

2.7 Supervision of Testing

The Specifiers should engage an experienced geotechnical engineer or engineering geologist as the supervising engineer to ensure that the laboratory can carry out the tests competently.

The supervising engineer is responsible for the overall supervision for the testing. He should communicate with the Specifiers regularly to ensure that the project requirements are met.

The supervising engineer should examine closely the soil samples in the laboratory to check whether the samples are representative of the geological units in the field, and are of the suitable quality for testing. The initial scheduling of soil tests is often based on original descriptions made by inspecting small volume jar samples or materials visible at the ends of sampling tubes. These descriptions may not represent truly the entire soil sample as material may vary within the sample. The supervising engineer should correct any inaccurate descriptions. He is responsible for selecting appropriate specimens for testing. The location of the specimen within the original sample should be recorded.

The supervising engineer should make detailed descriptions of the test specimens prepared. Though the presence of key features such as significant discontinuities, fabric, large particles and inclusions may render the test results invalid, it is sometimes impossible to prepare specimens completely free of these features. The supervising engineer should record accurately their locations and orientations in the specimen, so that these can be taken into account in interpreting the test results.

It is also the supervising engineer’s responsibility to review the testing plan during the course of testing in consultation with the Specifiers. He may need to visit the laboratory and supervise the critical procedures of the tests requested. Sometimes the engagement of experienced laboratory technical personnel may also be necessary to provide full time supervision of critical test procedures. For infrequent tests or tests using non-standard methods, the supervising engineer should witness the tests, which should first be carried out on dummy specimens. The data obtained should be reviewed, prior to confirming the testing specification on the actual samples.

Sample disturbance during extrusion of the soil from the sampling tube or during specimen preparation should be recorded. For oedometer and direct shear tests, an assessment should be made to ensure that the trimmed specimen has not been significantly disturbed. For the triaxial tests, the soil should not be excessively strained during extrusion, trimming and mounting of the specimen into the triaxial cell.

3 Technical Guidance to Specifiers

3.1 General

This Clause provides technical guidance to the Specifiers on the use of the soil tests given in this Geospec. The guidance should be read carefully before the Specifiers request for any testing to be carried out by a laboratory.

Reference could be made to Geoguide 1 (GEO, 1993) and Geotechnical Manual for Slopes (GCO, 1984) for general guidance on selection of soil parameters and principles of interpretation of test results. Additional guidance on the evaluation of test results could be found in Part 2 of Eurocode 7 (Eurocode, 1999).

3.2 Determination of Moisture Content

The methods for determining the moisture content of a soil sample are described in Clause 5.

The oven-drying method is the definitive procedure adopted in standard laboratory practice in Hong Kong for the determination of moisture content.

This definitive procedure offers two choices of standard oven temperatures, viz. 45 ± 5°C and 105 ± 5°C as stated in Test Methods 5.1 and 5.2 respectively. The Specifiers decide the temperature to be used for his tests.

The Specifiers should note that most of the saprolitic, residual and colluvial soils in Hong Kong contain varying amounts of minerals with water of hydration. This is not part of the free water in the soil that governs its usual engineering behaviour, and is released at higher temperatures that exceed 50°C.

The presence of water of hydration in a soil specimen can be confirmed by comparative tests, i.e. by determining the moisture content of a soil specimen by drying to constant mass at 45 ± 5°C and then at 105 ± 5°C in accordance with Test Method 5.3. A significant difference in the moisture content determined by the two methods would indicate the presence of water of hydration in the soil minerals. In such a case, all determinations of moisture content, including those related to other tests, should be carried out at the lower temperature of 45 ± 5°C, in accordance with Test Method 5.1. The comparative tests will only be carried out upon the request of the Specifiers.

If the Specifiers require the oven-drying to be carried out at temperatures other than the two standard temperatures, a record of the non-standard temperature range and duration of oven-drying must be made to the nearest 1°C and nearest 1 hour respectively.

The definitive procedure does not refer to the use of microwave ovens for drying samples because commercial microwaves generally do not have temperature controls. The Specifiers should note that a temperature higher than 110°C may alter the structure of clay and oxidise organic matters in a soil, and hence give inaccurate moisture content values. Without special controls, the use of microwave has the difficulty to ensure that the temperature of the soil does not exceed 110°C before all the water is removed. Therefore, the use of microwave ovens must be explicitly requested by the Specifiers and in such cases the determination of moisture content shall be carried out according to Appendix 6.2 of the General Specification for Civil Engineering Works, Volume 1 (HKSARG, 2006).

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When requesting the determination of moisture content, the Specifiers should provide the following information to facilitate the testing:

(a) general information as required in Clause 2.4, and

(b) whether comparative tests are required (Test Method 5.3).

3.3 Determination of Atterberg Limits

The methods for determining the Atterberg Limits are described in Clause 6 of this Geospec.

The determination of liquid limit, plastic limit and plasticity index is to be carried out in accordance with Test Method 6.1. The tests should only be carried out on soil specimens which contain little or no material retained on a 425 μm test sieve.

In Hong Kong the cone-penetrometer method is the definitive procedure adopted for the determination of liquid limit. The traditional ‘hand-rolling’ technique is adopted as the standard method in Hong Kong for the determination of plastic limit.

After the determination of moisture content by Test Method 5.1 or 5.2, and the determination of liquid and plastic limits by Test Method 6.1, the liquidity index can be calculated using Test Method 6.2.

All measurements of moisture content related to the determination of Atterberg Limits should be carried out in accordance with Test Method 5.1 or 5.2, as instructed by the Specifiers based on their assessment of the nature of the soil sample.

When requesting the determination of Atterberg Limits, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.4 Determination of Particle Density

The methods for determining the particle density of a soil sample are described in Clause 7 of this Geospec.

Both the gas jar and small pyknometer methods are definitive methods for the determination of particle density.

The gas jar method (Test Method 7.1) is suitable for soils containing up to 10% of particles retained on a 37.5 mm test sieve. The small pyknometer method (Test Method 7.2) is the definitive method for soils containing particles finer than 2 mm (i.e. sand or finer particles). Coarser particles may be ground down to sizes suitable for testing using Test Method 7.1 or 7.2 before testing. However, if these particles contain internal voids, tests on the ground materials could yield results different from those given by tests on the unground materials.

Particles of different sizes or mineralogy within a soil specimen often have different particle densities. The particle density so determined is the average for the range and distribution of the sizes and mineralogy of particles contained in the specimen tested. For some instances it may be desirable to determine the particle density separately on separate size fractions of the sample.

When requesting the determination of particle density, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.5 Determination of Particle Size Distribution

The methods for determining the particle size distribution (PSD) of a soil sample are described in Clause 8 of this Geospec.

The wet sieving methods (Test Methods 8.1 and 8.2) are definitive methods for the determination of the PSD of soils with coarse particles down to fine sand size (63 μm).

The sedimentation methods using pipettes (Test Methods 8.3 and 8.4) and methods using hydrometers (Test Methods 8.5 and 8.6) are standard methods adopted in Hong Kong for determining the PSD of soils with particles from coarse sand down to clay sizes (about 2 μm).

All PSD tests can be carried out with or without dispersant. The Specifiers should decide whether dispersant is to be used, taking into account the project need. Dispersant is used normally in sedimentation methods. The standard dispersant used in wet sieving is sodium hexametaphosphate solution, while a mixture of sodium hexametaphosphate and sodium carbonate solution is used in sedimentation methods. Dispersant may not be used for determining the PSD of materials for the following cases:

(a) materials to be used as engineering fills,

(b) materials to be used as granular filters, and

(c) ‘base soils’, in filter designs.

The wet sieving method together with the sedimentation method should, in theory, enable a complete and continuous PSD curve of a soil sample to be plotted. In practice, the PSD curve from a wet sieving test may not be able to join up with that from a sedimentation test for the same material. This mismatch, which is related to the method of testing, could be significant in some cases. Where the test results are critical for making engineering decisions, the Specifiers should examine carefully the individual data points on the PSD curve, and exercise engineering judgement in the use of the information. Test Method 8.7

gives a standard procedure for the construction of a continuous PSD curve from the results of wet sieving and the sedimentation tests.

BS 1377 : 1990 (BSI, 1990) requires the received sample to be oven-dried at 105°C to 110°C so that it can be crumbled and riffled prior to wet sieving. However, this practice is not recommended in this Geospec for saprolitic, residual and colluvial soils. Drying at such a high temperature can cause aggregation in these types of soil, which will make the subsequent separation of particles difficult. They should be tested, whenever possible, at their as-received state. Mechanical disaggregation can be carried out in accordance with Clause 4.5.1.

The pretreatment for organic matters contained in soil samples is not included in the standard methods because this process is unnecessary for most soils in Hong Kong. If requested by the Specifiers, it should be carried out in accordance with the recommended procedures described in Clause 9.4.6.1 of BS 1377 : Part 2 : 1990 (BSI, 1990). The Specifiers should understand that these pretreatment procedures are unlikely to have been accredited because they are not part of the standard methods.

When requesting the determination of PSD, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.6 Determination of Amount of Chemical Substances and Electro-chemical Properties

The methods for a number of commonly performed chemical and electro-chemical tests for soils or groundwater are described in Clause 9 of this Geospec.

The Walkley and Black method (Test Method 9.1), which uses dichromate oxidation, is used for the determination of organic matter content.

Heating a soil to a temperature of 440°C as described in Test Method 9.2 is the method used to determine the mass loss from a soil on ignition. For soils such as sandy soils that contain no clay, chalky materials, peats and organic clays containing more than about 10% organic matter, the mass loss on ignition is related to their organic content. For other soils, the major mass loss on ignition could be contributed by factors other than their organic content.

The gravimetric method (Test Method 9.3) is the definitive method for the determination of the total sulphate content of soils, and the sulphate content of groundwater and aqueous soil extracts. For aqueous soil extracts, both water extracts and acid extracts can be used in the method.

Some sulphates are not very soluble in water, e.g. calcium sulphate, the most commonly found sulphate salt. However, naturally occurring sulphates with rare exceptions are acid-soluble. Therefore, the total sulphate content of a soil sample determined by the acid extract method is likely to be misleading, if the sulphates present in the soil are predominantly calcium salt. This may give rise to false alarm of possible sulphate attack on buried concrete or cement-stabilised soils due to the presence of sulphates. In cases where the total sulphate content exceeds 0.5%, the water-soluble sulphate content of a 2:1 water-soil extract should be determined. As suggested in BS 1377 : Part 3 : 1990 (BSI, 1990), if calcium sulphate is the only sulphate salt present, its low solubility in water will keep the sulphate content of the aqueous extract below 1.2 g/litre. Sulphate contents in excess of this figure in soil-water extracts or groundwater will therefore indicate the presence of other and more harmful sulphate salts.

The ion-exchange method, which is included in BS 1377 : Part 3 : 1990 (BSI, 1990) as an alternative to the gravimetric method, is not recommended for general use because it cannot be used if groundwater or aqueous soil extracts contain chloride, nitrate or phosphate ions. Additional chemical tests to establish the absence of these ions must be carried out first before the ion-exchange method is used.

The Volhard's method (Test Method 9.4) is used for the determination of the water-soluble chloride content. The acidity of soil samples and groundwater can be determined by using a pH meter (Test Method 9.5).

When requesting the determination of the amount of chemical substances and electro-chemical properties, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.7 Determination of Dry Density/Moisture Content Relationship

The compaction test methods described in Clause 10 are used for the determination of the dry density/moisture content relationship of soils. The methods require compacting the soil in a specified manner over a range of moisture contents, from which the optimum moisture content and the maximum dry density are obtained.

A total of eight compaction test methods is offered, using a combination of two different sizes of compaction mould and two different weights of rammer, for soils containing particles which are either crushable or non-crushable during compaction.

A compaction mould of 1000 cc internal volume is used for soils containing particles all passing a 20 mm test sieve. For soils containing particles up to 37.5 mm in size, compaction tests may be carried out using a California Bearing Ratio (CBR) mould provided that the amount of particles exceeding 20 mm in size is small.

The light and heavy compaction tests are to be carried out using a 2.5 kg rammer and a 4.5 kg rammer respectively.

Soil samples should be prepared and tested using methods depending on whether they are susceptible to crushing during compaction or not, and whether they are saprolitic, residual or colluvial soils. They should be considered susceptible to crushing if they contain grains which are weak in nature and could break up under the action of a rammer or vibration hammer.

The decision as to which of the test methods is to be used rests with the Specifiers. Laboratories will treat a soil sample as containing particles which are susceptible to crushing during compaction, unless specified otherwise by the Specifiers. Moreover, a soil sample will be treated as a saprolitic soil by default, if the Specifiers have not provided any information on its geological origin.

Soil samples should be tested in their as-received states whenever possible. If drying of the samples is required for the testing, this should be done by either air-drying or oven-drying at a temperature ≤ 50°C. The method of drying should be recorded.

When requesting the determination of the dry density/moisture content relationship, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.8 Determination of In-situ Bulk Density, In-situ Dry Density and Relative Compaction

The methods for determining the in-situ bulk density, in-situ dry density and relative compaction of soils are described in Clause 11.

The sand replacement method using a 115 mm diameter sand-pouring cylinder (Test Method 11.1) is applicable for the determination of in-situ densities of natural or compacted fine- to medium-grained soils. For compacted soils, this method is applicable only where the compacted layers do not exceed 150 mm in thickness.

Where the natural or compacted soils contain coarse-grained particles, a similar method but using a larger pouring cylinder (Test Method 11.2) should be used. It is also an alternative test method for fine- to medium-grained soils. For compacted soils, this method is applicable for compacted layers up to 250 mm thick.

For the sand replacement methods, one common practice is to put large pieces of excavated materials, such as stones, brick, concrete fragments and, wood, back into the test hole before pouring of the replacement sand; this is not permitted. Correction procedures based on the measured mass and assumed densities of the large particles should be carried out as stated in the methods. The “corrected” density is only applicable where a comparison is required to a Proctor compaction density not including “large” particles.

While the sand replacement methods determine the in-situ densities of the soil by direct measurements of mass and volume, an indirect method which uses a nuclear densometer as a rapid non-destructive technique is available. The method described in Test Method 11.3 covers the determination of in-situ densities of fine- to medium-grained soils using the nuclear densometer method. [Amd GS3/01/2017]

The standard method for determining the relative compaction of fill materials is given in Test Method 11.4. The method is based on the results obtained from the in-situ density tests carried out in accordance with Test Method 11.1, 11.2 or 11.3 and those obtained from the compaction tests carried out in accordance with Clause 10. This method complies with Clause 6.81 of Section 6 of the General Specification for Civil Engineering Works, Volume 1 (HKSARG, 2006). The compaction tests should always be carried out on the batch of soil which corresponds to the type of fill found at the location where the corresponding in-situ density tests are carried out. [Amd GS3/01/2017]

Unless otherwise agreed by the Specifiers, each batch of fill should be tested to determine the relative compaction. Tests should be carried out after the fill materials have been deposited and compacted in their final position. The number of tests on each batch should be as stated in Table 3.1 below. If the result of any test does not comply with the minimum requirements specified for relative compaction of the fill, additional tests should be carried out on the same batch. The number of additional tests should also be as stated in Table 3.1.

Table 3.1 Number of Tests for Determining the Relative Compaction of Fill Materials

Description	Size of the Area of Fill in the Batch	No. of Samples/No. of Tests per Batch
Areas of fill in excavations for structures, pits and trenches and on formations	0 - 100 m^2	3
	100 - 500 m^2	2 for each 100 m^2 or part thereof
	over 500 m^2	1 for each 100 m^2 or part thereof
Other areas of fill	0 - 1 ha	4 for each 1000 m^2 or part thereof
	1 - 10 ha	3 for each 1000 m^2 or part thereof
	over 10 ha	2 for each 1000 m^2 or part thereof

The Specifiers should decide on the test positions which are representative of the batch of compacted fill materials, or which are at critical locations. Tests need not be carried out on:

(a) rock filling materials which contain an insufficient proportion of particles passing a 20 mm BS test sieve to permit meaningful determination of the relative compaction, and

(b) soft fill materials which have been deposited in intermediate areas of fill, by end-tipping or by pushing into position, until it forms a stable foundation onto which the works are to be constructed subsequently.

When requesting the determination of in-situ densities and relative compaction, the Specifiers should provide the general information as required in Clause 2.4 to facilitate the testing.

3.9 Determination of California Bearing Ratio

The laboratory method for determining the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil is described in Clause 12.

The principle of the method is to determine the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is pushed into the soil sample at a given rate. At specific values of penetration, the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio.

The sample may be soaked if required. Due to the limited size of the test specimen and that of the plunger, the test is suitable only for materials containing particles not greater than 20 mm.

When requesting a CBR test, the Specifiers should provide the following information:

(a) the general information as required in Clause 2.4,

(b) the target density and moisture content of the soil sample to be achieved, if needed,

(c) whether the test is to be carried out at one end or at both ends of the specimen,

(d) whether the test is required on the specimen in the soaked condition, and

(e) the amount of surcharge to be applied to the specimen for the test, and during soaking if needed.

3.10 Determination of Compressibility Characteristics

3.10.1 One-dimensional Consolidation Test

This test, commonly known as the oedometer test, is principally for the determination of the magnitudes and rates of consolidation of a saturated or near-saturated (say, degree of saturation ≥ 95%) specimen of soil subjected to a series of vertical loading pressures in a consolidation cell known as the oedometer. Each load increment is applied for a sufficiently long period until primary consolidation of the soil is completed. The loading period is extended if the secondary compression properties of the soil are required to be determined. As the oedometer permits the soil specimen to deform in the vertical direction only (with zero radial strain), the test is a one-dimensional consolidation test with only vertical straining and water flow.

The laboratory testing method is described in Test Method 14.1.

The following parameters can be obtained from the test:

(a) the coefficient of consolidation (c_v) and the coefficient of volume compressibility (m_v), for each load increment,

(b) the coefficient of secondary compression (C_{sec}), for each load increment, if required by the Specifiers, and

(c) a plot of void ratio, e (and vertical strain, ε_v), against the logarithm of applied pressure, σ', is given as part of the results for the range of loading, unloading and reloading pressures specified.

Note: Parameters related to unloading (swelling) of the soil may be determined from this plot. For overconsolidated soils, the preconsolidation pressure of the test specimen may also be determined.

This test is normally carried out for fine-grained soils and is not suitable for soils containing particles or inclusions with a size larger than about one-fifth of the height of the consolidation ring in the oedometer. For the 70 mm diameter by 19 mm high ring commonly used in Hong Kong, tests on soil specimens containing particles or inclusions (e.g. shells) larger than about 4 mm may yield unreliable results.

The standard test is also not suitable for soils containing large-scale fabric features. The small size of the specimen normally used for this test may not represent adequately the fabric features found in the natural deposits, such as laminations of silt in a soft marine clay, which collectively dominate the drainage characteristics of the ground and therefore the rate of settlement in-situ. Section 5.7 of Geoguide 1 (GEO, 1993) discusses this subject.

Consolidation and compressibility results can be seriously affected by sample disturbance in soft clays. High quality piston samples should be used for oedometer testing of such soils. Because of the need to trim off material disturbed by the sampling process and the subsequent extrusion of the soil from the sampling tube, tube samples of a diameter less than 76 mm may not allow a satisfactory specimen to be prepared.

The coefficient of secondary compression should not be confused with the secondary compression index, C_α, which is defined as $C_\alpha = \Delta e / \Delta \log t$. The relationship between C_{sec} and C_α is that $C_{sec} = C_\alpha / (1 + e_p)$, where e_p is the void ratio at the start of the linear portion of the e versus log t curve for a particular load increment. The Specifier may also use e_0, the in-situ void ratio, with no appreciable loss of accuracy.

When requesting a one-dimensional consolidation test, the Specifiers should provide the following information:

(a) the general information as required in Clause 2.4,

(b) whether the selection of test specimens from the samples will be carried out by the Specifiers,

(c) whether the determination of moisture content should be in accordance with Test Method 5.1 or 5.2,

Note: Where necessary, the Specifiers may request the initial moisture content of the soil to be determined from separate portions in the sample to Test Method 5.3. Test Method 5.3 could be carried out as part of this test or as a separate test. The results from Test Method 5.3 would enable preliminary values of void ratio to be calculated during the test before the final dry mass of the specimen is available. Also, they would enable the Specifiers to decide on the correct temperature to be used for the drying of the specimen later.

(d) the loading and unloading sequences for each series of tests (i.e. the initial pressure and the loading increments and decrements),

Note: Normally the number of unloading stages should be at least half the number of loading stages, and should provide reasonable, equally spaced, points on a log pressure scale.

(e) if the sequence of a second loading and unloading cycle is required, whether the coefficient of secondary consolidation needs to be determined, and

(f) the loading period, if the test is to extend beyond primary consolidation.

Note: For the standard test, the taking of specimen compression data will be discontinued at a convenient time after primary consolidation is complete.

A typical test comprises four to six increments of loading, with each applied stress being double that of the previous stage. Loading is removed in a smaller number of decrements. The load increments/decrements that are applied by the laboratory may be close to but not exactly the same as those specified, due to the values of available calibrated load sets. A variation of up to 10% is normally acceptable.

The initial pressure to be specified depends on the type of soil. For soils which tend to swell, the first loading increment should be sufficiently large to prevent swelling which could cause disturbance to the soil fabric. A general guide to the initial pressure to be applied is given in Table 3.2 below:

Table 3.2 Initial Pressure for One-dimensional Consolidation Test

Soil Consistency	Initial Pressure
Very soft	Very low, typically 6 kPa or 12 kPa. Initial consolidation under a small stress will improve strength to prevent squeezing out under the next load increment.
Soft	Appreciably less than σ_{vo}', the estimated present vertical effective stress in-situ at the horizon from which the specimen was taken; usually 25 kPa or less.
Firm	Somewhat less than σ_{vo}', preferably using the next lower recommended pressure.
Stiff	Equal to σ_{vo}', or the next higher recommended pressure if σ_{vo}' cannot prevent swelling.

For each specimen, the range of pressures should cover the maximum vertical effective stress likely to occur in-situ due to overburden as well as any loading or unloading resulting from the proposed construction. Loading of a specimen of an overconsolidated soil should, whenever possible, extend into the normal consolidation region. A range of pressures selected from the following sequence has been found to be satisfactory:

6, 12, 25, 50, 100, 200, 400, 800, 1600, 3200 kPa.

3.10.2 Isotropic Compression Test

This test determines the isotropic compression/swelling and consolidation properties of a soil when subjected to changes in the applied effective stress in a triaxial cell. It is useful for obtaining the isotropic compression and swelling lines and the yield point of a saprolitic soil, or a soil of sedimentary origin containing laminations of sand and silt, where the conventional oedometer ring is too small to test a representative specimen.

The laboratory testing method is described in Test Method 14.2.

In this test, a cylindrical soil specimen is subjected to predetermined increments (compression test) or decrements (swelling test) of an equal and all-round confining (cell) pressure, i.e. $\sigma_1 = \sigma_2 = \sigma_3$. Each pressure increment is held constant until virtually all the excess pore pressure due to that increment has dissipated. During this process, drainage is permitted from the top of the test specimen, resulting in consolidation (or swelling) and an increase (or reduction) in the effective spherical pressure of the specimen. The volume changes are measured at regular time intervals. At the same time, the pore water pressure at the bottom end of the specimen is monitored. Assuming that the soil has isotropic properties, these measurements can then be used for the determination of the relationship between void ratio and effective stress for isotropic compression, and for the calculation of coefficients of consolidation and compressibility.

Note: The coefficient of volume compressibility and the coefficient of consolidation derived from this isotropic compression test (Test Method 14.2) are not the same as those obtained from the one-dimensional consolidation test (Test Method 14.1).

An e versus log p' plot (i.e. the isotropic compression and swelling lines) can be obtained from the test, from which the following can be determined:

(a) the coefficient of volume compressibility, m_{vi}, and the coefficient of consolidation, c_{vi}, for isotropic compression/ swelling, and

(b) the yield point or preconsolidation pressure of the test specimen.

In the standard test, drainage is permitted only at the top of the soil specimen with pore pressure measurement at the bottom. For soils of very low permeability, the testing time can be long and filter paper side drains are sometimes fitted to the cylindrical surface of the specimen to allow drainage to take place from the radial boundary as well as from the ends of the specimen. This can reduce the testing time considerably. However, the introduction of filter paper side drains can cause differential drainage within the specimen due to non-uniform drainage boundary conditions. Modification factors for calculating the coefficient of consolidation for a soil specimen under different drainage conditions are provided in the standard test procedure. For soils with anisotropic stiffness or permeability properties, it may not be possible to interpret meaningfully the results of tests, especially those carried out with side drains.

This test is not suitable for soils containing particles or inclusions with a size larger than about one-fifth of the specimen diameter. For the 74 mm and 76 mm diameter samples (viz. Mazier and piston samples) commonly taken in Hong Kong, the standard test can be used for soils containing particles not greater than about 15 mm.

For a given soil, isotropic compression tests take longer time than oedometer tests due to longer drainage path and hence longer consolidation time. It can test specimen with bigger inclusions because of the bigger specimen size. Shortening the specimen can speed up the test. The minimum acceptable height/diameter ratio is one.

When requesting isotropic compression tests, the Specifiers should provide the following:

(a) the information stated in Clause 3.10.1 as required for the one-dimensional consolidation tests, and

Note: The loading and unloading sequence specified for the isotropic compression test refers to the cell/confining pressure increments and decrements.

(b) for specimens prepared by remoulding of the soil sample:

- the target density and moisture content, and
- the method and temperature of drying.

  Note: Oven-drying is to be at the same temperature as that adopted for the determination of moisture content, if not specifically requested otherwise.

The maximum effective confining pressure should not exceed the maximum safe pressure sustained by the triaxial cell minus the back pressure required to saturate the specimen. The Specifiers should consult the laboratory on the maximum pressure that can be delivered reliably by its pressure system which, if less than the maximum safe pressure of the cell, will pose a limit on the maximum cell pressure that can be applied.

The test may be carried out prior to performing a triaxial compression test (see Test Method 15.2 or 15.3), or simply on its own (Test Method 14.2). Where it is carried out as part of a triaxial compression test, the isotropic compression/swelling and consolidation is to bring the specimen to the effective stress state required for shearing. Data obtained from the consolidation stage are used for estimating a suitable rate of strain to be applied during the subsequent axial compression, and for computing the dimensions of the specimen at the start of the axial compression/swelling stage.

3.11 Determination of Shear Strength Using a Triaxial Apparatus

3.11.1 Unconsolidated Undrained (UU) Triaxial Compression Test

This test, commonly known as the UU test, is used for the determination of the undrained shear strength (s_u) of a cylindrical specimen of cohesive soil. In the test, the specimen is subjected to a constant all-round confining pressure and to strain-controlled axial loading until shear failure occurs, all under undrained condition. No change in total moisture content is allowed during the test, and no pore pressure measurement is carried out. The undrained shear strength (s_u) of a soil at a particular depth in the ground is normally determined by a number of tests carried out on a pre-selected set of similar specimens, subjected to different confining pressures.

The laboratory testing method is described in Test Method 15.1.

Specifiers should be aware of the limitations of the UU test. Disturbance to the soil during sampling, storage, handling and specimen preparation can change its moisture content and effective stress states. The specimen may be partial de-saturated. The test set up does not provide for checking its initial degree of saturation. If the specimen is not fully saturated before shearing, then the s_u value measured will not be correct, as the suction will induce apparent cohesion. For partially de-saturated specimen, applying a large cell pressure will increase its degree of saturation by reducing its air voids. But this consolidates the soil, which will increase the s_u value. In addition, there is no means to assess if the strain rate applied empirically (usually 5 min to 15 min) will achieve equalisation of pore water pressure within the specimen during the test.

In view of the above, the s_u value obtained from the UU test may not reflect the actual in-situ undrained shear strength. The problems and interpretation of the UU test have been discussed by Bolton (1991), Chen & Kulhawy (1993) and Kulhawy (1992). Kulhawy has recommended the use of the isotropically consolidated undrained triaxial compression test (the CU test) to determine the undrained shear strength of a soil instead of the UU test. Notwithstanding the weaknesses of the UU test, there has been some accumulated experience in the use of the test for determining the s_u values of clays of sedimentary origin. Provided that its deficiencies are recognised, a few UU tests could be performed in conjunction with the CU tests to calibrate against the existing empirical design experience. The UU test is not recommended for determining the shear strength of saprolitic, residual and colluvial soils.

When requesting a UU test, the Specifiers should provide the following information to facilitate the testing:

(a) the general information as required in Clause 2.4, and

(b) the cell confining pressures for each series of tests.

Note: The Specifiers should consult the laboratory on the maximum pressure that can be delivered reliably by its pressure system, as explained in Clause 3.10.2 for the isotropic compression tests.

In Hong Kong, piston samples are usually taken for soft clays and Mazier samples for firm clays. For such samples, two or three specimens can normally be prepared from each sample and tested as a set, and the remaining material in the sample is used for obtaining representative specimens for a set of classification tests. Where driven tube samples (e.g. U76) are obtained, only one specimen can be prepared from each sample for the UU test, and a number of samples from the same horizon will need to be tested (at a range of cell pressures) to determine the s_u value for the horizon.

Driven tube samples are often not of adequate quality for strength testing. Instead, the moisture content (or void ratio) and plasticity indices determined from such samples, if fully saturated, permit a check of the undrained shear strength of a firm to stiff clay of sedimentary origin from empirical correlations.

For normally consolidated soils, a set of three specimens are normally tested at cell pressures of about $0.5\sigma_v$, σ_v and $2\sigma_v$, where σ_v is the estimated present vertical total in-situ stress at the horizon from which the samples were taken. For overconsolidated soils, the lowest cell pressure should not normally be less than σ_v. The s_u values at different stress levels should theoretically be the same for specimens of a given soil type at the same moisture content (or void ratio), if the soil is fully saturated. In practice they are different due to soil variability, the presence of air in the specimens and the deficiencies of the UU test.

3.11.2 Isotropically Consolidated Triaxial Compression Test

These tests are used for the determination of the effective shear strength of saturated soils.

In the standard tests, the specimen is first saturated by application of a back pressure from the top with measurement of pore pressure at the base. After saturation, the specimen is subjected to isotropic compression/consolidation and then sheared by axial compression, under a constant confining pressure, by increasing the axial strain at a constant rate. The specimens are in the form of right cylinders of nominal diameters (commonly 74 mm to 76 mm or 100 mm) and of a height approximately equal to twice the diameter.

The laboratory testing methods are described in Test Methods 15.2 and 15.3.

Two types of test are commonly carried out: the consolidated undrained (CU) test with pore pressure measurement (Test Method 15.2) and the consolidated drained (CD) test with measurement of volume change (Test Method 15.3).

The following information can be obtained from the CU test:

(a) the total stress parameters (including the undrained shear strength) of the saturated specimen (at a given initial moisture content or void ratio), corresponding to a known initial effective stress, and

(b) the pore pressure changes during shearing, from which the effective stresses of the specimen and the pore pressure coefficient A for the test can be derived.

The following information can be obtained from the CD test:

(a) the drained shear strength of the saturated specimen, and

(b) the volume change characteristics during shearing, of the specimen from which the pore water is allowed to drain freely.

The CU test is generally preferred for routine testing, because it can be carried out more quickly than the CD test, especially for soils of low permeability. Also, useful information can be obtained from the effective stress path of the test. However, particular care should be taken to ensure that an undrained test is carried out sufficiently slowly to ensure equalisation of pore pressure within the specimen.

Multi-stage CD tests are generally not recommended because of the likelihood of overstraining the specimens. Even for CU tests, significant errors in the assessment of shear strength will result if the strain to failure for each intermediate test stage is excessive. Therefore, sufficient samples should be taken during the ground investigation for single stage testing. Single stage tests should be specified initially for the samples, and only when a sufficient number of representative and suitable specimens cannot be obtained on extrusion of the samples in the laboratory should the testing schedule be amended to carry out multi-stage tests.

Filter paper side drains should generally not be used in triaxial tests, because they may lead to errors in strength measurement and are generally unnecessary for soils in Hong Kong except for soft clays of low permeability. Membrane corrections must be made in the usual way.

A number of criteria have been used to define the stress condition at failure in a triaxial test. These include:

(a) maximum effective principal stress ratio (σ_1'/σ_3'),

(b) maximum deviator stress, i.e. maximum principal stress difference, denoted by (σ_1 - σ_3), being reached, and

(c) when shearing continues at constant pore pressure (undrained) or with no change in volume (drained), and at a constant shear stress.

Criterion (c) corresponds to the condition when the critical state of a soil is deemed to have been reached. For soils which do not exhibit a peak shear stress in the CU or CD test (e.g. normally consolidated clays), criteria (b) and (c) would theoretically give the same ϕ' value (viz. ϕ_{cv}'). Criterion (a) would also give the same ϕ' value for the CD test. For soils which exhibit a peak shear stress in the CU test, criterion (a) would normally be reached in the test first, followed by criterion (b) and then (c). The failure stress points on a stress path plot corresponding to the three criteria are normally different and hence different effective shear strength parameters would be derived depending on which criterion is used. The designer should examine the full stress path of the tests in interpreting the test results, rather than examining the individual failure stress points only. Some guidance is given by Bishop & Henkel (1976) on the choice of the failure criterion and interpretation of test results.

The following sources of error should be borne in mind, especially in the low stress range:

(a) Test specimens tend to barrel at high strains, which leads to an over-estimation of the shear strength.

(b) The saturation process prior to shearing can lead to specimen disturbance in the form of unintended volume change. Strong (dense) materials tend to swell during saturation, which frequently results in loss of strength. Very weak (loose) materials may occasionally compress, giving misleadingly high shear strengths.

Sometimes, failure is conditioned by the presence of relict discontinuities in the specimen. In such cases, a Mohr circle stress analysis using the test data may be appropriate (e.g. to determine the shear strength of the discontinuity which exhibits shearing failure). Such an analysis demands reliable record of the orientation of the failure plane (discontinuity) on the specimen relative to the principal stress directions.

When requesting a CU or CD test, the Specifiers should provide the following information:

(a) the general information as required in Clause 2.4,

(b) whether undisturbed or remoulded specimens are to be tested,

(c) the type of drainage, i.e. CU or CD test,

(d) the effective confining pressure for each specimen and the isotropic compression/swelling required prior to the test (see Clause 3.10.2),

(e) whether a single-stage or multi-stage triaxial test is to be carried out, and

(f) whether filter paper side drains are to be used.

Note: Side drains should be used for CD tests, only upon request of the Specifiers on soil specimens of very low permeability for reducing the length of drainage path and hence the testing time.

Normally, Mazier or piston samples are taken for triaxial compression testing. A number of tube samples are taken for each soil type and two or three specimens are prepared from each sample and tested at various stress levels. The cell pressures to be applied should aim at giving failure stress levels which are relevant to the engineering problem in hand. The in-situ void ratio (or dry density) and the degree of decomposition of the soil (and SPT values obtained close to the samples, if available) are useful indices for dividing the samples into groups of ground units for the planning of the testing schedule and interpretation of test results.

In standard triaxial compression tests, the specimen is saturated by back pressure. Where other means of saturation is to be applied, e.g. percolating de-aired water under a small hydraulic gradient through the specimen until air stops bubbling from it, followed by back pressure saturation or use of carbon dioxide to facilitate the saturation process, the Specifiers should agree with the laboratory the detailed procedures to be followed.

In planning the range of effective confining pressures to be used, the following general guidelines may be useful. First of all, an estimate should be made of the range of normal effective stress (σ_n') acting on the potential failure surfaces in the ground. The corresponding effective confining pressures (σ_3') may then be estimated using Mohr circle analysis and assumed shear strength parameters. It is recommended that a few tests should also be carried out at sufficiently high confining stresses for estimating the critical state strength of the soil.

For the standard triaxial equipment and test procedures, effective confining pressures of less than 25 kPa are not recommended due to the limited accuracy of the measuring instruments in routine use.

Where soil shear strengths at low stress levels are to be determined, non-standard test equipment and procedures will need to be specified (e.g. failure by increasing the pore water pressure following anisotropic consolidation).

3.12 Determination of Shear Strength Using a Shear Box Apparatus

The shear box apparatus is used for carrying out the direct shear test. The box restrains laterally a prism of soil for shearing along a predefined plane while a pressure is applied normal to that plane. The shearing force is measured at regular intervals of displacement. Failure is normally defined as the maximum shearing force the soil can sustain. The cross-sectional area over which the specimen is sheared is assumed to remain constant during the test.

As there is no control of drainage, the shear box apparatus can be used only for carrying out drained tests. The specimen is normally soaked for a prescribed period. After soaking, the specimen is consolidated under a vertical load until primary consolidation is completed. It is then sheared at a rate of displacement that is considered slow enough to prevent development of excess pore pressures. The drained shear strength of a soil is obtained from a direct shear test.

The laboratory testing methods are described in Test Methods 16.1 and 16.2.

Two types of direct shear apparatus are commonly used: the small shear box for testing specimens of 60 mm or 100 mm square by 20 mm or 44 mm thick (Test Method 16.1), and the large shear box for specimens of 300 mm square by about 150 mm thick (Test Method 16.2). Because of its size, the large shear box is mainly used for testing compacted specimens of remoulded soils. While not common in Hong Kong, a circular shear box, which accepts specimens prepared directly from tube samples, is also used; but its details are not included in this Geospec.

Specimens for the direct shear test are normally prepared from block samples. For fine-grained soils containing particles not greater than about 4 mm, a specimen size of 60 mm square by 20 mm thick is acceptable. A specimen size of 100 mm square by 44 mm thick has been found to give satisfactory results for completely decomposed granites with grains up to about 10 mm in size (Cheung et al, 1988). The shear strength can be determined on any pre-determined plane in the sample by trimming specimens at the correct orientation.

With suitable modification, the standard shear box can be used for the determination of coefficient of friction (or interaction) between a soil and various construction materials (e.g. steel and geosynthetic reinforcement).

A number of researchers have discussed the limitations and interpretation of the direct shear tests (see, for example, Jewell, 1989).

When requesting a direct shear test, the Specifiers should provide the following information:

(a) the general information as required in Clause 2.4,

(b) the method (Method A or Method B) to be adopted for this test,

Note: For specimens prepared from a block sample, Method B will be used if not specifically requested otherwise.

(c) the size of the shear box to be adopted if Method A is specified,

Note: A specimen of a nominal size of 60 mm or 100 mm square by 20 mm thick is commonly used for Method A. A specimen of a nominal size of 100 mm square is normally used if Method B is adopted.

(d) whether ‘undisturbed’ or remoulded specimens are to be tested,

(e) for preparation of remoulded specimens for the large shear box test, in addition to the items listed in Clause 2.4 (n), whether vibratory compaction or static compaction is to be adopted,

Note: The vibrating hammer method and the static compaction method are preferable respectively for soils containing not more than and more than 10% by mass of material passing the 63 µm BS sieve. Also, if the material passing the 20 mm BS test sieve contains over 50% of particles passing a 2 mm BS test sieve, static compaction is preferred.

(f) the test method for the determination of particle size distribution of the soil, and

(g) the normal stress to be applied for each specimen.

Normally, block samples are taken for direct shear testing. A number of such samples are taken for each soil type and a few specimens are prepared from each sample and tested at various stress levels. The normal stress levels to be applied should be relevant to the engineering problem in hand.

In the standard tests, minimum soaking times are given for different types of soils. It has been found that a period of twelve hours is usually adequate for most decomposed granites (Grades V and VI). The Specifiers should check whether the minimum soaking time is adequate for the specimens (by examining the degree of saturation of the soil after soaking) and specify a longer period of soaking to be determined on the basis of trials if necessary.

Where the coefficient of friction (or interaction) between a soil and a construction material is required to be determined, the modifications to the standard test, including the method of incorporating the construction material into the shear box apparatus, should be specified.

Part II

4 General Procedures for Sample Preparation for Phase I Tests

4.1 General

This Clause describes the general procedures for the initial preparation of soil samples for Phase I tests. These procedures shall be followed for all Phase I tests, unless otherwise specified in the test procedures for individual tests.

The following apparatus are required:

(a) a balance, readable to 0.01 g and accurate to 0.05 g,

(b) a balance, readable to 0.1 g and accurate to 0.3 g,

(c) a balance, e.g. platform scales, of 25 kg capacity, readable to 5 g,

(d) a means of breaking up aggregations of soil without breaking up individual particles, e.g. a mortar and a rubber-headed pestle or a suitable mechanical device which has an action no more severe than that of a rubber-headed pestle,

(e) test sieves, with aperture sizes 425 μm, 2 mm, 3.75 mm, 5 mm, 10 mm, 20 mm and 37.5 mm, and a receiver,

(f) drying ovens, capable of maintaining temperatures at 45 ± 5°C and 105 ± 5°C,

(g) sample dividers, e.g. of the multiple-slot type (riffle box),

(h) a tray made of corrosion-resistant metal, large enough for mixing the soil sample,

(i) a metal scoop,

(j) a palette knife,

(k) watertight and corrosion-resistant containers, or strong polyethylene bags, and

(l) a supply of distilled water at room temperature.

4.2 Assessment Sieving

For the purpose of the testing described in this Geospec, a soil sample shall first be classified as fine-grained, medium-grained or coarse-grained, as defined in Clause 1.2. In doubtful cases or where confirmation is required, an assessment sieving shall be carried out. A portion of the sample shall be sieved through the appropriate sieve(s) in accordance with Clause 8.1 or 8.2. The minimum mass of sample required for assessment sieving is as follows:

Fine-grained	Medium-grained	Coarse-grained
100 g	2 kg	15 kg

4.3 Moisture Content Determination

If the as-received state of moisture content is required for a soil sample, a portion of the sample with the minimum mass as stated in Table 2.1 shall be obtained by riffling or quartering. To retain the natural moisture content of a soil sample, the use of shallow trays for handling or storing shall be avoided. The sample shall be sealed or at least covered immediately after retrieval.

4.4 Drying of Samples

The methods for drying have been defined in Clause 1.2. However, many definitive test procedures require that a soil sample should not be allowed to dry before testing. Whenever possible, the as-received state of the sample should be retained. For some soils, irreversible changes take place after being dried at a high temperature. For some other soils such as organic soils or certain tropical soils, irreversible changes occur even when air-dried. When it is not practicable to use the soil sample in its as-received state, the reasons shall be stated and the method of drying shall be reported.

When it is necessary to reduce the moisture content of a soil sample to a level to make it suitable for further processing, the sample should be air-dried, unless drying at a temperature higher than the room is specified. Weighing should be carried out periodically to check that the desired level has been reached. The soil should be turned over from time to time during drying to avoid drying out locally. For most purposes the soil should be dried no more than is necessary to enable it to be crumbled, or to bring it to a suitable state for a test. No part of the soil shall be allowed to dry out completely.

4.5 Mechanical Processing

4.5.1 Mechanical Disaggregation

For many classification tests, mechanical disaggregation is necessary, such that only constituent particles are retained on a 2 mm test sieve.

After drying (if any) in accordance with Clause 4.4, aggregations of particles in a soil sample shall be broken up, using an action that is no more severe than that applied by a rubber pestle. This process shall be carried out in such a way as to avoid crushing of the individual particles, and shall continue until only constituent particles are retained on the specified test sieve. The broken-up sample shall be mixed thoroughly for further processing.

For testing of a soil sample in its as-received state, disaggregation may be achieved by soaking it in distilled water.

For soils containing materials of low strength such as limestone and sandstone, the soil particles in their as-received state could break up easily under the action of the pestle. Soil samples containing these materials should be considered susceptible to crushing during compaction.

4.5.2 Subdividing

When representative specimens are required to be taken from a soil sample, this shall be done through subdivision of the sample by quartering, riffling or other suitable means. The minimum masses required for representative specimens are specified in the respective standard methods.

5 Determination of Moisture Content

5.1 Determination of Moisture Content by Oven-drying at 45 ± 5°C

5.1.1 Scope

This method is used for the determination of the moisture content of soil by oven-drying at 45 ± 5°C. The presence of dissolved salts in saline water is not dealt with in this method.

5.1.2 General

The guidance given in Clause 3.2 shall be noted.

5.1.3 Apparatus

The following apparatus are required:

(a) a drying oven, capable of maintaining a temperature of 45 ± 5°C,

(b) for fine-grained soils:

- a glass weighing bottle, fitted with a ground glass stopper or cap, or a suitable airtight corrosion-resistant metal container of about 50 g capacity,
- a balance, readable to 0.01 g and accurate to 0.05 g, and
- 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-dried are capable of absorbing water from it.

(c) for medium-grained soils:

- a corrosion-resistant container of about 500 g capacity,
- a balance, readable to 0.1 g and accurate to 0.3 g, and
- a scoop of suitable size,

(d) for coarse-grained soils:

- a corrosion-resistant container of about 4 kg capacity,
- a balance, readable to 1 g and accurate to 3 g, and
- a scoop of suitable size.

5.1.4 Sample Preparation

5.1.4.1 The minimum mass of soil required for the preparation of a test specimen for the oven-drying method shall be as follows:

Fine-grained	Medium-grained	Coarse-grained
30 g	300 g	3 kg

5.1.4.2 Preparation of sample shall be carried out in accordance with Clauses 4.2, 4.3 and 4.5, as appropriate.

5.1.5 Test Procedures

5.1.5.1 For fine-grained soils, the test shall be carried out as follows:

(i) 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).

(ii) Remove the lid or stopper, and place the container or bottle with its lid and contents in the oven and dry at 45 ± 5°C. Do not replace the lid or stopper while the sample is in the oven. The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see Steps (iii) and (iv) below) at intervals of 4 h do not exceed 0.1% of the original mass of the sample.

(iii) 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.

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

(v) Record the duration of all oven-drying activities to the nearest hour.

5.1.5.2 For medium-grained soils, the test shall be carried out as follows:

(i) 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).

(ii) Remove the lid and place the container and contents in the oven and dry at 45 ± 5°C. Do not replace the lid while the sample is in the oven. The period required for drying will vary with the type of soil, the size of sample and the number of samples in the oven. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see Steps (iii) and (iv) below) at intervals of 4 h do not exceed 0.1% of the original mass of the soil.

(iii) After drying, replace the lid and allow the whole to cool.

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

(v) Record the duration of all oven-drying activities to the nearest hour.

5.1.5.3 For coarse-grained soils, the test shall be carried out as follows:

(i) 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).

(ii) Remove the lid and place the container and contents in the oven and dry at 45 ± 5°C. Do not replace the lid while the sample is in the oven. The period required for drying will vary with the type of soil and the size of the sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see Steps (iii) and (iv) below) at intervals of 4 h do not exceed 0.1% of the original mass of the soil.

(iii) After drying, replace the lid and allow the whole to cool.

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

(v) Record the duration of all oven-drying activities to the nearest hour.

5.1.6 Calculations

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

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

where m_1 is the mass of container (in g);
m_2 is the mass of container and wet soil (in g); and
m_3 is the mass of container and dry soil (in g).

5.1.6.2 If the moisture content is to be used for the determination of Atterberg Limits, and the soil contains material retained on a 425 μm sieve, the measured moisture content, w (%), can be corrected to give the equivalent moisture content, w_a (%), 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 Clause 6.1.6.1(vi) of Test Method 6.1.

5.1.6.3 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:

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

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

5.1.6.4 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.

5.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the moisture content,

(c) the duration of all drying activities, and

(d) if undisturbed samples are used for the test where the required sample mass cannot be achieved, the actual mass used.

5.2 Determination of Moisture Content by Oven-drying at 105 ± 5°C

5.2.1 Scope

This method is used for the determination of the moisture content of soil by oven-drying at 105 ± 5°C. The presence of dissolved salts in saline water is not dealt with in this method.

5.2.2 General

The guidance given in Clause 5.1.2 as for Test Method 5.1 shall be noted.

5.2.3 Apparatus

The apparatus as stated in Clause 5.1.3 as for Test Method 5.1 shall be used, except that the drying oven shall be capable of maintaining a temperature of 105 ± 5°C.

5.2.4 Sample Preparation

Sample preparation shall follow Clause 5.1.4 as for Test Method 5.1.

5.2.5 Test Procedures

Test procedures shall follow Clause 5.1.5 as for Test Method 5.1, except that the drying temperature of the oven shall be maintained at 105 ± 5°C.

5.2.6 Calculations

The calculations shall follow Clause 5.1.6 as for Test Method 5.1.

5.2.7 Test Report

The test report shall include all the information as listed in Clause 5.1.7 as for Test Method 5.1.

5.3 Comparative Test for the Determination of Moisture Content by Oven-drying

5.3.1 Scope

This method sets out the standard procedures for carrying out comparative tests on soil samples for the determination of moisture content at the drying temperature of 45 ± 5°C and 105 ± 5°C. The presence of dissolved salts in saline water is not dealt with in this method.

5.3.2 General

The guidance given in Clause 5.1.2 as for Test Method 5.1 shall be noted.

5.3.3 Apparatus

The apparatus as stated in Clause 5.1.3 as for Test Method 5.1 shall be used, except that two drying ovens are required: one shall be capable of maintaining the temperature of 45 ± 5°C, the other shall be capable of maintaining the temperature of 105 ± 5°C.

5.3.4 Sample Preparation

Sample preparation shall follow Clause 5.1.4 as for Test Method 5.1.

5.3.5 Standard Procedures

5.3.5.1 The test procedures in Clause 5.1.5 as for Test Method 5.1 shall be followed.

5.3.5.2 The test procedures are then repeated using the same sample except that the sample is oven-dried at 105 ± 5°C. After this second round of oven-drying, the weighing of the container or bottle and contents shall give a new value m_4.

5.3.6 Calculations

5.3.6.1 The calculation of moisture content shall follow Clause 5.1.6.1 as for Test Method 5.1.

5.3.6.2 The above calculation shall be repeated for the drying of the same sample at 105 ± 5°C except that m_3 shall be replaced by m_4.

5.3.6.3 The moisture contents determined by drying at 45 ± 5°C and 105 ± 5°C, and their difference shall be reported to the nearest 0.1%. No rounding-off of the moisture contents determined at each temperature shall be carried out prior to the calculation of their difference.

5.3.7 Report

The test report shall include all the information as listed in Clause 5.1.7 as for Test Method 5.1. In addition, both the moisture contents obtained as a result of oven-drying at two different temperatures and their difference shall be reported.

6 Determination of Atterberg Limits

6.1 Determination of Liquid Limit, Plastic Limit and Plasticity Index

6.1.1 Scope

This test is used for the determination of the liquid limit, plastic limit and plasticity index of soil.

6.1.2 General

The guidance given in Clause 3.3 shall be noted.

A soil sample should be tested in its as-received state whenever possible. When its initial moisture content is so high that drying is necessary to facilitate the test, this may be achieved by air-drying at room temperature or oven-drying at a temperature of ≤ 50°C. The extent of drying shall be the minimum necessary to enable the testing of the sample. The temperature range (to the nearest 1°C) and duration (to the nearest 1 hour) for this initial drying process shall be recorded. The method of drying shall also be reported.

6.1.3 Apparatus

The following apparatus are required:

(a) apparatus for the determination of moisture content in accordance with Test Method 5.1 or 5.2, as appropriate, except that the balance for fine-grained soils should be accurate to 0.01 g,

(b) test sieves, of sizes 425 μm and 2 mm, with receiver,

(c) a sharp knife,

(d) an implement for shredding cohesive soil,

(e) two palette knives or spatulas,

(f) a corrosion-resistant airtight container large enough to take 200 g to 300 g of wet soil,

(g) a flat glass plate, convenient size being 10 mm thick and about 500 mm square,

(h) a wash bottle containing distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990 (BSI, 1990),

(i) a corrosion-resistant container, of 600 mL or 1000 mL capacity,

(j) a glass stirring rod,

(k) a penetrometer as used for bituminous material testing complying with BS 2000 : Part 50 : 1993 (BSI, 1993),

(l) a cone of stainless steel or duralumin of about 35 mm long, with a smooth, polished surface and an angle of 30 ± 1°. 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 6.1),

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

(m) one or more metal cups, 55 ± 2 mm in diameter and 40 ± 2 mm deep with the rim parallel to the flat base,

(n) an evaporating dish, about 150 mm in diameter,

(o) a metal straightedge about 100 mm long on a straight-bladed spatula,

(p) a stopclock or stopwatch readable to 1 s,

(q) a flat glass plate, a convenient size being 10 mm thick and about 500 mm square on which the soil is mixed,

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

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.

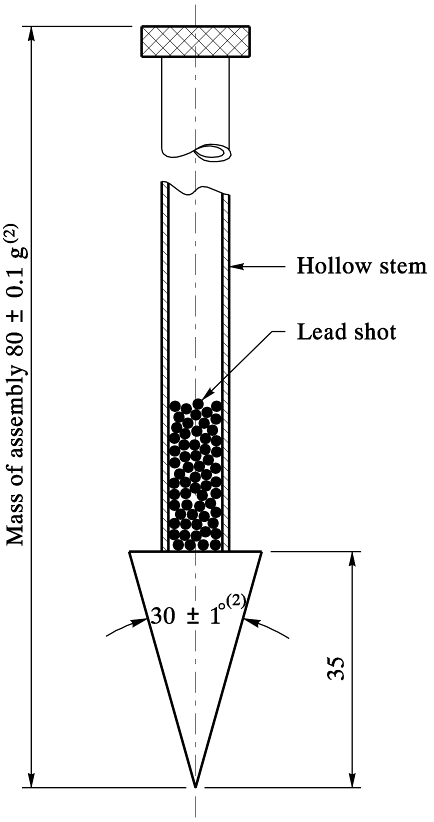
(s) a rod 3 mm in diameter and about 100 mm long.

6.1.4 Sample Preparation

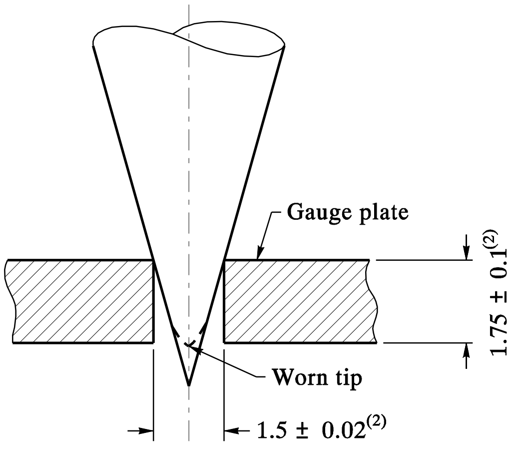
6.1.4.1 Preparation of sample shall be carried out in accordance with Clauses 4.2, 4.3, 4.4 and 4.5, as appropriate.

6.1.4.2 The minimum mass of soil passing a 425 μm test sieve required for the preparation of a test specimen shall be as follows:

Liquid Limit (Cone Penetrometer Method)	Plastic Limit
300 g	20 g



(a) Cone Assembly



(b) Tip Gauge

Notes:
(1) all dimensions shown are in millimetres.
(2) these are manufacturing tolerances or limits on the essential dimensions.
(3) all other dimensions are given for guidance only.

Figure 6.1 Details of Cone for the Liquid Limit Test

6.1.4.3 For soils in the natural state containing little or no material retained on a 425 μm sieve, separation of coarse particles shall be carried out by hand as follows:

(i) Take a representative sample from the soil weighing about 500 g. Cut it into small pieces using a knife or shredder.

(ii) Remove any coarse particles by hand or with tweezers. Determine the mass of particles removed and the mass of sample remained.

(iii) Transfer the soil to a flat glass plate. Add distilled water and mix thoroughly with two palette knives for at least 10 minutes or until the mass becomes a thick homogeneous paste, whichever is longer. All mixing time shall be recorded to the nearest minute.

(iv) Place the paste in an airtight container and allow it to stand for at least 24 h long enough to enable the water to permeate through the soil.

6.1.4.4 For soils containing material retained on a 425 μm sieve, separation of coarse particles shall be carried out by wet sieving as follows:

(i) 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.

(ii) From the sample take a representative specimen and determine its moisture content, w_n (in %), in accordance with Test Method 5.1 or 5.2, as appropriate.

(iii) Weigh the remainder of the sample 1 g (m_6).

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

(v) Wet sieve the soil sample by pouring 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 the sieve and into the receiver, or into a large container if necessary, until the water passing the 425 μm test sieve is virtually clear. The wet sieving process may be assisted by crumbling by hand but care must be taken to prevent any loss of fines during sieving. Any aggregations of particles in the as-received soil sample shall be broken up by mechanical disaggregation in accordance with Clause 4.5.1, such that only constituent particles are to be retained on a 425 μm test sieve. Care should be taken to ensure that the test sieve is not overloaded (see Table 6.1 below).

Table 6.1 Maximum Allowable Mass of Materials Retained on Each Test Sieve in Wet Sieving

Maximum Mass of Materials to be Retained on Each Test Sieve at the Completion of Sieving			
Test Sieve Aperture Size	Maximum Mass on Sieve of Diameter		
	450 mm	300 mm	200 mm
(mm)	(kg)	(kg)	(g)
50	10	4.5	–
37.5	8	3.5	–
28	6	2.5	–
20	4	2.0	–
14	3	1.5	–
10	2	1.0	–
6.3	1.5	0.75	–
5	1.0	0.5	–
3.35	–	–	300
2	–	–	200
1.18	–	–	100
(μm)			
600	–	–	75
425	–	–	75
300	–	–	50
212	–	–	50
150	–	–	40
63	–	–	25

Note: The maximum amount of material initially on the 63 μm test sieve shall not exceed:
150 g for a 200 mm diameter test sieve,
350 g for a 300 mm diameter test sieve, and
750 g for a 450 mm diameter test sieve.

(vi) Collect together the washed material retained on the sieves, dry it at 45 ± 5°C or 105 ± 5°C, as appropriate, and weigh it to an accuracy of 1 g (m_7).

Note: In order to prevent any alteration of material properties as a result of drying at high temperatures, drying of the washed material retained on the sieves shall be carried out at the same oven temperature as that used for the determination of the moisture content (w_n).

(vii) Allow the fine soil particles in the wash water to settle in the receiver for a suitable period and then pour off any clear water from the suspension.

(viii) Allow the suspension to partially dry in a current of warm air, protected from dust, until it forms a stiff paste to the desired consistency.

Note: A suitable consistency corresponds to not more than 15 mm penetration of the cone penetrometer liquid limit apparatus.

6.1.5 Test Procedures

6.1.5.1 The procedures for the determination of liquid limit shall be as follows:

(i) Take a specimen of about 300 g from the soil paste prepared as specified in Clause 6.1.4 (sieved or un-sieved) and place it on the glass mixing plate.

(ii) Mix the paste for at least 10 min or until the soil mass becomes a thick homogeneous paste, whichever is longer, using the two palette knives. If necessary add more distilled water so that the first cone penetration reading is about 15 mm. All mixing times shall be recorded to the nearest minute.

Note: Some soils, such as clays of high plasticity and residual soils, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results. Comparative tests should be carried out if this is in doubt.

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

(iv) With the penetration cone locked in the raised position, adjust 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 so that it comes into contact with the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm.

(v) 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 so that it comes into contact with the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm. Record the difference in dial gauge readings before and after the drop of the cone penetration.

(vi) Lift up the cone and clean it carefully to avoid scratching.

(vii) Add a little more wet soil to the cup, taking care not to trap any air, make the surface smooth as in Step (iii) above and repeat Steps (iv) to (vi).

(viii) If the difference between the first and second penetration readings is less than or equal to 0.5 mm, record the average of the two penetrations and proceed to Step (ix) below. 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 Step (ix) below. If the overall range is more than 1 mm, remove the soil from the cup, remix the soil for at least 10 minutes or until the soil mass becomes a thick homogeneous paste, whichever is longer. All mixing times shall be recorded to the nearest minute. Repeat the above Steps (iii) to (viii) until consistent results are obtained and then proceed to Step (ix) below.

(ix) Take a moisture content specimen of about 10 g from the area penetrated by the cone and determine the moisture content in accordance with Test Method 5.1 or 5.2, as appropriate, except that Clauses 5.1.4 and 5.2.4 need not be followed.

(x) Repeat the above Steps (iii) to (ix) at least three more times using the same specimen to which more distilled water have been added. The re-mixing of soil shall be carried out for at least 10 minutes or until the soil mass becomes a thick homogeneous paste, whichever is longer. All mixing times shall be recorded to the nearest minute. 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. When soil is removed from the cup each time for the addition of water, wash and dry the cup.

(xi) If at any time during the above procedure the soil has to be left for some time on the glass plate, cover the soil with an evaporating dish or a damp cloth to prevent the soil from drying out.

6.1.5.2 The procedures for the determination of plastic limit shall be as follows:

(i) Take a specimen of about 20 g from the soil paste prepared as specified in Clause 6.1.4 (sieved or un-sieved) and place it on the glass mixing plate.

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

(iii) 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 specimen into two halves of about 10 g each and carry out a separate determination on each half. Divide each half into four approximately equal parts and treat each part as specified in the following Steps (iv) to (viii).

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

(v) 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 ten 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, and not to reduce the pressure as the thread diameter approaches 3 mm.

(vi) 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 Step (v) above.

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

(vii) Repeat the previous Step (vi) 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.

(viii) Gather together the pieces of crumbled soil thread, transfer them to a suitable container and replace the lid immediately.

(ix) Repeat Steps (iv) to (viii) above on the other three parts of the half specimen, placing them all in the same container. Determine the moisture content of the soil in the container in accordance with Test Method 5.1 or 5.2, as appropriate.

(x) Repeat Steps (iii) to (ix) above on the other half specimen formed in Step (iii).

6.1.6 Calculations

6.1.6.1 Determine the liquid limit as follows:

(i) Calculate the moisture content of each moisture content specimen as specified in Test Method 5.1 or 5.2, as appropriate.

(ii) Plot the relationship between moisture content and cone penetration with the percentage moisture contents as abscissas and the cone penetrations as ordinates, both on linear scales.

(iii) Draw the best straight line fitting the plotted points.

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

(v) 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.

(vi) For the sieved soil sample, calculate the percentage of material passing the 425 µm test sieve correct to the nearest whole number as below:

Calculate the dry mass, m_d (in g), of the initial sample from the equation below:

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

where w_n is the moisture content (in %) as determined in Clause 6.1.4.4 (ii); and

m_6 is the mass of the samples (in g) as determined in Clause 6.1.4.4 (iii).

Calculate the percentage of particles passing the 425 µm test sieve, p_a, from the equation below, and express it to the nearest whole number:

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

where m_7 is the mass of the sample (in g) as determined in Clause 6.1.4.4 (vi).

6.1.6.2 Determine the plastic limit as follows:

(i) Calculate the moisture content of both moisture content specimens used in the plastic limit test in Clause 6.1.5.2 in accordance with Test Method 5.1 or 5.2 as appropriate. If the two results differ by more than 0.5% moisture content, repeat the whole test.

(ii) Calculate the average of the two moisture content values and express to the nearest whole number. This is the plastic limit, w_p.

(iii) Calculate the plasticity index, I_p, from the equation below:

$$I_p = w_L - w_p$$

Three significant figures shall be used for w_L and w_p. The final result shall then be reported to the nearest whole number.

6.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the liquid limit, the plastic limit and the plasticity index, unless it is not possible to determine the plastic limit in which case this shall be reported,

(c) the percentage of material passing the 425 μm test sieve, and

(d) the history of the sample, report as either "Tested as-received", "Tested after air-drying" or "Tested after oven-drying at ≤ 50°C"; except for samples tested in their as-received state, the temperature range (to the nearest 1°C) and duration (to the nearest 1 hour) of the initial drying of the sample shall also be reported; if wet sieving has been carried out, indicate that "the sample has been subjected to wet sieving".

6.2 Determination of Liquidity Index

6.2.1 Scope

This method is used for the determination of the liquidity index of soil.

6.2.2 General

The guidance given in Clause 3.3 shall be noted.

6.2.3 Standard Procedures

6.2.3.1 Determine the liquid limit (w_L) and the plastic limit (w_p) in accordance with Test Method 6.1, except for the higher precision of the results to be reported to 3 significant places instead of 1.

6.2.3.2 Determine the moisture content, w_a, of the fraction of the soil sample which passes a 425 μm test sieve, in its natural condition, in accordance with Test Method 5.1 or 5.2 (see Clauses 5.1.6.2 and 5.1.6.3), as appropriate.

6.2.4 Calculations

Calculate the liquidity index, I_L, from the following equation:

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

Three significant figures shall be used for w_a, w_L and w_p. The final result shall then be reported to two decimal places.

6.2.5 Report

The report shall affirm that the determination of the liquidity index was determined in accordance with this method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the liquidity index, unless it is not possible to determine the plastic limit in which case this shall be reported, and

(c) the history of the sample, report as either “Tested as-received”, “Tested after air-drying” or “Tested after oven-drying at ≤ 50°C”; except for samples tested in their as-received state, the temperature range (to the nearest 1°C) and duration (to the nearest 1 hour) of the initial drying of the sample shall also be reported; if wet sieving has been carried out, indicate that “the sample has been subjected to wet sieving”.

7 Determination of Particle Density

7.1 Determination of Particle Density by Gas Jar Method

7.1.1 Scope

This method is the definitive method for the determination of particle density for soils containing up to 10% of particles retained on a 37.5 mm test sieve.

7.1.2 General

The guidance given in Clause 3.4 shall be noted.

7.1.3 Apparatus

The following apparatus are required:

(a) a gas jar, 1 L in capacity, fitted with a rubber bung,

Note: A gas jar has been found to make a very effective pyknometer but any container of similar capacity can be used provided that it can be shaken in a mechanical shaking apparatus, and that the mouth can be sealed in such a way that there is no leakage.

(b) a ground glass plate for closing the gas jar,

(c) a mechanical shaking apparatus capable of rotating the gas jar, end over end, at about 50 revolutions/min,

Note: An end-over-end shaker has been specified but shaking machines giving a vibrating motion would also be suitable. The choice of shaking machine depends on the type of pyknometer used.

(d) a balance, readable to 0.1 g and accurate to 0.3 g,

(e) a thermometer to cover the temperature range from 0°C to 40°C, accurate to 0.5°C,

(f) a drying oven, capable of maintaining the temperature of 45 ± 5°C or 105 ± 5°C, as appropriate, and

(g) a riffling box.

7.1.4 Sample Preparation

7.1.4.1 A sample of soil of about 1 kg mass shall be prepared as specified in Clauses 4.2, 4.4 and 4.5. Coarse material in excess of 10% retained on a 37.5 mm test sieve, or any particles retained on a 50 mm test sieve, shall be broken up to less than 37.5 mm size.

7.1.4.2 At least two specimens shall be obtained from the sample by riffling. These duplicate specimens are needed for two separate determinations of the particle density. The minimum mass of soil for the preparation of a test specimen shall be as follows:

Fine-grained	Medium-grained	Coarse-grained
200 g	300 g	400 g

7.1.5 Test Procedures

7.1.5.1 Clean and dry the gas jar and ground glass plate and weigh them together to the nearest 0.1 g (m_1).

7.1.5.2 Transfer the first soil specimen from its sealed container directly into the gas jar. Weigh the gas jar, ground glass plate and contents to the nearest 0.1 g (m_2).

7.1.5.3 Add about 500 mL of water at a temperature within ± 2°C of the average room temperature during the test to the soil. Insert the rubber stopper into the gas jar. For medium- and coarse-grained soils, set aside for at least 4 h.

Note: If there is a large difference between the room temperature and the water temperature, sufficient water should be drawn for the required number of tests and allowed to stand in the room in which the tests are being done until the temperature is within the given range.

7.1.5.4 Immediately after the addition of water in the case of fine-grained soils, or after setting aside for 4 h in case of medium- and coarse-grained soil, shake the gas jar by hand until the particles are in suspension.

7.1.5.5 Place the gas jar securely in the shaking apparatus and shake for a period of 20 min to 30 min.

7.1.5.6 Remove the stopper carefully and wash any soil particles adhering to the stopper or the top of the gas jar into the jar. Disperse any froth with a fine spray of water. Add water to the gas jar to within 2 mm of the top and allow the soil to settle for a few minutes, then fill the gas jar to the brim with more water. Place the ground glass plate on the top of the jar taking care not to trap any air under the plate.

Note: This operation may be easier if the gas jar is inclined under a slow stream of water while the ground glass plate is slid upwards over the rim.

7.1.5.7 Dry the gas jar and plate carefully on the outside and weigh the whole to the nearest 0.1 g (m_3).

7.1.5.8 Empty the gas jar, wash it out thoroughly and fill it to the brim with water at a temperature within ± 2°C of the average room temperature. Place the ground glass plate in position taking care not to trap any air under the plate. Ensure that the water in the jar contains no air bubbles.

7.1.5.9 Dry the gas jar and plate carefully on the outside and weigh the whole to the nearest 0.1 g (m_4).

7.1.5.10 Repeat the above Clauses 7.1.5.1 to 7.1.5.7 using the second specimen of the same sample so that two values of particle density can be obtained. If the results differ by more than 0.03 Mg/m^3 repeat the tests.

7.1.6 Calculations

7.1.6.1 Calculate the particle density, ρ_s (in Mg/m^3), from the equation:

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where m_1 is the mass of gas jar and ground glass plate (in g);
m_2 is the mass of gas jar, plate and soil (in g);
m_3 is the mass of gas jar, plate, soil and water (in g); and
m_4 is the mass of gas jar, plate and water (in g).

7.1.6.2 Calculate the average of the results obtained from testing the two specimens if they differ by no more than 0.03 Mg/m^3.

7.1.6.3 Express the average value of particle density to the nearest 0.01 Mg/m^3.

7.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the average value of the particle density of the soil sample, and

(c) for saprolitic, residual or colluvial soils, the type of drying process adopted, including air-drying or oven-drying, if any drying has been carried out during sample preparation.

7.2 Determination of Particle Density by Small Pyknometer Method

7.2.1 Scope

This method is the definitive method for the determination of particle density for soils consisting of particles finer than 2 mm.

7.2.2 General

The guidance given in Clause 7.1.2 as for Test Method 7.1 shall be noted.

7.2.3 Apparatus

The following apparatus are required:

(a) two 50 mL density bottles (pyknometers) with stoppers, complying with BS 733 : Part 2 : 1987 (BSI, 1987),

(b) a water bath maintained at a constant temperature in the range 20°C to 30°C to within ± 0.2°C,

(c) a vacuum desiccator with protective cage and a vacuum gauge accurate to at least 5 mm,

(d) a desiccator containing anhydrous silica gel,

(e) a drying oven, capable of maintaining the temperature of 45 ± 5°C or 105 ± 5°C, as appropriate,

(f) a source of vacuum, e.g. a filter pump or a vacuum pump,

(g) a chattaway spatula having a blade small enough to go through the neck of the density bottle, or a piece of glass rod about 150 mm long and 3 mm diameter,

(h) a wash bottle containing air-free distilled water,

Note 1: Air-free distilled water may be obtained by boiling a quantity of water for at least 30 min in a container that can be sealed from the atmosphere during cooling. Take care to see that the container is strong enough to resist the reduction in pressure inside it during cooling.

Note 2: With non-polar materials, e.g. coal particles, the use of a wetting agent may be necessary. Add 20% by volume of a very dilute solution of wetting agent in distilled water in the wash bottle. A longer period under vacuum may be required.

(i) a sample divider of the multiple slot type (riffle box) with a 5 to 7 mm width of opening,

(j) a length of rubber vacuum tubing to fit the vacuum pump and the desiccator, and

(k) a balance, readable to 0.001 g and accurate to 0.005 g.

7.2.4 Sample Preparation

7.2.4.1 A sample of soil of about 100 g shall be obtained as specified in Clauses 4.2, 4.4 and 4.5. Large particles shall be ground to pass a 2 mm test sieve.

7.2.4.2 At least two specimens, each between 5 g and 10 g, shall be obtained by riffling. These duplicate specimens are needed for two separate determinations of particle density, which may be carried out concurrently.

7.2.5 Test Procedures

7.2.5.1 Clean the density bottle and stopper. Dry by rinsing with acetone or an alcohol-ether mixture and then blowing warm air through it. Weigh the bottle with the stopper to the nearest 0.001 g (m_1).

Note: In order to avoid distortion, the density bottle should not be dried by placing it in an oven.

7.2.5.2 Transfer the first specimen to the density bottle direct from its sealed container. Weigh the bottle, contents and stopper to the nearest 0.001 g (m_2).

7.2.5.3 Add sufficient air-free distilled water or other liquid (see Note below) just to cover the soil in the bottle, without disturbing the soil excessively. Place the bottle and contents, without the stopper, in the vacuum desiccator. Evacuate the desiccator gradually, reducing the pressure to about 20 mm of mercury. Take care during this operation to ensure that air trapped in the soil does not bubble too violently, which could lead to small drops of suspension being lost through the mouth of the bottle. When using a vacuum pump, take care to ensure that the required vacuum is maintained.

Leave the bottle in the evacuated desiccator for at least 1 h until no further loss of air is apparent.

Note: With certain soils such as those containing soluble salts, kerosene (paraffin oil) or white spirit may be preferable to distilled water. If one of these is used, record the fact and carry out a separate experiment to determine the density of the liquid at the temperature of the test.

7.2.5.4 Release the vacuum and remove the lid of the desiccator. Stir the soil in the bottle carefully with the chattaway spatula, or vibrate the bottle. Before removing the spatula from the bottle, wash off any particles of soil adhering to the blade with a few drops of air-free liquid. Replace the lid of the desiccator and evacuate it again as specified in the previous Clause 7.2.5.3.

7.2.5.5 Repeat Clauses 7.2.5.3 and 7.2.5.4 until no more air is evolved from the soil.

Note: Experience has shown that the largest source of error in the test comes from the difficulty in ensuring the complete removal of air from the specimen. To obtain reliable results, the soil should be left under vacuum for several hours, preferably overnight.

7.2.5.6 Remove the density bottle and contents from the desiccator and add more air-free liquid to fill the bottle. Insert the stopper and immerse the bottle up to the neck in the constant-temperature bath. Leave the bottle in the bath for at least 1 h or until the contents have attained the constant temperature of the bath.

Note: If a constant-temperature room or cabinet is available then this procedure need not be carried out in a water bath.

7.2.5.7 If there is an apparent decrease in the volume of the liquid, remove the stopper, add more liquid to fill the bottle and replace the stopper. Return the bottle to the bath and again allow the contents to attain the constant temperature.

Note: If surplus liquid other than water exudes through the capillary in the stopper, it should be carefully absorbed by a filter paper to avoid contamination of the water bath.

7.2.5.8 Repeat Clause 7.2.5.7 if necessary until the bottle remains completely full.

7.2.5.9 Take the stoppered bottle out of the bath, carefully wipe it dry with the minimum of handling and weigh the whole to the nearest 0.001 g (m_3).

7.2.5.10 Clean out the bottle, fill it completely with de-aerated liquid, insert the stopper and immerse the bottle in the constant temperature bath for the period specified in Clause 7.2.5.6.

7.2.5.11 If necessary fill the bottle as specified in Clauses 7.2.5.7 and 7.2.5.8.

7.2.5.12 Take the stoppered bottle out of the bath, wipe it dry as specified in Clause 7.2.5.9 and weigh it to the nearest 0.001 g (m_4).

Note 1: If Clause 7.2.5.10 is used to find the volume of the density bottle, then the test may be carried out at any temperature provided it is constant throughout the test.

Note 2: Clauses 7.2.5.10 to 7.2.5.12 can be carried out yearly provided that the density bottle has no damage and the temperature of the water bath, as specified in Clause 7.2.3 (b), is maintained at the same temperature as in Clauses 7.2.5.6 to 7.2.5.8.

7.2.5.13 Repeat Clauses 7.2.5.1 to 7.2.5.9 using the second specimen of the same sample so that two values of particle density can be obtained. If the results differ by more than 0.03 Mg/m^3, repeat the test.

Note: Many soils have a substantial proportion of heavier or lighter particles. Such soils will give erratic values for the particle density even with the greatest care in testing and a number of repeated tests may be needed to obtain a good average value.

7.2.6 Calculations

7.2.6.1 Calculate the particle density, ρ_s (in Mg/m^3), from the equation:

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where m_1 is the mass of density bottle (in g);
m_2 is the mass of bottle and dry soil (in g);
m_3 is the mass of bottle, soil and water (in g); and
m_4 is the mass of bottle when full of water only (in g).

7.2.6.2 If liquid other than distilled water is used in Clause 7.2.5.3, the particle density of the soil, ρ_s (in Mg/m^3), shall then be calculated from the following equation:

$$\rho_s = \frac{\rho_L (m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$$

where ρ_L is the density of the liquid used at constant temperature (in Mg/m^3);
m_1 is the mass of density bottle (in g);
m_2 is the mass of bottle and dry soil (in g);
m_3 is the mass of bottle, soil and liquid (in g); and
m_4 is the mass of bottle when full of liquid only (in g).

7.2.6.3 Calculate the average of the results obtained from testing the two specimens if they differ by no more 0.03 Mg/m^3.

7.2.6.4 Express the average value of the particle density to the nearest 0.01 Mg/m^3.

7.2.7 Report

The test report shall include all the information as listed in Clause 7.1.7 for Test Method 7.1, and the liquid used other than distilled water.

8 Determination of Particle Size Distribution

8.1 Determination of Particle Size Distribution by Wet Sieving (with Dispersant)

8.1.1 Scope

This test is used for the determination of the particle size distribution of soil by wet sieving. In this method the soil is pretreated with a dispersant.

8.1.2 General

The guidance given in Clause 3.5 shall be noted.

Soil samples will be prepared and tested by different methods depending on whether they are saprolitic, residual or colluvial soils, or are soils other than saprolitic, residual or colluvial soils. If there is any uncertainty about the geological origin of a soil sample, it shall be treated as a saprolitic, residual or colluvial soil by default.

8.1.3 Apparatus

The following apparatus are required:

(a) test sieves having the following aperture sizes:

75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm, 6.3 mm, 5 mm, 3.35 mm, 2 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm, 63 µm and appropriate receivers,

Note 1: Alternatively, test sieves complying with BS 410 : 2000 (BSI, 2000) having the ISO series of aperture sizes may be used.

Note 2: The aperture sizes of the test sieves used for the test should adequately cover the range for the particular soil sample tested, but it will not generally be necessary to use every size for a test.

(b) a balance, readable to 1 g and accurate to 3 g,

(c) a balance, readable to 0.1 g and accurate to 0.3 g,

(d) sample dividers, e.g. the multiple slot type (riffle boxes),

(e) a drying oven, capable of maintaining the temperature of 45 ± 5°C or 105 ± 5°C, as appropriate,

(f) an evaporation dish of about 150 mm diameter,

(g) a corrosion-resistant tray, a convenient size being about 300 mm square and 40 mm deep,

(h) two or more large corrosion-resistant metal or plastic watertight trays with sides of about 80 mm deep, or a bucket of about 12 L capacity,

(i) a scoop,

(j) sieve brushes, and a wire brush or similar stiff brush,

(k) a quantity of rubber tubing of about 6 mm internal diameter,

(l) a sprayer such as a small watering-can hose,

(m) a mechanical sieve shaker (optional), and

(n) sodium hexametaphosphate solution, as the dispersant, which shall be prepared by dissolving 2 g of sodium hexametaphosphate in distilled water to make 1 litre of solution. The sodium hexametaphosphate solution shall be freshly prepared once a month. The date of preparation shall be recorded on the bottle.

8.1.4 Sample Preparation

8.1.4.1 Assessment sieving of soil shall be carried out in accordance with Clause 4.2.

8.1.4.2 The minimum mass of soil required for a test sample shall be as follows:

Fine-grained	Medium-grained	Coarse-grained
150 g	2.5 kg	17 kg

8.1.4.3 The sample shall then be subdivided as specified in Clause 4.5.2 to give the minimum mass of soil for the preparation of a test specimen for sieving as specified in Table 8.1.

8.1.4.4 Drying of soil, where necessary, shall be carried out as specified in Clause 4.4, except that oven-drying at 105 ± 5°C shall not be carried out for saprolitic, residual or colluvial soils.

8.1.4.5 The soil may be mechanically disaggregation in its as-received state using a rubber pestle and mortar, in accordance with Clause 4.5.1. For saprolitic, residual or colluvial soils, large lumps of soil can be crumbled by hand.

Table 8.1 Minimum Mass of Soil Specimen for Sieving

Maximum Size of Material Present in Substantial Proportion (More Than 10%) Test Sieve Aperture (mm)	Minimum Mass of Specimen to be Taken for Sieving (kg)
63	50
50	35
37.5	15
28	6
20	2
14	1
10	0.5
6.3	0.2
5	0.2
3.35	0.15
2 or smaller	0.1

8.1.5 Test Procedures

8.1.5.1 For soils other than saprolitic, residual or colluvial soils, the procedures shall be as follows (Figure 8.1 - Method A):

(i) Weigh the dried test sample to 0.1% of its total mass (m_1).

(ii) Place the sample on the 20 mm test sieve and brush any particles too coarse to pass through the test sieve with a wire brush or similar stiff brush until the individual particles are cleared of any finer materials.

Note: If adhering fine material cannot be removed easily by brushing, the following procedures may be followed:
(1) Remove the fine particles from the coarse particles by washing.
(2) Dry and weigh the coarse particles to 0.1% of their mass.
(3) Dry the washings, add them to the soil passing the 20 mm test sieve, and mix thoroughly.

Take care when dealing with soft materials to ensure that the brushing does not remove parts of the coarse particles.

Sieve the fraction retained on the 20 mm test sieve using appropriate larger test sieves and weigh the amount retained on each test sieve. If any test sieve becomes overloaded, sieve the material on the test sieve in parts, and each part shall not exceed the limits given in Table 6.1.

(iii) Weigh the portion of the dried soil passing the 20 mm test sieve to 0.1% of its total mass, m_2. Riffle the portion so that a test specimen of the required minimum mass as specified in Table 8.1 is obtained. Weigh the specimen to 0.1% of its total mass, m_3.

(iv) Spread the soil specimen in the large tray, or place it in a bucket, and cover it with water. Add sodium hexametaphosphate to the water.

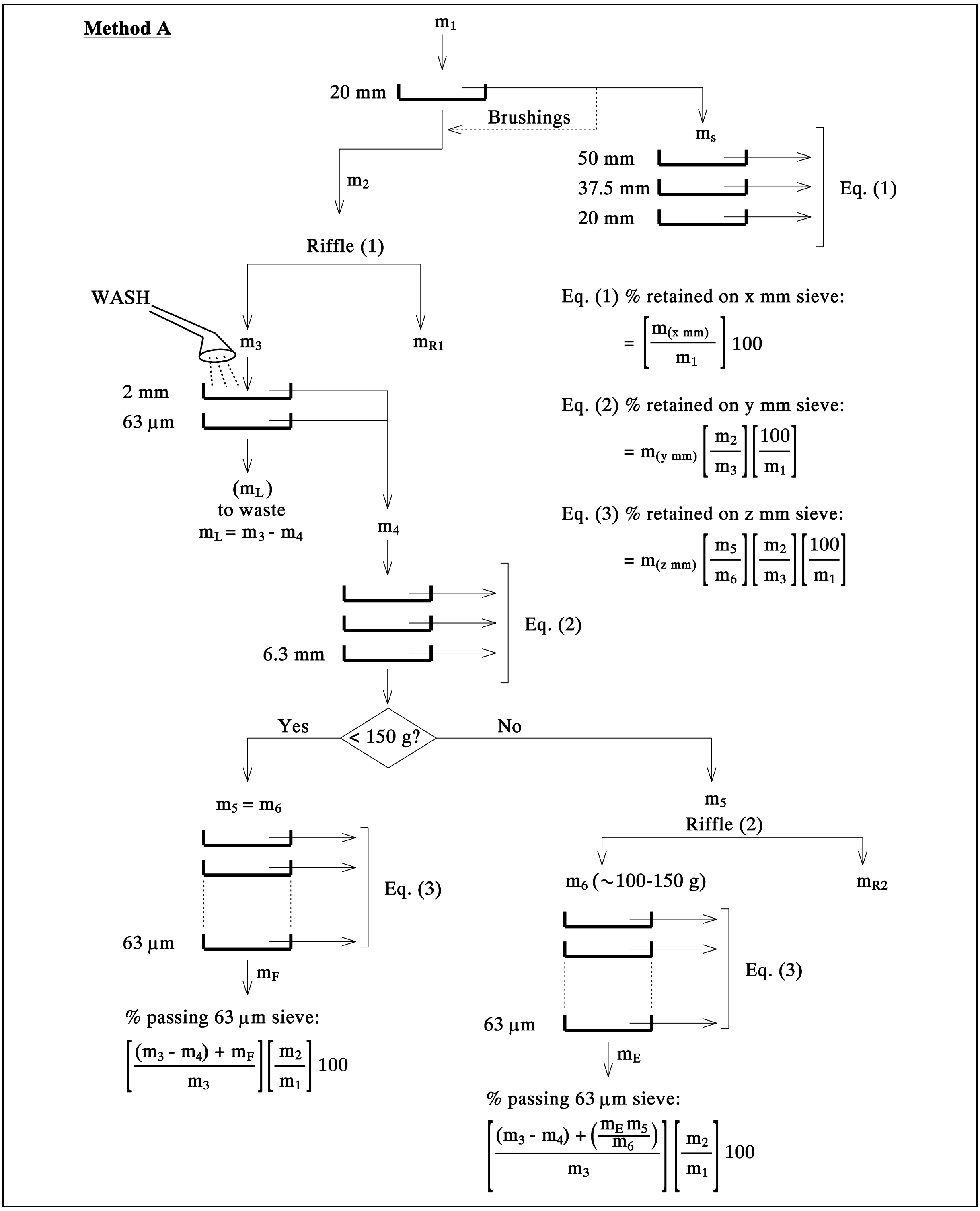


Figure 8.1 Procedure for Wet Sieving - Method A

(v) Stir the mixture well to wet the soil and break down any lumps of soil. Allow the mixture to stand for at least 1 h. During this period, the solution shall be stirred by hand for approximately 30 seconds at intervals of about 10 minutes.

(vi) Wash the soil specimen, a little at a time, through a 2 mm test sieve nested in a 63 μm test sieve, allowing the soil passing the 63 μm sieve to run to waste. Continue washing until the water passing the 63 μm test sieve is virtually clear. Ensure that the two test sieves are not overloaded in the process, either with solids or with water (see Table 6.1). The maximum amount of material initially on the 63 μm test sieve shall not exceed 150 g for a 200 mm diameter test sieve, 350 g for a 300 mm diameter test sieve or 750 g for a 450 mm diameter test sieve.

(vii) Transfer all the soil retained on both the sieves into a tray or evaporating dish and dry it in an oven at 45 ± 5°C or 105 ± 5°C, as appropriate.

Note: The soil should not be dried on the sieves, as it is detrimental to the sieves upon heating.

(viii) Weigh the dried fraction when cooled, to 0.1% of its total mass, m_4.

(ix) Sieve the dried fraction through the appropriate sieves down to the 6.3 mm test sieve, using the dry sieving procedure as follows:

Note: Although the 6.3 mm test sieve is specified as the size at which riffling is carried out, test sieves of other aperture size may be used to fit the grading of the soil. The principle remains the same, but the relevant worksheet should be modified accordingly.

(1) Fit to the receiver the test sieve of the largest aperture size appropriate to the maximum size of the soil particles present, and put the specimen on the sieve (see BS 1796 : Part 1 : 1989 (BSI, 1989)).

Note: If the assembly is not too heavy to handle, several sieves, in order of aperture size, may be fitted together and used at the same time.

(2) Agitate the test sieve so that the soil rolls in an irregular motion over the test sieve. Particles may be hand placed to see if they will fall through but they shall not be pushed through. Make sure that only individual particles are retained. Weigh the amount retained on the test sieve to 0.1% of its total dry fraction.

(3) Transfer the soil retained in the receiver to a tray and fit the receiver to the test sieve of the next largest aperture. Place the contents of the tray on the sieve and repeat Step (2) above.

Note: If the mass of the soil passing the 20 mm test sieve is substantially greater than 2 kg, the sample should be riffled to obtain a specimen of about 2 kg and due allowance should be made in the calculation for the subdivision of the original sample.

(4) Repeat Steps (2) and (3) through all the test sieve sizes used.

(5) If any test sieve becomes overloaded, sieve the soil on the test sieve in parts, and each part shall not exceed the limit given in Table 6.1.

(x) If the fraction passing the 6.3 mm test sieve is small, i.e. not more than 150 g, the soil may be sieved by dry sieving on the appropriate sieves down to and including the 63 µm test sieve. Weigh the amount retained on each sieve, and any fines passing the 63 µm test sieve, m_F, to 0.1% of its total fraction passing the 6.3 mm sieve.

Note 1: If a mechanical shaker is available, Clauses 8.1.5.1 (ix) and (x) above can be performed in one operation provided that the test sieves are all of the same diameter. Take care to ensure that sieving is complete. The period of shaking shall be at least 10 min. but not more than 20 min.

Note 2: See Note to Clause 8.1.5.1 (ix) above.

(xi) If the fraction passing the 6.3 mm test sieve is large, i.e. substantially greater than 150 g, weigh it (m_5), and then riffle it so that a fraction of 100 g to 150 g is obtained. Weigh this fraction, m_6, and then sieve it using appropriate sieves down to and including the 63 µm test sieve. Weigh the amount retained on each sieve, and any fines passing the 63 µm test sieve, m_E. If riffling is not necessary, m_6 is the same as m_5. Weigh to 0.1% of total fraction passing the 6.3 mm sieve.

Note: See Note to Clause 8.1.5.1 (ix) above.

8.1.5.2 For saprolitic, residual or colluvial soils, the procedures shall be as follows (Figure 8.2 - Method B):

(i) Before weighing the sample to be tested, take at least two representative specimens from the test sample, discard any individual particles larger than 20 mm and determine the moisture contents according to Test Method 5.1 or 5.2 as appropriate. The average of the two results (w%) is taken as the moisture content of the < 20 mm fraction of the sample.

(ii) Weigh the remaining soil in its as-received state to 0.1% of its total mass (W_1).

(iii) Spread the soil out on a tray, or trays, or place it in the bucket and add sufficient dispersant to cover the soil. Stir the mixture well as specified in Clause 8.1.5.1 (v).

(iv) Remove any individual particles larger than 20 mm (referred to here as "stones") by hand, using the 20 mm sieve as a gauge. Brush and wash them with the dispersant, if necessary, to ensure that these stones have been washed free of fine particles, which are to remain with the specimen.

(v) Dry the stones in the oven at the same temperature as that adopted in Step (i) above (i.e. Test Method 5.1 or 5.2, as appropriate) and weigh them when cooled (m_s). Separate the stones into size fractions using larger sieves as required and weigh each size fraction.

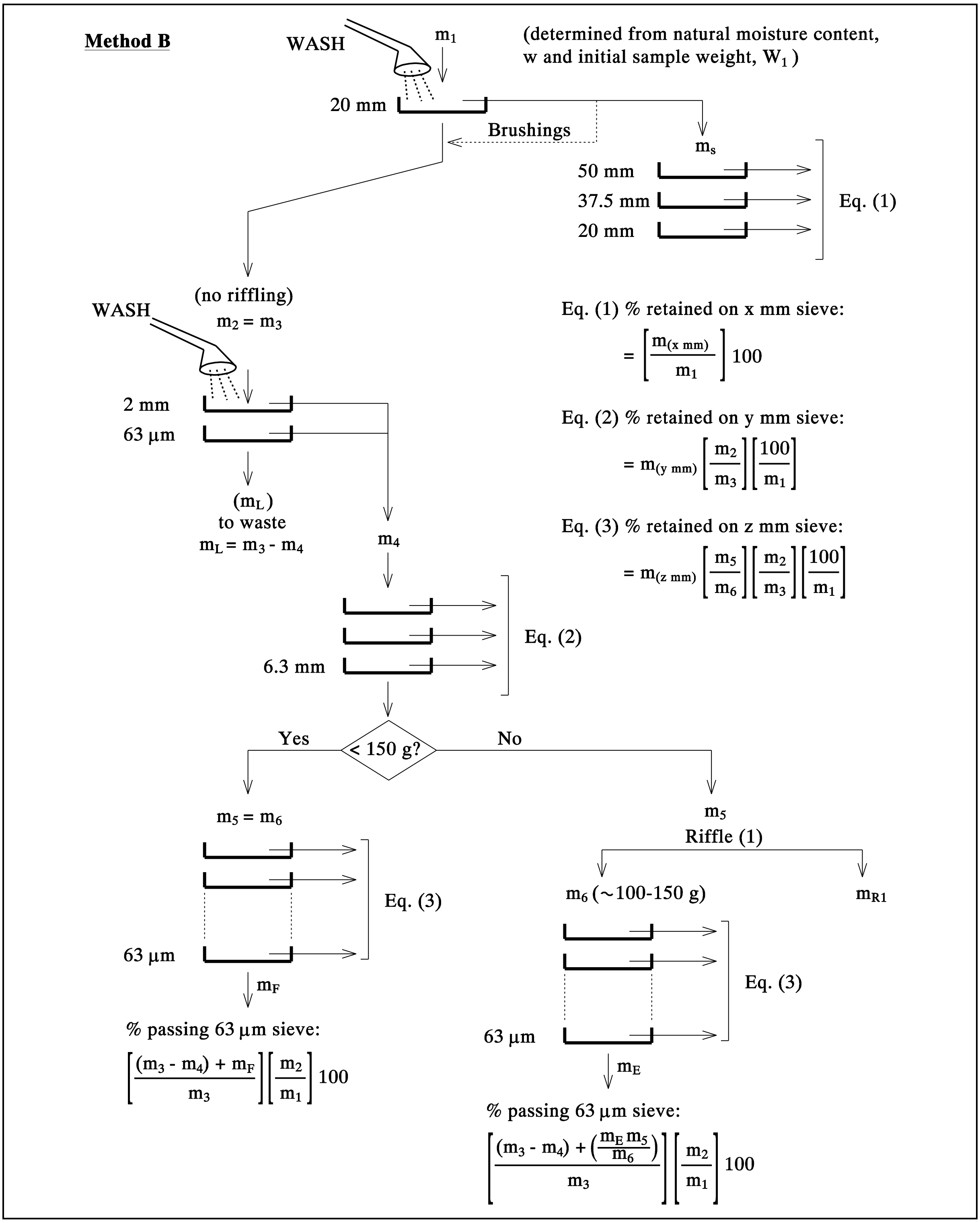


Figure 8.2 Procedure for Wet Sieving - Method B

(vi) Take the specimen from Step (iv) above and wash the soil, a little at a time with a jet or spray of clean water, through a 20 mm sieve nested on a 2 mm sieve which is in turn nested on a 63 μm sieve, allowing the soil passing the 63 μm sieve to run to waste. Continue washing until the water passing the 63 μm test sieve is virtually clear.

(vii) The maximum mass of material to be retained on each test sieve at the completion of sieving is given in Table 6.1. If these quantities are likely to be exceeded, the material shall be sieved separately in two or more portions.

Note: An additional 425 μm or 600 μm sieve can be included to protect the 63 μm sieve from overloading if the soil contains a large proportion of coarse or medium sand.

(viii) Oven-dry the soil retained on these sieves at the same temperature as that used for the determination of moisture content in Step (i) above.

Note: The soil should not be dried on the sieves as it is detrimental to the sieves upon heating.

(ix) Weigh the whole of the retained, washed and dried soil when cooled to 0.1% of its total mass (m_4).

(x) Carry out Clause 8.1.5.1 (ix).

(xi) Carry out Clause 8.1.5.1 (x) or (xi), as appropriate.

8.1.6 Calculations

8.1.6.1 For soils other than saprolitic, residual or colluvial soils (tested using Clause 8.1.5.1 - Method A), perform the calculations as follows:

(i) For samples containing particles larger than 20 mm, calculate the sum of masses of soil retained on each sieve together with the mass of soil m_2, passing the 20 mm sieve. If this sum of masses differs from the initial dry mass m_1 by more than 1%, this stage of the test shall be repeated. Calculate the proportion by mass of soil retained on each of the coarse series of sieves as a percentage of m_1.

For example:

$$\text{Percentage retained on 28 mm sieve} = \left\{ \frac{m_{(28\text{ mm})}}{m_1} \right\} 100$$

(ii) Calculate the sum of masses retained on each sieve together with the mass m_5 passing the 6.3 mm sieve. If this total differs from the dried riffled mass m_4 by more than 1%, this stage of the test shall be repeated.

Calculate the corrected mass of soil retained on each of the sieves between 20 mm and 6.3 mm through multiplying by m_2/m_3, then calculate this mass as a percentage of m_1.

For example:

$$\text{Percentage retained on 10 mm sieve} = m_{(10\,\text{mm})}\left(\frac{m_2}{m_3}\right)\left(\frac{100}{m_1}\right)$$

(iii) Calculate the sum of masses retained on each sieve together with the mass m_F or m_E passing the 63 µm sieve. If this total differs from the dried riffled mass m_6 by more than 1%, this stage of the test shall be repeated. Calculate the corrected mass of soil retained on each of the sieves finer than the 6.3 mm sieve by multiplying by (m_5/m_6) (m_2/m_3) and then calculate this mass as a percentage of m_1.

For example:

$$\text{Percentage retained on 300 µm sieve} = m_{(300\,\mu\text{m})}\left(\frac{m_5}{m_6}\right)\left(\frac{m_2}{m_3}\right)\left(\frac{100}{m_1}\right)$$

(iv) Calculate the cumulative percentages by mass of the soil passing each of the sieves from the general relationship:

(% passing this sieve) =
(% passing previous sieve) – (% retained on this sieve)

(v) Calculate the fraction passing the 63 µm test sieve by difference. The mass of fines lost by washing in Clause 8.1.5.1 (vi) equal to $(m_3 - m_4)$. To this is added the mass of any fine material (m_F) passing the 63 µm sieve when dry sieved (see Clause 8.1.5.1 (x)), and the percentage finer than 63 µm is equal to:

$$\left\{\frac{(m_3 - m_4) + m_F}{m_3}\right\}\left(\frac{m_2}{m_1}\right)100$$

If the sample was subdivided (see Clause 8.1.5.1 (xi)) the mass of fines, m_E, is increased in the ratio m_5/m_6, and the percentage finer than 63 µm is equal to:

$$\left\{\frac{(m_3 - m_4) + \left(\dfrac{m_E m_5}{m_6}\right)}{m_3}\right\}\left(\frac{m_2}{m_1}\right)100$$

where m_1 see Clause 8.1.5.1 (i);
m_2 see Clause 8.1.5.1 (iii);
m_3 see Clause 8.1.5.1 (iii);
m_4 see Clause 8.1.5.1 (viii);
m_5 see Clause 8.1.5.1 (xi);
m_6 see Clause 8.1.5.1 (xi);
m_E see Clause 8.1.5.1 (xi); and
m_F see Clause 8.1.5.1 (x).

Express the results on a semi-logarithmic chart. Alternatively, the results may be reported in the form of a table showing, to the nearest 1%, the percentage by mass passing each of the sieves used.

8.1.6.2 For saprolitic, residual or colluvial soils (tested using Clause 8.1.5.2 - Method B), perform the calculations as follows:

(i) It is assumed that particles larger than 20 mm contain no absorbed water, or that the quantity held is negligible. The undried mass of soil passing 20 mm (W_2) is therefore equal to the undried mass of the original sample with the particles larger than 20 mm removed, i.e.:

$$W_2 = W_1 - m_s$$

Note: If the particles larger than 20 mm contain appreciable amount of absorbed water in their as-received state, this can be measured separately and allowed for by adjusting m_s.

(ii) Since the moisture content of the < 20 mm fraction is known (w%), the dry mass (m_2) of this fraction is given by:

$$m_2 = \frac{100\ W_2}{100 + w}$$

(iii) By adding back the dry mass of particles larger than 20 mm, the initial dry mass (m_1) of the whole sample is obtained:

$$m_1 = m_2 + m_s$$

(iv) This mass (m_1) is used as a starting point for subsequent calculations in accordance with Clauses 8.1.6.1 (i) to (v).

Note: In this case m_3 is equal to m_2 because there is no riffling of the test sample at this stage.

8.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B, and

(b) the particle size distribution curve or the tabulated percentages, as specified in Clause 8.1.6.1 (v).

8.2 Determination of Particle Size Distribution by Wet Sieving (without Dispersant)

8.2.1 Scope

This test is used for the determination of the particle size distribution of soil by wet sieving. It is suitable for soils with particles down to the fine sand size. In this method the soil is mixed with distilled water prior to wet sieving, and no dispersant is used.

8.2.2 General

The guidance given in Clause 8.1.2 as for Test Method 8.1 shall be noted.

8.2.3 Apparatus

The apparatus as listed in Clause 8.1.3 as for Test Method 8.1 shall be used, except that Item (n), the dispersant, is not required, and should be replaced by distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990 (BSI, 1990).

8.2.4 Sample Preparation

Sample preparation shall follow Clause 8.1.4 as for Test Method 8.1.

8.2.5 Test Procedures

The test procedures shall follow Clauses 8.1.5 as for Test Method 8.1, except that distilled water shall be used in Clauses 8.1.5.1(iv) and 8.1.5.2(iii) for soaking the soil. No dispersant should be used.

8.2.6 Calculations

The calculations shall follow Clause 8.1.6, Method A or B as appropriate, as for Test Method 8.1.

8.2.7 Report

The test report shall include all the information as listed in Clause 8.1.7 as for Test Method 8.1.

8.3 Determination of Particle Size Distribution by the Pipette Method (With Dispersant)

8.3.1 Scope

This test is used for the determination of the particle size distribution of soil by the pipette method. In this test the soil is pretreated with a dispersant.

8.3.2 General

The guidance given in Clause 8.1.2 as for Test Method 8.1 shall be noted.

8.3.3 Apparatus

The following apparatus are required:

(a) a sampling pipette of the type illustrated in Figure 8.3, fitted with a pressure and suction inlet, and having a capacity of approximately 10 mL. The pipette shall be so arranged that it can be inserted to a fixed depth into a cylinder (see Item (b) below) when the latter is immersed in a constant-temperature bath (see Figure 8.4),

(b) two glass cylinders, 50 mm diameter and approximately 350 mm long graduated at 500 ± 10 mL volume, with rubber bungs to fit,

(c) nine glass weighing bottles, approximately 25 mm in diameter and 50 mm high fitted with ground glass stoppers. The masses of the bottles shall be known to the nearest 0.001 g,

(d) a constant-temperature bath capable of being maintained at 25°C, into which a cylinder can be immersed up to the 500 mL mark. The bath shall not cause any vibration sufficient enough to disturb a sample,

(e) a mechanical shaker capable of keeping 30 g of soil and 150 mL of water in continuous suspension. A device which is capable of rotating the container end-over-end at 30 revolutions/min to 60 revolutions/min is satisfactory,

(f) a sample divider of the multiple slot type (riffle box),

(g) a balance, readable to 0.001 g and accurate to 0.005 g,

(h) a drying oven, capable of maintaining the temperature of 45 ± 5°C or 105 ± 5°C, as appropriate,

(i) a stopclock or stopwatch readable to 1 s,

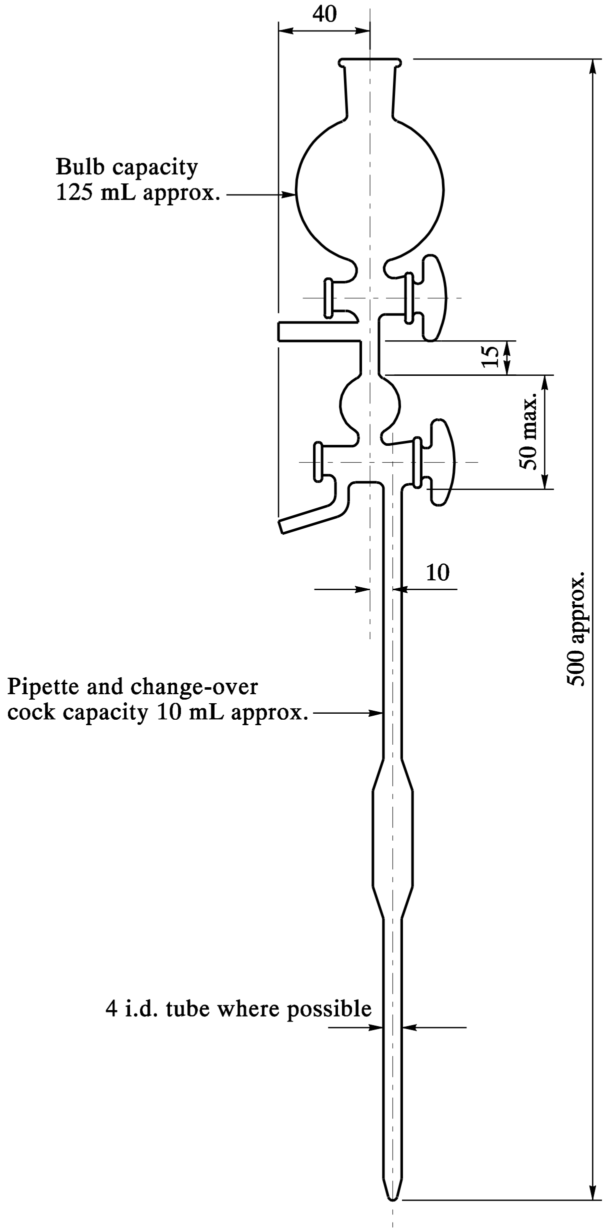
(j) a desiccator containing anhydrous silica gel,

(k) a 650 mL or 1 L conical flask with a cover glass to fit, and a small beaker,

(l) a 100 mL measuring cylinder,

(m) a 25 mL pipette or measuring cylinder,

(n) a glass filter funnel about 100 mm in diameter,



Notes: (1) This design has been found satisfactory, but alternative designs may be used.

(2) All dimensions shown are in millimetres.

(3) All other dimensions are given for guidance only.

Figure 8.3 Sampling Pipette for the Sedimentation Test

(o) a wash bottle containing distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990 (BSI, 1990),

(p) a glass rod, 150 mm to 200 mm long and 4 mm to 5 mm in diameter, fitted at one end with a rubber policeman, and

(q) sodium hexametaphosphate solution, as the dispersant, which shall be prepared by dissolving 33 g of sodium hexametaphosphate and 7 g of sodium carbonate in distilled water to make 1 litre of solution. This solution is unstable and shall be freshly prepared once a month. The date of preparation shall be recorded on the bottle.

8.3.4 Calibrations

8.3.4.1 The sampling pipette shall be calibrated as follows:

(i) Clean the sampling pipette thoroughly, and dry it and immerse the nozzle in distilled water. Close tap B and open tap E to pipette G (see Figure 8.4).

(ii) By means of a rubber tube attached to C, suck water up into the pipette until it rises above E. Close tap E, and remove the pipette from the water. Pour off surplus water drawn up into the cavity above E through F into the small beaker.

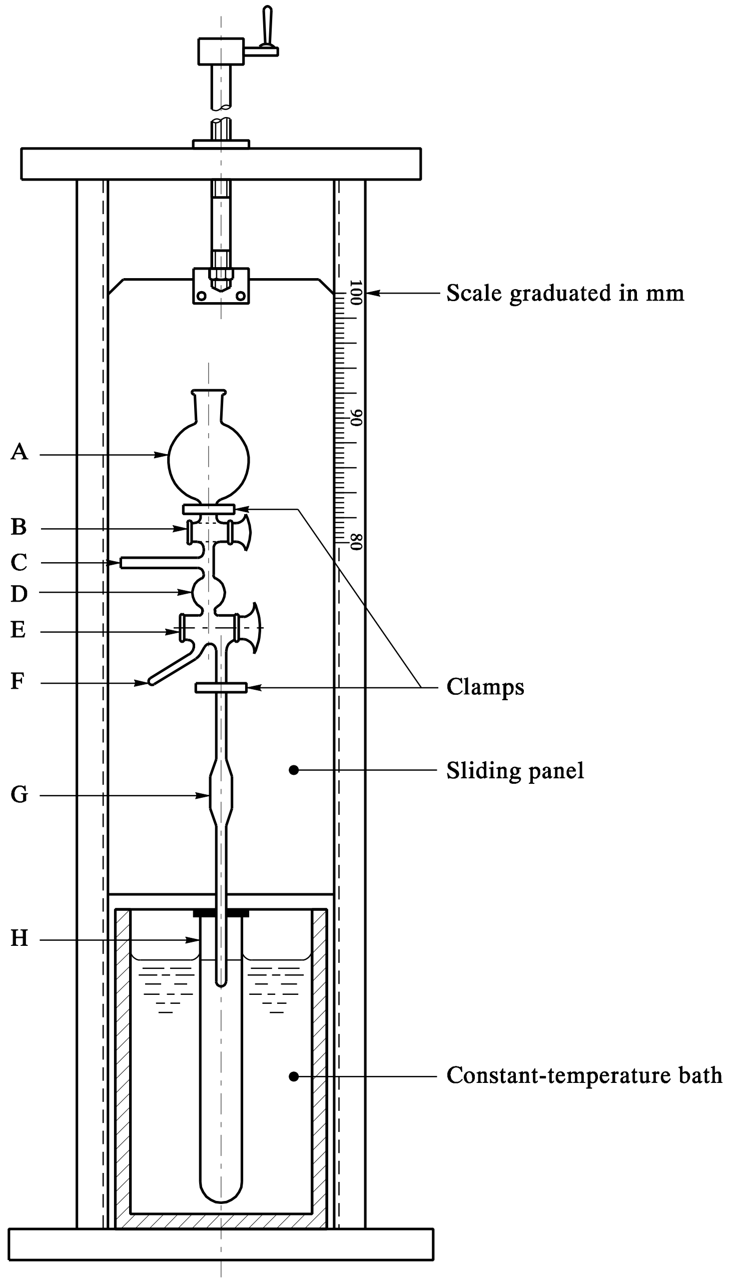
(iii) Discharge the water contained in the pipette and tap E into a glass weighing bottle of known mass, and determine the mass. From this mass calculate the internal volume, V_p (in mL), of the pipette and the tap to the nearest 0.05 mL.

(iv) Make three determinations of the volume as above and take the average value as V_p (in mL).

8.3.4.2 When a fresh batch of dispersant is used, dispersant correction shall be made as follows:

(i) Between any of the times at which samples are taken from the sedimentation cylinder (see Clause 8.3.6 for sample preparation below), take a sample of V_p (in mL) from the cylinder containing the dispersant solution using the pipette. Following the procedure specified in Clauses 8.3.6.5 to 8.3.6.11 except that there is no need to time the sampling operation and the depth of the sampling is not important.

(ii) Determine the mass of solid residue in the sample to 0.001 g (m_r).



Legend:

A & B	125 mL bulb funnel with stopcock
C	Safety bulb suction inlet tube
D	Safety bulb
F	Outlet tube
G	Sampling pipette
H	Sedimentation tube

Notes: (1) This design has been found satisfactory, but alternative designs may be used.

(2) D, F and G are joined to three-way stopcock E.

Figure 8.4 Arrangement for Lowering Sampling Pipette into Soil Suspension

8.3.5 Sample Preparation

8.3.5.1 Assessment sieving of soil shall be carried out in accordance with Clause 4.2. The minimum mass of soil required for a test sample shall be 100 g for a fine-grained soil. For a medium- or coarse-grained soil, the amount of soil shall be sufficient to give the minimum mass of 100 g of fine-grained soil.

8.3.5.2 The sample shall be subdivided as specified in Clause 4.5.2 to give the following minimum dry mass for the preparation of a test specimen:

Clayey Soil	Silty Soil	Sandy Soil
12 g	12 g	30 g

Note 1: The minimum dry mass is applicable only to soils with more than 10% passing the 63 μm test sieve.

Note 2: Stokes' Law applies to a single sphere falling in a large body of liquid. It is not applicable to a highly concentrated suspension, when the particles are close enough to influence each other. It has been established that if the mass of solid matter in the suspension is not too large, the deviation from Stokes' Law is negligible.

8.3.5.3 Drying of soil, where necessary, shall be carried out as specified in Clause 4.4, except that oven-drying at 105 ± 5°C shall not be carried out for saprolitic, residual or colluvial soils.

8.3.5.4 The soil may be mechanically processed in its as-received state using rubber pestle and mortar, in accordance with Clause 4.5.1. For saprolitic, residual or colluvial soils, partial drying is not allowed and large lumps of soil can be crumbled by hand.

8.3.5.5 For soils other than saprolitic, residual or colluvial soils, carry out the following:

(i) Weigh the test specimen to 0.001 g and obtain its initial dry mass, m_0.

(ii) Place the specimen in a wide-mouthed conical flask or a glass cylinder.

8.3.5.6 For saprolitic, residual or colluvial soils, carry out the following:

(i) Determine the initial dry mass (m_0) of the test specimen, take at least two small representative specimens from the soil sample and determine their moisture contents in accordance with either Test Method 5.1 or 5.2, as appropriate. The average of the two (w%) is taken as the moisture content of the test specimen.

(ii) Weigh the remaining soil in its as-received undried state to 0.1% of its total mass (W_0).

(iii) Assuming that all the particles contain absorbed water, the initial dry mass of the sample shall be calculated by the following equation:

$$m_0 = \frac{100\ W_0}{100 + w}$$

8.3.5.7 Visible organic matters, e.g. small roots etc., shall be removed by hand and the presence of any organic matters in the soil shall be recorded. Pretreatment for organic matters shall not be carried out.

8.3.5.8 Carry out dispersion as stated below:

(i) Add 100 mL of the distilled water to the soil in the conical flask or glass cylinder. Shake vigorously until all the soil is in suspension, then add 25 mL of the dispersant from a pipette.

(ii) Shake the flask or glass cylinder using the mechanical shaking device for 4 hours ± 15 minutes. Alternatively, when a conical flask is used and specifically required by the Specifiers, the suspension may be agitated by the blade of a vibrating stirrer. The duration of the shaking (to the nearest 5 minutes) shall be recorded for all tests.

Note 1: When dealing with soils which may be broken down by shaking, e.g. some shales, a reduced period of shaking should be adopted, i.e. less than 4 h.

Note 2: Sodium hexametaphosphate has been specified as the dispersant in view of the success with which it has been employed in the analysis of a large number of soils. However, certain very strongly aggregated soils may not be dispersed completely by the technique described, and it may be found necessary to add additional amounts of this or other dispersant. In such cases, the incomplete dispersion obtained is indicated by the formation of relatively large crumbs or flocs of soil which fall rapidly through the water leaving a sharply defined, clear layer above the suspension. When this occurs, allow the soil to settle to the bottom of the cylinder and decant as much of the supernatant liquid as possible. Add a further 25 mL of dispersant, shake well and make up to 500 mL with water. If flocculation still occurs, some other method of dispersion should be tried. However, any additional quantities of the standard dispersant and the type, concentration and quantity of other dispersant, if used, must be clearly recorded.

(iii) Transfer the suspension from the flask or cylinder to the 63 μm test sieve placed on the receiver, and wash the soil in the sieve using a jet of distilled water from the wash bottle. Care shall be taken to ensure that the 63 μm test sieve is not overloaded (see Table 6.1). The amount of suspension that has passed through the sieve shall not exceed 500 mL.

(iv) Transfer the suspension that has passed through the sieve to the 500 mL cylinder and make up to the 500 mL graduation mark with distilled water. Use this suspension for the sedimentation analysis specified in Clause 8.3.6.

(v) Transfer the soil retained on the 63 μm test sieve to an evaporating dish and dry it in accordance with Test Method 5.1 or 5.2 as appropriate. The temperature of which the soil retained is dried shall be the same as the temperature for the determination of the moisture content (w%) used during sample preparation.

(vi) When cool, weigh the soil to 0.001 g.

(vii) Add any soil passing the 63 μm test sieve to the sedimentation cylinder.

Note: In the wet sieving operation for the separation of sand particles, grains with diameters just slightly smaller than the apertures of the 63 μm test sieve tend to be retained due to the surface tension of the water held between the sieve meshes. The absence of such particles from the suspension is not detrimental to the subsequent sedimentation provided that they form only a small proportion of the total sample. If it is found that a large part of the sample passes the 63 μm test sieve during the dry sieving operation, the soil passing shall be added to the suspension in the measuring cylinder prior to the sedimentation.

8.3.6 Test Procedures

8.3.6.1 Insert the rubber bung into the cylinder containing the soil suspension, shake it and place it in the constant-temperature bath so that it is immersed in water up to the 500 mL graduation mark.

8.3.6.2 Add 25 mL of the dispersant from a pipette or measuring cylinder to the second 500 mL sedimentation cylinder and dilute with distilled water up to the 500 mL graduation mark. Insert the rubber bung and place this cylinder in the constant-temperature bath alongside the first.

8.3.6.3 After at least 1 h, or when the cylinders and contents have reached the temperature of the bath, take out the cylinders, shake them vigorously applying about 120 end-over-end cycles in 2 min and immediately replace them in the bath.

8.3.6.4 At the instant when the cylinder with the soil suspension is replaced upright in the bath, start the timer. Remove the rubber bungs, carefully and lightly lay them on the top of each cylinder.

Note: Froth on the surface of the suspension can be dispersed by adding two drops of methylated spirit.

8.3.6.5 About 15 s before a sample is due to be taken (see Table 8.2), lower the pipette, with tap E closed (see Figure 8.4) vertically into the soil suspension until the end is 100 ± 1 mm below the water surface. Take great care to avoid creating turbulence in the suspension. This operation shall take about 10 s.

8.3.6.6 Open tap E so that a sample of soil suspension, V_p (in mL), is drawn up into the pipette. Close the tap when the pipette and the bore in the tap E are filled with the suspension. The sampling operation shall be completed in about 10 s.

8.3.6.7 Withdraw the pipette from the cylinder containing the suspension, taking about 10 s to complete this operation.

Table 8.2 Pipette Sampling Times and Equivalent Particle Diameters

Particle Density of Silt and Clay Fraction (Mg/m^3)	Times after Shaking of Starting Sampling Operation					
	lst Sample		2nd Sample		3rd Sample	
	min	s	min	s	h	min
2.50	4	30	50	30	7	35
2.55	4	20	49	0	7	21
2.60	4	10	47	30	7	7
2.65	4	5	46	0	6	54
2.70	4	0	44	30	6	42
2.75	3	50	43	30	6	30
2.80	3	40	42	0	6	20
2.85	3	35	41	0	6	10
2.90	3	30	40	0	6	0
2.95	3	25	39	0	5	50
3.00	3	20	38	0	5	41
3.05	3	15	37	0	5	33
3.10	3	10	36	0	5	25
3.15	3	5	35	0	5	18
3.20	3	0	34	30	5	10
Equivalent particle diameter	0.02 mm		0.006 mm		0.002 mm	

8.3.6.8 During the sampling operation in Clause 8.3.6.6 above, a small amount of the suspension may have been drawn up into the bulb D above the bore of tap E. Run this surplus into a beaker down the outlet tube F by opening the tap E so that D and F are connected. Wash out with distilled water from the bulb funnel A into D and out through F until no suspension remains in this part of the system.

8.3.6.9 Place a weighing bottle of known mass, measured to 0.001 g, under the end of the pipette and open tap E so that the contents of the pipette are released into the bottle. Wash any suspension left on the inner walls of the pipette into the weighing bottle by allowing distilled water from the bulb A to run through B, D and E into the pipette G and then into the weighing bottle.

8.3.6.10 Place the weighing bottle and contents in the oven maintained at 45 ± 5°C or 105 ± 5°C, as appropriate, and dry the sample.

8.3.6.11 Cool the bottle together with its contents in the desiccator, and then weigh them to the nearest 0.001 g.

8.3.6.12 Determine the mass of soil to 0.001 g.

8.3.6.13 Carry out the above Clauses 8.3.6.5 to 8.3.6.12 two more times at the times specified in Table 8.2 above. The successive masses of the soil determined in Clause 8.3.6.12 are denoted by m_1, m_2, m_3.

Note: If required, additional readings, making a total of not more than six, may be taken to give a good spread of points over the silt particle size range, 0.06 mm to 0.002 mm, when plotted on a logarithmic scale.

8.3.7 Calculations

8.3.7.1 Carry out the following calculations for sieving of fines:

(i) Calculate the proportion of soil retained on each sieve as a percentage of the dry mass of soil used, m_0 (in g),

For example:

$$\text{Percentage retained on the 600 µm test sieve} = \left(\frac{m_{(600\ \mu m)}}{m_0}\right) 100$$

(ii) Calculate the cumulative percentages by mass passing each of the sieves from the general relationship:

(cumulative % passing this sieve) =
(cumulative % passing previous sieve) – (% retained on this sieve)

8.3.7.2 Carry out the following calculations for sedimentation:

(i) Calculate the mass of soil, W_1, W_2, etc. (in g), in 500 mL of suspension for each pipette sampling time from the equation:

$$W_1, W_2, \text{etc.} = (m_1 \text{ or } m_2, \text{etc.}/V_p)\ 500$$

where m_1, m_2, etc. are the masses of soil from the first, second, etc. sampling (in g); and
V_p is the calibrated volume of the pipette (in mL).

Similarly the mass of soil in 500 mL of dispersant, W_r (in g), is given by the equation:

$$W_r = \left(\frac{m_r}{V_p}\right) 500$$

where m_r is the mass of residue as determined in Clause 8.3.4.2 (ii).

(ii) Obtain the equivalent particle diameter, D (in mm), for each sampling operation from Table 8.2.

Note: If required, additional readings, making a total of not more than six, may be taken to give a good spread of points over the silt particle size range, 0.06 mm to 0.002 mm, when plotted on a logarithmic scale. The equivalent particle diameter, D (in mm), for each sampling operation is calculated from the equation:

$$D = 0.005531 \sqrt{\frac{\eta H}{(\rho_s - \rho_f)t}}$$

where η is the dynamic viscosity of water at the test temperature (in mPa.s) as shown in Table 8.3;
H is the sample depth at which the density of the suspension is measured (in mm);
ρ_s is the mean particle density (in Mg/m^3);
ρ_f is the density of the liquid (water with dispersant) containing the soil suspension (in Mg/m^3);
t is the pipette sampling time (in min); and
0.005531 is a constant.

(iii) Calculate the percentage by mass, K, of particles smaller than each equivalent particle diameter, D (in mm), from the equation:

$$K = \left(\frac{W_1, W_2, \text{etc.} - W_r}{m} \right) 100$$

where m is the mass of dry soil used (in g).

Table 8.3 Viscosity of Water

Temperature T, °C	Viscosity of Water η, mPa.s
10	1.304
15	1.137
20	1.002
25	0.891
30	0.798

Note: Intermediate values may be obtained by interpolation.

8.3.7.3 Present the results of the sedimentation analysis, and of the sieving analysis if appropriate, on a semi-logarithmic chart in the form of a continuous curve. Alternatively, present the results in terms of various size fractions in the form of a table showing, to the nearest 1%, the percentage finer than each fraction.

8.3.8 Reports

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the results of the sedimentation analysis,

(c) the results of the sieve analysis if appropriate, and

(d) the presence of any visible organic matters in the soil.

8.4 Determination of Particle Size Distribution by the Pipette Method (without Dispersant)

8.4.1 Scope

This test is used for the determination of the particle size distribution of soil by the pipette method. It is suitable for soils with fine particles down to the clay size. In this test the soil is not pretreated with a dispersant.

8.4.2 General

The guidance given in Clause 8.1.2 as for Test Method 8.1 shall be noted.

8.4.3 Apparatus

The apparatus as listed in Clause 8.3.3 as for Test Method 8.3 shall be used, except that Items (l) and (q), the 100 mL measuring cylinder and the dispersant, are not required for this test.

8.4.4 Calibration

The calibration of the sampling pipette shall follow Clause 8.3.4.1 as for Test Method 8.3.

8.4.5 Sample Preparation

The sample preparation shall follow Clause 8.3.5 as for Test Method 8.3, except that the addition of a dispersant is not required in this test, and all notes relating to the use of a dispersant is not applicable.

8.4.6 Test Procedures

The test procedures shall follow Clause 8.3.6 as for Test Method 8.3, except that Clause 8.3.6.2 shall be replaced by “Add distilled water to the sedimentation cylinder to exactly 500 mL. Insert the rubber bung and place this cylinder in the constant-temperature bath alongside the first.”.

8.4.7 Calculations

The calculations shall follow Clause 8.3.7 as for Test Method 8.3, except that the reference to ρ_f, density of the liquid (water with dispersant) in the Note to Clause 8.3.7.2 (ii) should be regarded as distilled water instead.

8.4.8 Report

The test report shall include all the information as listed in Clause 8.3.8 as for Test Method 8.3.

8.5 Determination of Particle Size Distribution by the Hydrometer Method (with Dispersant)

8.5.1 Scope

This test is used for the determination of the particle size distribution of soil by the hydrometer method. In this test the soil is pretreated with a dispersant.

8.5.2 General

The guidance given in Clause 8.1.2 as for Test Method 8.1 shall be noted.

8.5.3 Apparatus

The following apparatus are required:

(a) a hydrometer of the type illustrated in Figure 8.5, or otherwise fulfilling the requirements of BS 718 : 1991 (BSI, 1991) as set out as follows:

- The bulb and stem shall be made of glass as free as possible from visible defects. The glass shall be resistant to chemicals and shall be well annealed.

- Where a solid loading material is used, it shall be fixed at the bottom part of the hydrometer by means of a cementing material which does not soften if heated to 80°C. Where mercury is the loading material it shall be confined at the bottom part of the hydrometer.

- The scale and inscriptions shall be marked clearly in permanent black ink on high quality paper having a smooth surface, e.g. an esparto paper, i.e. 65% to 75% esparto, with the strips cut with their length in the machine direction of the paper.

- The stem and bulb shall be circular in cross section and shall be symmetrical about the main axis. There shall be no abrupt changes in cross section such as will hinder cleaning or drying or permit air bubbles to be trapped. The hydrometer shall always float, at all points within its range, with the stem within 1° of the vertical.

- The graduation lines shall be fine, distinct and of uniform thickness, and shall show no evident irregularities in spacing. The scale shall be straight and without twist, with the graduation lines at right angles to the axis of the hydrometer.

- The graduation lines shall be at intervals of 0.0005 g/mL, every alternate line shall extend beyond the shortest lines, and every tenth graduation shall exceed that of all the intervening lines and shall be numbered in full.

- The basis of the scale shall be density (mass per unit volume) in g/cm^3 or g/mL. When used in pure water at 20°C, the hydrometer shall indicate the density of water at that temperature.

- The adjustment of the hydrometer shall be related to a liquid having a surface tension of 55 mN/m.

- The maximum permissible scale error on the hydrometer is plus or minus one scale division.

- The following information shall be marked legibly on the stem or bulb of each hydrometer and shall not encroach on the scale or the figuring:
  - the basis of scale, e.g. g/mL at 20°C,
  - the maker's or vendor's name or mark,
  - an identification number, and
  - the number and version of the British Standard, i.e. BS 718 : 1991 (BSI, 1991).

(b) two 1 L graduated glass measuring cylinders with parallel sides, or two parallel-sided glass cylinders with ground glass stoppers, about 60 mm diameter and 360 mm high marked at 1 L volume. The sectional area shall be constant throughout the length of the cylinder,

(c) a thermometer to cover the temperature range from 0°C to 40°C, accurate to 0.5°C,

(d) a mechanical shaker capable of keeping 75 g of soil and 150 mL water in continuous suspension. A device which is capable of rotating the container end-over-end at about 30 revolutions/min to 60 revolutions/min is satisfactory,

(e) test sieves comprising at least the 2 mm, 600 μm, 212 μm, 63 μm sizes and a receiver,

(f) a balance readable to 0.01 g and accurate to 0.05 g,

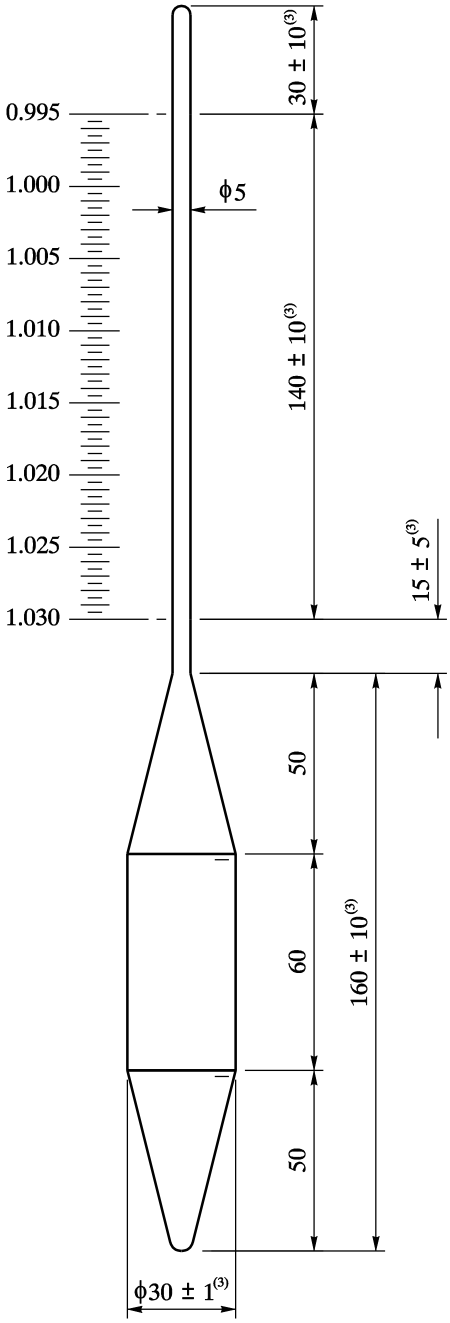
(g) a drying oven, capable of maintaining the temperature of 45 ± 5°C or 105 ± 5°C, as appropriate,

(h) a stopclock or stopwatch readable to 1 s,

(i) a dessicator containing anhydrous silica gel,

(j) an engineer's steel rule,

(k) four evaporating dishes, about 150 mm in diameter,



Notes:

(1) Graduation in g/mL at 20˚C.

(2) All dimensions shown are in millimetres.

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 8.5 Hydrometer for the Determination of Fine Particle Size

(l) a wide-mouthed conical flask or a glass cylinder, of 1 L capacity,

(m) two measuring cylinders, of capacity 100 mL and 500 mL,

(n) a wash bottle containing distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990 (BSI, 1990),

(o) a glass rod about 150 mm to 200 mm long and 5 mm in diameter,

(p) a constant-temperature bath capable of being maintained at 25 ± 0.5°C into which the sedimentation cylinder can be immersed up to the 1 L mark. The bath shall not cause any vibration sufficient enough to disturb a specimen,

(q) pipettes, or measuring cylinders of capacity 100 mL and 50 mL, and

(r) sodium hexametaphosphate solution as specified in Clause 8.3.3 (q) for Test Method 8.3.

8.5.4 Calibration

8.5.4.1 The volume of the hydrometer bulb, V_h, shall be determined as follows:

(i) Weigh the hydrometer to the nearest 0.1 g.

(ii) Record the mass (in g) as the volume of the hydrometer, V_h (in mm^3). This includes the volume of the bulb plus the volume of the stem below the 1.000 graduation mark. For practical purposes the error due to the inclusion of this stem volume may be neglected.

8.5.4.2 The scale of the hydrometer shall be determined as follows:

(i) Measure the distance, L (in mm), from the 100 mL scale marking to the 1000 mL scale marking on the sedimentation cylinder, to the nearest mm. For a cylinder with a scale mark only at 1000 mL, determine the 100 mL level by adding a measured 100 mL (or 100 g) of water.

(ii) Measure and record the distances from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks, R_h.

(iii) Measure and record the distance, N, from the neck of the bulb to the nearest calibration mark. The distance, H, corresponding to a reading, R_h, is equal to the sum of the distances measured in Clauses 8.5.4.2 (ii) and (iii), ($N + d_1$, $N + d_2$, etc., see Figure 8.6).

(iv) Measure and record the distance, h, from the neck to the bottom of the bulb as the height of the bulb.

(v) Calculate the effective depth, H_R (in mm), corresponding to each of the major calibration marks, R_h, from the equation:

$$H_R = H + \frac{1}{2}\left(h - \frac{V_h}{900} L\right)$$

where H is the length from the neck of bulb to graduation R_h (in mm);

h is the length of the bulb, or twice the length from the neck of the bulb to its centre of volume (in mm) (see note below);

V_h is the volume of hydrometer bulb (in mL); and

L is the distance between the 100 mL and the 1000 mL scale markings of the sedimentation cylinder (in mm).

Note: The above formula and Figure 8.6 assume a symmetrical bulb with its centre of volume located at h/2 below the neck. If an asymmetrical bulb is used, the centre of volume can be determined with sufficient accuracy by projecting the shape of the bulb on to a sheet of paper and finding the centre of gravity of the projected area. In the formula, h is then replaced by 2 h_g, i.e. twice the length from the neck of the bulb to its centre of volume.

(vi) Plot the relationship between H_R and R_h as a smooth curve.

Note: This relationship gives the effective depth of the suspension, the relative density of which is given by the hydrometer reading. It allows for the rise of the liquid in the graduated cylinder.

If the calibration curve is linear, the relationship may be expressed as an equation of the form:

$$H_R = j_1 + j_2 \, R_h$$

where j_1 is the intercept on the H_R axis corresponding to $R_h = 0$;

j_2 is the slope of the line, always negative; and

R_h is any hydrometer specific gravity reading (see Figure 8.6) consisting of the decimal part only with the decimal point moved three places to the right.

(vii) Record the identification number of the hydrometer on the calibration readings and graph.

8.5.4.3 Meniscus correction shall be carried out as follows:

(i) Insert the hydrometer in a 1 L cylinder containing about 800 mL water. Add more water if necessary such that the bottom of the hydrometer will not touch the bottom of the cylinder.

(ii) By placing the eye slightly below the plane of the surface of the liquid and then raising it slowly until the surface seen as an ellipse becomes a straight line, determine the point where the plane intersects the hydrometer scale.

Note: In order to obtain an accurate reading on the hydrometer scale, the stem has to be perfectly clean so that the meniscus round the stem can be fully developed.

(iii) By placing the eye slightly above the plane of the surface of the liquid, determine the point where the upper limit of the meniscus intersects the hydrometer scale.

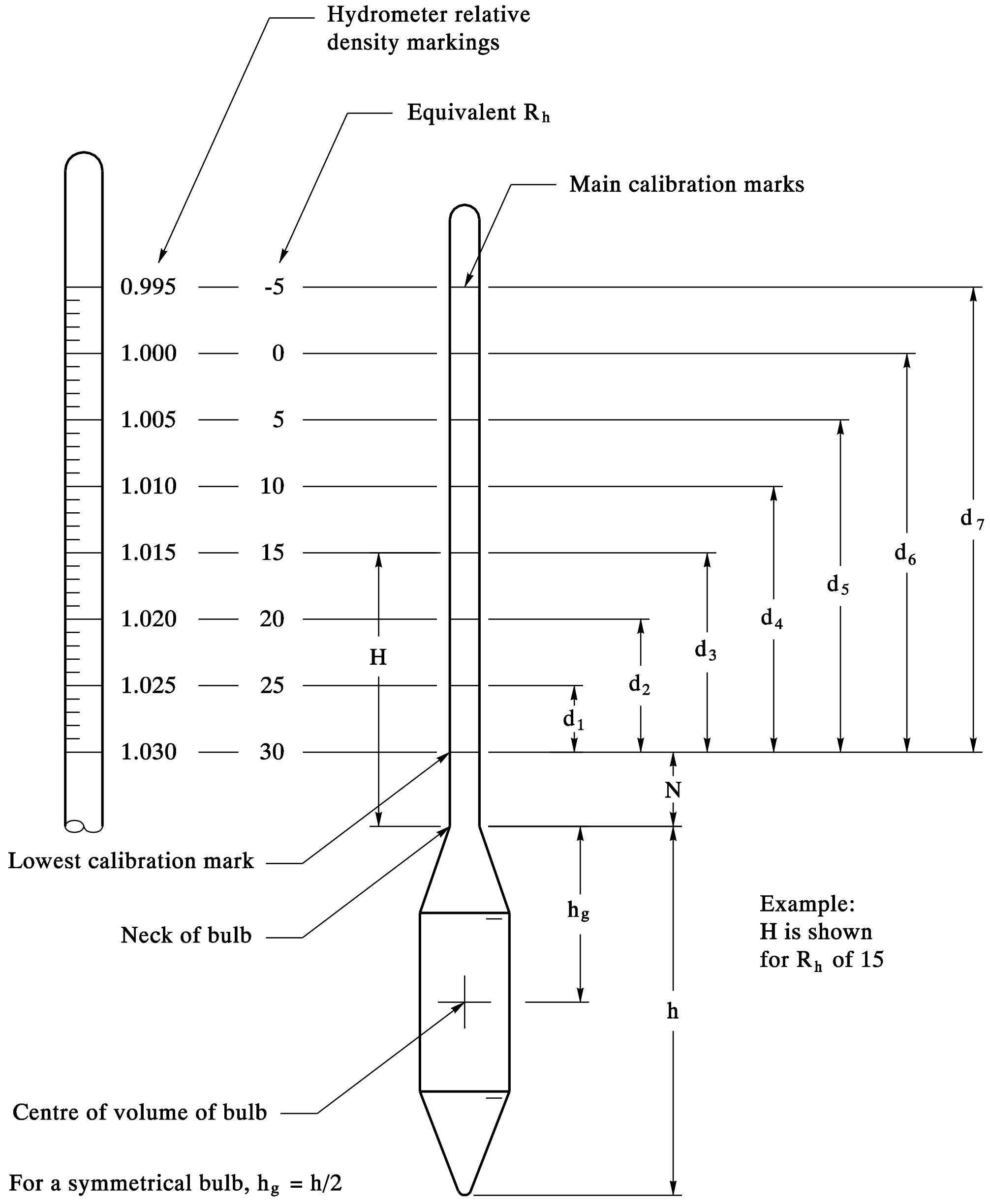


Figure 8.6 Essential Measurements for Calibration of Hydrometer

(iv) Record the difference between the two readings in the above Clauses 8.5.4.3 (ii) and (iii) as the meniscus correction, C_m.

Note: Hydrometers are calibrated to read correctly at the surface of a liquid. However, soil suspensions are not transparent enough to permit a reading to be taken at the surface, and the reading, R_h', has to be made at the upper rim of the meniscus. The meniscus correction, C_m, which has to be added to R_h' in order to obtain R_h, the true reading, is a constant for each hydrometer.

8.5.5 Sample Preparation

8.5.5.1 Assessment sieving shall be carried out in accordance with Clause 4.2. The minimum mass of soil required for a test sample shall be 250 g for a fine-grained soil. For a medium- or coarse-grained soil, the amount of soil shall be sufficient to give the minimum mass of 250 g of fine-grained soil.

8.5.5.2 The sample shall be subdivided as specified in Clause 4.5.2 to give the followings minimum dry mass for the preparation of a test specimen:

Clayey Soil	Silty Soil	Sandy Soil
30 g	50 g	100 g

Note: Refer to the notes to Clause 8.3.5.2 as for Test Method 8.3.

8.5.5.3 Carry out sample preparation following Clauses 8.3.5.3 to 8.3.5.7 as for Test Method 8.3, except that the test specimen shall only be weighed to 0.01 g in Clause 8.3.5.5 (i).

8.5.5.4 Carry out dispersion as stated below:

(i) Add 100 mL of the dispersant from a pipette to the soil in the conical flask or glass cylinder. Shake the mixture thoroughly until all the soil is in suspension.

(ii) Shake the flask or glass cylinder in the mechanical shaking device following Clause 8.3.5.8 (ii) as for Test Method 8.3, except that when incomplete dispersion occurs, a further 100 mL (instead of 25 mL as stated in Note 2 of that step) of dispersant shall be added, followed by shaking well and making up to 1 L (instead of 500 mL as stated in Note 2 of that step) with water.

(iii) Transfer the suspension from the flask or cylinder to the 63 μm test sieve placed on the receiver, following Clause 8.3.5.8 (iii) as for Test Method 8.3, except that the amount of suspension that has passed through the sieve shall not exceed 1L (instead of 500 mL).

(iv) Transfer the suspension that has passed through the sieve to the 1 L measuring cylinder and make up to the 1 L graduation mark with distilled water. Use this suspension for the sedimentation analysis specified in Clause 8.5.6.

(v) Transfer the soil retained on the 63 μm test sieve to an evaporating dish and dry it following Clause 8.3.5.8 (v) as for Test Method 8.3.

(vi) When cool, re-sieve this material on the sieves down to the 63 μm size, as specified in Clause 8.1.5 of Test Method 8.1. Weigh the soil retained on each sieve to 0.01 g.

(vii) Add any soil passing the 63 μm test sieve to the measuring cylinder.

Note: Refer to Note to Clause 8.3.5.8 (vii) in Test Method 8.3.

8.5.6 Test Procedures

8.5.6.1 Insert the rubber bung into the cylinder containing the soil suspension, shake it and place it in the constant-temperature bath so that it is immersed in water at least up to the 1 L graduation mark.

Note: The constant-temperature bath shall be used at all times. Asymmetrical heating of the suspension causes convection currents, which affect the sedimentation process. The suspension shall therefore be kept out of direct sunlight and away from any local source of heat. Evaporation would be retarded by keeping a cover on the measuring cylinder between readings. The hydrometer shall be kept at the same temperature as the soil suspension before taking each hydrometer reading (see Clause 8.5.6.5 below). This may be achieved by keeping the hydrometer in distilled water contained in a cylinder placed inside the constant-temperature bath between taking the hydrometer readings.

8.5.6.2 Add 100 mL of the dispersant from a pipette or measuring cylinder to the second 1 L sedimentation cylinder and dilute with distilled water to exactly 1 L. Insert the rubber bung and place this cylinder in the constant-temperature bath alongside the first.

8.5.6.3 After at least 1 h, or when the cylinders and contents have reached the temperature of the bath, take out the cylinder containing the dispersant, shake it thoroughly and replace it in the bath. Take out the cylinder containing the soil suspension, shake it vigorously end-over-end at a rate of about 60 times in 2 minutes until all soil is in suspension and then continue the shaking for a further 2 minutes. The cylinder shall then be replaced in the bath immediately after shaking.

8.5.6.4 At the instant when the cylinder with the soil suspension is replaced upright, start the timer. Remove the rubber bungs carefully from the cylinders.

8.5.6.5 Immerse the hydrometer in the suspension to a depth slightly below its floating position and allow it to float freely.

Note: Froth on the surface of the suspension can be dispersed by adding two drops of methylated spirit.

8.5.6.6 Take hydrometer readings at the upper rim of the meniscus after periods of 0.5 min, 1 min, 2 min and 4 min. Record the relevant readings.

8.5.6.7 Remove the hydrometer slowly, rinse in distilled water and place it in the cylinder of distilled water with dispersant at the same temperature as the soil suspension. Observe and record the top of the meniscus reading, R_0'.

8.5.6.8 Re-insert the hydrometer in the soil suspension and take and record readings after periods of 8 min, 30 min, 2 h, 8 h, and 24 h from the start of sedimentation, and twice during the following day if appropriate. The precise times are not critical provided that the exact time period is recorded. Insert the hydrometer slowly about 15 s before a reading is due.

Note 1: The test should normally continue until the percentage finer than about 2 μm can be determined. In most cases if the correct amount of soil has been used, this will be reached within about 24 h.

Note 2: A greater or lesser number of readings (but not less than three) may be acceptable. The minimum of three readings should enable the percentages of fine, medium and coarse silt to be determined.

Insert and withdraw the hydrometer before and after taking each reading very carefully to avoid disturbing the suspension unnecessarily. Allow 10 s for each operation. Avoid vibration of the suspension.

8.5.6.9 Observe and record the temperature of the suspension once during the first 15 min and then after every subsequent reading. Read the temperature to an accuracy of ± 0.5°C. If the temperature varies by more than ± 1°C, take another hydrometer reading in the dispersant as specified in Clause 8.5.6.7.

8.5.7 Calculations

8.5.7.1 The calculation for fine sieving shall follow Clause 8.3.7.1 as for Test Method 8.3.

8.5.7.2 Carry out the following calculations for sedimentation:

(i) Calculate the true hydrometer reading, R_h (in mm), from the equation:

$$R_h = R_h' + C_m$$

where C_m is the meniscus correction derived as specified in Clause 8.5.4.3; and

R_h' is the observed hydrometer reading.

(ii) Obtain the effective depth, H_r (in mm), at which the density of the suspension is measured, corresponding to the reading, R_h, from the hydrometer scale calibration curve derived as specified in Clause 8.5.4.2, either by reading off from the curve or by calculation from its equation.

(iii) Calculate the equivalent particle diameter, D (in mm), from the following equation:

$$D = 0.005531\sqrt{\frac{\eta H_r}{(\rho_s - 1)\,t}}$$

where	η	is the dynamic viscosity of water at the test temperature (in mPa.s) as shown in Table 8.3;
	H_r	is the effective depth at which the density of the suspension is measured (in mm);
	ρ_s	is the particle density (in Mg/m^3);
	t	is the elapsed time (in min); and
	0.005531	is a constant.

Record the value of D, calculated from each set of readings.

Note: Alternatively the value of D may be determined by using a nomographic chart for the application of Stokes' Law. These charts are available commercially.

(iv) Calculate the modified hydrometer reading, R_d, from the equation:

$$R_d = R_h' - R_0'$$

where R_0' is the hydrometer reading at the upper rim of the meniscus in the dispersant solution.

Note: If the density of the dispersant is less than 1000 g/mL, R_0' will be negative.

(v) Calculate the percentage by mass, K, of particles smaller than the corresponding equivalent particle diameter, D (in mm), from the equation:

$$K = \left\{\frac{100\ \rho_s}{m\ (\rho_s - 1)}\right\} R_d$$

where m is the mass of the dry soil used (in g).

Note: The total dry mass, m, of the sample used for the test is inserted here whether or not any particles were retained on the 63 μm test sieve.

8.5.7.3 Present the results of the sedimentation analysis, and of the sieving analysis if appropriate, in accordance with Clause 8.3.7.3 as for Test Method 8.3.

Note: In presenting the results of the sedimentation analysis on a continuous particle size distribution curve, the hydrometer reading taken at 30 sec from the start of the sedimentation may be ignored in order that a smooth curve can be produced, in which case this 30 sec reading shall be plotted on the same chart to indicate the deviation.

8.5.8 Report

The test report shall include all the information as listed in Clause 8.3.8 as for Test Method 8.3.

8.6 Determination of Particle Size Distribution by the Hydrometer Method (without Dispersant)

8.6.1 Scope

This test is used for the determination of the particle size distribution of soil by the hydrometer method. It is suitable for soils with fine particles down to the clay size. In this test the soil is not pretreated with a dispersant.

8.6.2 General

The guidance given in Clause 8.1.2 as for Test Method 8.1 shall be noted.

8.6.3 Apparatus

The apparatus as listed in Clause 8.5.3 as for Test Method 8.5 shall be used, except that Item (r), the dispersant, shall be replaced with distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990 (BSI, 1990).

8.6.4 Calibration

The calibration shall follow Clause 8.5.4 as for Test Method 8.5.

8.6.5 Sample Preparation

The sample preparation shall follow Clause 8.5.5 as for Test Method 8.5, except that in Clause 8.5.5.4 (i), 100 mL of distilled water (instead of dispersant) shall be added to the soil for this test, and Clause 8.5.5.4 (ii) regarding the use of dispersant is not applicable.

8.6.6 Test Procedures

The test procedures shall follow Clause 8.5.6 as for Test Method 8.5, except that in Clause 8.5.6.2, distilled water (instead of dispersant solution) shall be used. Similarly, the distilled water containing no dispersant shall be used in Clause 8.5.6.7.

8.6.7 Calculations

The calculations shall follow Clause 8.5.7 as for Test Method 8.5.

8.6.8 Report

The test report shall include all the information as listed in Clause 8.3.8 as for Test Method 8.3.

8.7 Construction of a Continuous Particle Size Distribution Curve from the Results of Wet Sieving and Sedimentation Tests

8.7.1 Scope

This method sets out the standard test procedures to be adopted for construction of a continuous particle size distribution (PSD) curve from the results of wet sieving and sedimentation tests on the same soil sample.

8.7.2 General

The guidance given in Clause 3.5 shall be noted.

8.7.3 Standard Procedures

8.7.3.1 The part of the PSD curve produced from wet sieving shall be prepared in accordance with Test Method 8.1 or 8.2 as appropriate.

8.7.3.2 The part of the PSD curve produced from sedimentation testing of the same sample shall be prepared in accordance with Test Method 8.3, 8.4, 8.5 or 8.6, as appropriate.

8.7.4 Calculations

8.7.4.1 The percentage passing the 63 µm sieve obtained from wet sieving (Test Method 8.1 or 8.2 as appropriate) shall be used as a "reference value".

8.7.4.2 The value of percentage passing the 63 µm sieve obtained from sedimentation testing (Test Method 8.3, 8.4, 8.5 or 8.6 as appropriate) of the same sample is divided into the above "reference value" to give a modification factor (X), i.e.

$$X = \frac{\text{percentage passing } 63\ \mu\text{m (from wet sieving)}}{\text{percentage passing } 63\ \mu\text{m (from sedimentation)}}$$

8.7.4.3 All percentage passing values obtained from the sedimentation test (Test Method 8.3, 8.4, 8.5 or 8.6) are multiplied by (X) and these modified percentage-passing values are added to the PSD line from wet sieving (Test Method 8.1 or 8.2) to give a continuous PSD curve.

8.7.4.4 The initial modified readings (0.5 min, 1 min etc.) from the sedimentation tests shall be ignored if they do not lie on a smooth curve continued from the sieving curve. The data points from these readings must, however, be plotted on the PSD curve.

8.7.5 Report

The report shall affirm that the construction of the PSD curve was carried out in accordance with this method and shall contain the following information:

(a) All the information required by the wet sieving and sedimentation tests as specified in Clauses 8.1.7 (Test Method 8.1), 8.3.8 (Test Method 8.3) and 8.5.8 (Test Method 8.5), as appropriate.

(b) A continuous PSD curve on a semi-logarithmic chart. Alternatively, if requested by the Specifiers, the results can be reported in the form of a table showing, to the nearest 1%, the percentage of each of the size fractions.

9 Determination of Amount of Chemical Substances and Electro-chemical Properties

9.1 Determination of Organic Matter Content

9.1.1 Scope

This test is used for the determination of the percentage by dry mass of organic matter in a soil sample. The method which uses dichromate oxidation is known as the Walkley & Black’s method. Soils containing sulphides or chlorides have been found to give high results by this method. The procedures for checking the presence of these compounds, and for their removal before testing if present, are included.

9.1.2 General

The guidance given in Clause 3.6 shall be noted.

A good practice in chemical testing requires that duplicate specimens should be tested. In each of the test methods, the measurement of only one value of the overall result is described.

All of reagents used for chemical testing shall be of recognised analytical reagent quality. Where accurately standardised solutions are required, it may be more convenient to use those in standardised concentrated form and to dilute them as necessary in accordance with the manufacturer’s instructions.

9.1.3 Apparatus

The following apparatus are required:

(a) a drying oven, capable of maintaining a temperature of 50 ± 2.5°C,

(b) a balance, readable to 1 g, and accurate to 3 g,

(c) a balance, readable to 0.001 g, and accurate to 0.005 g,

(d) a volumetric flask, 1 L,

(e) burettes, 25 mL, graduated to 0.1 mL,

(f) a 10 mL pipette and a 1 mL pipette, each fitted with a rubber teat,

(g) conical flasks, each of 500 mL capacity,

(h) a 200 mL and a 20 mL graduated measuring cylinders,

(i) a desiccator, (a convenient size is about 200 to 250 mm in diameter) containing anhydrous silica gel,

(j) a glass weighing bottle, approximately 25 mm in diameter, 50 mm high and fitted with a ground glass stopper,

(k) test sieves, 2 mm and 425 μm aperture sizes with a receiver,

(l) sample dividers of the multiple-slot type (riffle boxes) having widths of opening of 7 mm and 15 mm,

(m) a pestle and mortar, or any suitable mechanical crusher,

(n) a wash bottle, preferably made of plastics, containing distilled water,

(o) a glass boiling tube,

(p) a filter funnel, of approximately 100 mm diameter,

(q) filter papers, of a diameter appropriate to the size of the funnel: medium grade (e.g. Whatman No. 40) and fine grade (e.g. Whatman No. 42), and

(r) blue litmus paper.

9.1.4 Reagents

The following reagents, which shall be of recognised analytical reagent quality, are required:

(a) potassium dichromate solution ($K_2Cr_2O_7$, 0.167 mol/L),

Note: The solution can be prepared by dissolving 49.035 g of potassium dichromate in distilled water to make 1 L of solution.

(b) ferrous sulphate solution ($FeSO_4$, approximately 0.5 mol/L),

Note 1: This solution can be prepared by dissolving approximately 140 g of ferrous sulphate heptahydrate in sulphuric acid solution (H_2SO_4, 0.25 mol/L) to make 1 L solution. The 0.25 mol/L sulphuric acid solution can be prepared by adding 14 mL of concentrated sulphuric acid to distilled water to make 1 L of the solution.

Note 2: This solution is unstable in air. Keep it tightly stoppered and standardised against the potassium dichromate solution before use. Record the date the solution is made on the bottle.

(c) concentrated sulphuric acid (density of 1.84 g/mL),

(d) orthophosphoric acid solution (at 85% (V/V), and at a density of 1.70 to 1.75 g/mL),

(e) indicator solution,

Note: This solution can be prepared by dissolving 0.25 g of sodium diphenylaminesulphonate in 100 mL of distilled water.

(f) hydrochloric acid (a 25% (V/V) solution),

Note: The solution can be prepared by diluting 250 mL of concentrated hydrochloric acid (at a density of 1.18 g/mL) to 1 L with distilled water.

(g) lead acetate paper, and

Note: Both commercially available lead acetate paper or filter paper that has been dipped in a 10% solution of lead acetate can be used.

(h) Sulphuric acid (H_2SO_4, at a concentration of approximately 1 mol/L).

Note: The solution can be prepared by adding 53 mL of concentrated sulphuric acid to about 500 mL of distilled water, then make up to 1 L with distilled water.

9.1.5 Sample Preparation

9.1.5.1 Obtain an initial soil sample for analysis with the minimum masses as follows:

Fine-grained	Medium-grained	Coarse-grained
150 g	600 g	3.5 kg

9.1.5.2 Process the sample in accordance with Clause 4 to give the following minimum dry masses of soil for preparation of a test specimen:

Fine-grained	Medium-grained	Coarse-grained
100 g	500 g	3.0 kg

9.1.5.3 Dry the sample in the oven to constant mass at 50 ± 2.5°C, and cool it to room temperature in the desiccator.

9.1.5.4 Weigh the sample to the nearest 1 g and record the mass m_1 (in g).

9.1.5.5 Sieve the sample on a 2 mm test sieve (if appropriate, guarded by a test sieve of larger apertures) and crush any retained particles other than stones to pass the 2 mm sieve.

9.1.5.6 Reject the stones, ensuring that no fines adheres to them by brushing. Record the mass of the sample passing the 2 mm test sieve (in g) to the nearest 1 g (m_2). Throughout these and subsequent operations take care to ensure that there is no loss of fines.

9.1.5.7 Divide the soil passing the 2 mm sieve by successive riffling through the 15 mm divider to produce a sample weighing approximately 100 g.

9.1.5.8 Pulverise this sample so that it passes the 425 μm test sieve.

9.1.5.9 Subdivide the sample by riffling on the 7 mm divider to obtain the following test specimens, as appropriate:

(i) two test specimens each weighing about 5 g, if sulphides and chlorides are known to be absent,

(ii) a test specimen of about 5 g, for a check test to determine if sulphides are present,

(iii) a test specimen of about 50 g, for a check test to determine if chloride is present, and

(iv) a specimen of about 50 g, if sulphides and/or chlorides are present.

Throughout this and any subsequent operations, mix the material available thoroughly before any subdivision and take care to avoid segregation during riffling.

9.1.5.10 Place each specimen in a glass weighing bottle and dry it in the oven at a temperature of 50 ± 2.5°C. A specimen is deemed to be dry when the differences in successive weighing, carried out at intervals of 4 h, do not exceed 0.1% of the original mass of the specimen.

9.1.5.11 Allow the specimens to cool to room temperature in the desiccator and weigh each bottle and contents to the nearest 0.001 g.

9.1.6 Testing Procedures

9.1.6.1 The standardisation of ferrous sulphate solution shall be carried out as follows:

(i) Run 10 mL of the potassium dichromate solution from a burette into a 500 mL conical flask.

(ii) Add 20 mL of concentrated sulphuric acid to the solution very carefully, swirl the mixture and allow it to cool for some minutes.

(iii) Add 200 mL of distilled water very carefully to the mixture followed by 10 mL of phosphoric acid and cool the mixture to room temperature and add 1 mL of indicator.

(iv) Add ferrous sulphate solution from the second burette and swirl the contents of the flask until the colour of the solution changes from blue to green.

(v) Add a further 0.5 mL of the potassium dichromate solution, changing the colour back to blue.

(vi) Slowly add ferrous sulphate solution drop by drop with continued swirling until the colour of the solution changes from blue to green after the addition of a single drop.

(vii) Record the total volume of ferrous sulphate solution used, x, to the nearest 0.05 mL.

9.1.6.2 A qualitative check for the presence of sulphides shall be carried out as follows:

(i) Place the 5 g check specimen in a boiling tube and add about 20 mL of hydrochloride acid, 25% solution.

(ii) Boil the acid and check for hydrogen sulphide by holding a piece of lead acetate paper in the vapour. If hydrogen sulphide is present, the paper will turn black.

(iii) If the presence of sulphides is indicated, remove them from the test specimen as described in Clause 9.1.6.3 below before proceeding with the analysis for organic matters, otherwise a result that is too high will be obtained.

9.1.6.3 The elimination of sulphides shall be carried out as follows:

(i) Weigh about 50 g of soil, after cooling as described in Clause 9.1.5.11, to the nearest 0.01 g and place it in a 500 mL conical flask.

(ii) Add sulphuric acid solution (1.0 mol/L) until no further evolution of hydrogen sulphide occurs, as determined by testing with a piece of lead acetate paper.

(iii) Filter the contents of the conical flask on a medium grade filter paper, take care to retain all solid particles. Wash several times with hot distilled water until the washings do not indicate acidity when tested with blue litmus paper.

(iv) Dry the soil retained on the filter paper at 50 ± 2.5°C and cool it in the desiccator to constant weight.

(v) Carefully remove the soil from the filter paper and determine its mass to the nearest 0.01 g.

(vi) Subdivide the treated sample to obtain test specimens, as described in Clause 9.1.5.9 (i), and dry and cool each test specimen as described in Clauses 9.1.5.10 and 9.1.5.11.

9.1.6.4 The qualitative check for the presence of chlorides shall be carried out as follows:

(i) Place the 50 g check specimen in a 500 mL conical flask and add to it an approximately equal mass of distilled water.

(ii) Agitate the contents intermittently for 4 h, allow them to settle and pour off some of the supernatant solution into a beaker.

(iii) Obtain about 25 mL of clear solution by filtering, if necessary, through a medium grade filter paper, e.g. Whatman No. 40.

(iv) Acidify the liquid with nitric acid, add about 5 drops of silver nitrate solution and allow it to stand for 10 min.

(v) If turbidity is apparent after this time, this indicates the presence of chlorides and they shall be removed from the test specimen as described in Clause 9.1.6.5 below before proceeding with the analysis for organic matter.

9.1.6.5 Elimination of chlorides shall be carried out as follows:

(i) Weigh about 50 g of the soil, after cooling as described in Clause 9.1.5.11 to the nearest 0.01 g

(ii) Place the soil on a medium grade filter paper (Whatman No. 40 or equivalent) in a funnel and wash with distilled water.

(iii) Continue washing until no turbidity is observed when a drop of the wash water is tested with silver nitrate solution.

(iv) Dry the soil retained on the filter paper at 50°C and cool it in the desiccator to repeat this process until constant weight is obtained. Carefully remove all the soil from the filter paper and determine its weight to 0.01 g.

(v) Subdivide the treated sample, as described in Clause 9.1.5.9 (i), and dry and cool each test specimen as described in Clauses 9.1.5.10 and 9.1.5.11.

9.1.6.6 Analysis for organic matter shall be carried out as follows:

(i) Weigh each weighing bottle containing soil as prepared in accordance with Clause 9.1.5, and after the removal of sulphides and/or chlorides in accordance with Clauses 9.1.6.3 and/or 9.1.6.5 respectively, to the nearest 0.001 g.

(ii) Transfer a small quantity, from 5.0 g to 0.2 g, depending on the organic content, to a dry 500 mL conical flask, reweigh the weighing bottle and determine the mass of soil removed by calculating difference.

Note: The size of the sample for chemical analysis will vary with the amount of organic matter present in the soil. As much as 5 g may be required for soil low in organic matter content, and as little as 0.2 g may be required for a very peaty soil. After making a number of determinations, experience will indicate the most suitable size of sample to be taken. Where this is not so, it is suggested that a series of samples of varying sizes should be tested. The determination giving a total of 5 mL to 8 mL of potassium dichromate solution reduced should be taken as the one giving correct result.

(iii) Run 10 mL of the potassium dichromate solution into the conical flask from a burette, and add 20 mL concentrated sulphuric acid very carefully from a measuring cylinder. Swirl the mixture thoroughly for about 1 min, and then allow it to stand for 30 minutes to allow complete oxidation of the organic matter to occur. During this period cover the flask with a watch glass to protect the flask from cool air and draughts.

(iv) Add 200 mL of distilled water very carefully to the mixture, followed by 10 mL of orthophosphoric acid and shake the mixture thoroughly. Allow the mixture to cool to room temperature then add 1 mL of indicator.

(v) Add ferrous sulphate solution from the second burette and swirl the contents of the flask until the colour of the solution changes from blue to green.

(vi) Add a further 0.5 mL of potassium dichromate solution to change the colour from back to blue.

(vii) Add ferrous sulphate solution slowly drop by drop with continued swirling until the colour of the solution changes from blue to green after the addition of a single drop.

(viii) Record the total volume of ferrous sulphate solution used, y, to the nearest 0.05 mL.

9.1.7 Calculations

9.1.7.1 The total volume, V (in mL), of potassium dichromate solution used to oxidise the organic matter in the soil sample is calculated from the equation:

$$V = 10.5\left(1 - \frac{y}{x}\right)$$

where y is the total volume of ferrous sulphate solution used (in mL) in Clause 9.1.6.6 (viii); and

x is the total volume of ferrous sulphate solution used (in mL) in the Clause 9.1.6.1 (vii), standardisation test.

9.1.7.2 Calculate the percentage of the original soil sample passing the 2 mm test sieve from the equation:

$$\text{fraction finer than 2 mm} = \left(\frac{m_2}{m_1}\right)100$$

where m_1 is the initial dry mass of sample (in g); and
m_2 is the mass of the sample passing the 2 mm test sieve (in g).

9.1.7.3 Calculate the percentage of organic matter present in the fraction of the soil specimen finer than 2 mm for each determination from the equation:

$$\text{percentage organic matter content} = \frac{0.67\ V}{m_3}$$

where m_3 is the mass of soil used in the test (g).

Note: The material is based on wet oxidation of the organic content of the soil, and it is assumed that soil organic matter contains an average of 58% (m/m) of carbon. The method employed oxidises approximately 77% of the carbon in the organic matter, and these factors are taken into account in the equation in Clause 9.1.7.1. The factors will give correct results only for soil containing natural organic matter.

9.1.7.4 If duplicate specimens have been tested, and if the individual results expressed as a percentage of organic matter differ by no more than 2%, calculate the mean result. If they differ by more than 2%, repeat the test starting with two new representative portions of the soil.

9.1.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the average organic matter content present in the soil fraction passing a 2 mm test sieve to the nearest 0.1% of the original oven-dry mass of soil,

(c) the percentage by dry mass of the original sample passing the 2 mm test sieve to the nearest 1%, and

(d) if sulphides or chlorides are identified in the soil, it shall be stated.

9.2 Determination of the Mass Loss on Ignition

9.2.1 Scope

This test method is used for the determination of the proportion by mass that is lost from a soil by ignition at 440 ± 25°C.

9.2.2 General

The guidance given in Clause 9.1.2 as for Test Method 9.1 shall be noted.

9.2.3 Apparatus

The following apparatus are required:

(a) a drying oven, capable of maintaining a temperature of 50 ± 2.5°C,

(b) a balance, readable to 1 g and accurate to 3 g,

(c) a balance, readable to 0.001 g and accurate to 0.005 g,

(d) a desiccator, containing anhydrous silica gel,

(e) test sieves, 2 mm and 425 μm aperture sizes, with a receiver,

(f) a pestle and mortar, or a suitable mechanical crusher,

(g) sample dividers of multiple-slot type (riffle boxes), having widths of opening of 7 mm and 15 mm,

(h) a crucible or similar container, of about 30 mL capacity, and

(i) an electric muffle furnace, capable of maintain a temperature of 440 ± 25°C.

9.2.4 Reagents

No reagents are required for this test.

9.2.5 Sample Preparation

The sample preparation and minimum masses required for the preparation of test samples and specimens shall follow Clause 9.1.5 as for Test Method 9.1, except for the following:

(i) Clause 9.1.5.6: For Test Method 9.2, the mass of sample passing the 2 mm test sieve shall be recorded to the nearest 0.1% (m_2).

(ii) Clause 9.1.5.7: For Test Method 9.2, divide the soil to a sample weighing approximately 10 g.

(iii) Clause 9.1.5.9: For Test Method 9.2, this step shall read "Subdivide the sample by riffling on the 7 mm divider to obtain test specimens each weighing approximately 5 g. Throughout this and any subsequent operation, mix the material available thoroughly before any division, and avoid segregation during riffling."

(iv) Clause 9.1.5.10: For Test Method 9.2, the specimen shall be placed in a prepared crucible for drying.

9.2.6 Test Procedures

9.2.6.1 The crucible shall be prepared as follows:

(i) Place the crucible in the muffle furnace, heat it to 440 ± 25°C and maintain the temperature for 1 hour.

(ii) Remove the crucible from the furnace and allow it to cool to room temperature in the desiccator.

(iii) Weigh the crucible to the nearest 0.001 g (m_c).

9.2.6.2 Ignition of soil shall be carried out as follows:

(i) Place the crucible with soil in the unheated muffle furnace, heat it to 440 ± 25°C, and maintain this temperature for a period of not less than 3 hour, or until a constant mass is achieved.

Note: The period required for ignition will vary with the type of soil and size of the sample.

(ii) Remove the crucible together with its contents from the furnace and allow it to cool to room temperature in the desiccator.

(iii) Weigh the crucible and contents to the nearest 0.001 g (m_4).

9.2.7 Calculations

9.2.7.1 Calculate the mass loss on ignition, LOI, as a percentage of the dry mass of soil passing a 2 mm test sieve from the equation:

$$\mathrm{LOI} = \left(\frac{m_3 - m_4}{m_3 - m_c} \right) 100$$

where m_3 is the mass of the crucible and oven-dry soil specimen (in g);
m_4 is the mass of the crucible and specimen after ignition (in g); and
m_c is the mass of the crucible (in g).

9.2.7.2 Calculate the percentage of the original soil sample passing the 2 mm test sieve from the equation in Clause 9.1.7.2 as for Test Method 9.1.

9.2.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the mass loss on ignition as a percentage of the soil fraction passing the 2 mm test sieve to two significant figures, and

(c) the percentage by dry mass of the original sample passing the 2 mm test sieve to the nearest 1%.

9.3 Determination of Total Sulphate Content of Soils and Sulphate Content of Groundwater and of Aqueous Soil Extracts by Gravimetric Method

9.3.1 Scope

This test method is used for the determination of total sulphate content of soils or the content of water-soluble sulphate of soil or groundwater by the gravimetric method.

9.3.2 General

The guidance given in Clause 9.1.2 as for Test Method 9.1 shall be noted.

9.3.3 Apparatus

The apparatus for the preparation of soil and its acid extract and testing are as follows:

(a) a drying oven, capable of maintaining a temperature of 75°C to 80°C, and 105°C to 110°C,

(b) a balance, readable to 1 g and accurate to 3 g,

(c) a balance, readable to 0.001 g and accurate to 0.005 g,

(d) a desiccator, containing anhydrous silica gel,

(e) test sieves, 2 mm and 425 μm aperture sizes, with a receiver,

(f) a pestle and mortar, or a suitable mechanical crusher,

(g) sample dividers of multiple-slot type (riffle boxes), having widths of opening of 7 mm and 15 mm,

(h) a glass weighing-bottle, approximately 50 mm in diameter, 25 mm high and fitted with a ground-glass stopper,

(i) red litmus paper and blue litmus paper,

(j) either:

- a sintered silica filtering crucible of porosity grade No. 4 and about 35 mm diameter and 40 mm high, or
- an ignition crucible about 35 mm diameter and 40 mm high, capable of maintaining a constant mass when heated to 800 ± 50°C,

(k) a suitable means of igniting the precipitate, preferably an electric muffle furnace capable of maintaining a temperature of 800 ± 50°C, Note: Alternatively a Bunsen burner or similar burner, tripod and suitable pipeclay triangle may be used.

(l) two 500 mL conical beakers with glass rods and cover glasses,

(m) a electric hot-plate, capable of being controlled to boil the contents of the beakers,

(n) a Buchner funnel, of about 100 mm diameter,

(o) a vacuum filtration flask, of about 500 mL capacity, to take the funnels,

(p) filter papers, of medium grade (e.g. Whatman No. 40), hardened medium grade (e.g. Whatman No. 540) and fine grade (e.g. Whatman No. 42) to fit the funnels,

(q) a source of vacuum, e.g. a filter pump,

(r) a length of rubber vacuum tubing, to fit the vacuum pump and filter flask,

(s) two glass rods, about 150 mm to 200 mm long and 3 mm to 5 mm in diameter,

(t) a wash bottle, preferably made of plastics, containing distilled water,

(u) a glass filter funnel, about 100 mm diameter,

(v) a dropping pipette, 10 mL capacity, and

(w) an amber coloured glass container.

The apparatus for the preparation of soil and its 2:1 water-soil extract and testing shall include the above Items (a) to (k) and the following:

(x) a mechanical shaker or stirrer, capable of keeping 50 g of soil in continuous suspension in 100 mL of water,

(y) an extraction bottle, of approximately 100 mL capacity,

(z) a piece of 75 mm diameter watch glass, and

(aa) a 50 mL and a 25 mL pipette.

The apparatus for the preparation of groundwater for testing are as follows:

(ab) a filtration funnel and a stand,

(ac) filter papers of a suitable diameter to fit the funnel, Whatman No. 44 grade or similar,

(ad) three 500 mL glass conical beakers,

(ae) two 250 mL conical beakers,

(af) a 100 mL glass measuring cylinder,

(ag) a 50 mL pipette, and

(ah) a wash bottle, preferably made of plastics, containing distilled water.

9.3.4 Reagents

The following reagents, which shall be of recognised analytical reagent quality, are required:

(a) hydrochloric acid (a 10% (v/v) solution),

Note: This solution can be prepared by diluting 100 mL of concentrated hydrochloric acid (of relative density 1.18) to 1 L with distilled water.

(b) dilute ammonia solution,

Note: This solution can be prepared by diluting 500 mL of ammonia (of relative density 0.880) to 1 L with distilled water.

(c) silver nitrate (a 0.5% (v/v) solution),

Note: This solution can be prepared by dissolving 0.5 g of silver nitrate in 100 mL of distilled water and store the solution in an amber-coloured glass container.

(d) concentrated nitric acid (of density 1.42 g/mL),

(e) distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990, and

(f) barium chloride (a 5% (m/m) solution).

Note: This solution can be prepared by dissolving 50 g of barium chloride in 1 L of water and filter it before use if necessary.

9.3.5 Sample Preparation

9.3.5.1 The preparation of soil and its acid extract shall be carried out as follows:

(i) Obtain an initial sample in accordance with Clause 9.1.5.1 and 9.1.5.2.

(ii) Dry this sample in the oven at a temperature between 75°C and 80°C and allow it to cool to room temperature in the desiccator.

Note: Soils containing sulphates in the form of gypsum will lose water of crystallization if heated above the specified temperature.

(iii) Weigh the sample to the nearest 0.1% and record the mass m_1 (in g).

(iv) Sieve the sample on a 2 mm test sieve (if appropriate, guarded by a test sieve of larger aperture), and crush particles other than stones to pass through the sieve.

Note: It is assumed that any soil retained on the 2 mm test sieve will not contain sulphates. This is generally true but certain soils may contain lumps of gypsum larger than 2 mm in diameter and in such cases, the gypsum should be removed by hand, crushed to pass a 2 mm test sieve and incorporated in the fraction passing the sieve.

(v) Reject the stones ensuring that no fines adheres to them, e.g. by brushing. Record (in g) the mass of the sample passing the 2 mm test sieve to the nearest 0.1% (m_2). Throughout these and subsequent operations ensure that there is no loss of fines.

(vi) Divide the soil passing the 2 mm sieve by successive riffling through the 15 mm divider to produce a sample weighing approximately 100 g.

(vii) Pulverise this sample so that it passes the 425 μm test sieve. Throughout this and any subsequent operation, mix the material thoroughly before any division and take care to avoid segregation during riffling.

(viii) Subdivide the sample by successive riffling through the 7 mm divider to obtain test specimens each weighing approximately 10 g.

(ix) Place each specimen in a glass weighing bottle and dry it in the oven at a temperature of 75°C. The specimens are deemed to be dry when the differences in successive weighings at intervals of 4 h do not exceed 0.1% of the specimen mass.

(x) Allow the specimens to cool to room temperature in the desiccator and weigh each bottle and contents to the nearest 0.001 g.

(xi) Transfer a representative sample of about 2 g to a 500 mL beaker, reweigh the weighing bottle and determine the mass (m_3) of the sample by calculating the difference.

Note: The mass of sample to use depends on the amount of sulphate present. Ideally a mass should be chosen such that it will produce a precipitate of barium sulphate weighing approximately 0.2 g.

(xii) Add 100 mL of 10% hydrochloric acid to the sample, taking care if frothing occurs to ensure that no material is lost.

Note: Materials containing sulphides will release H_2S on acidification, which can be detected by its smell. In these cases there is a danger that this procedure will overestimate the sulphate content because of sulphide oxidation. If the soil contains sulphides, place 100 mL of the acid in a 500 mL beaker and heat it to boiling. Remove it from the heat source and whilst stirring the acid solution, sprinkle the weighed analytical sample into the acid.

(xiii) Cover the beaker with a cover glass, boil and simmer its contents gently for 15 min in a fume cupboard. Rinse the underside of the cover glass, collect all washing in the beaker and analyse the acid extract as described in Clause 9.3.6.

(xiv) For saprolitic, residual and colluvial soils, the following additional procedures shall also be carried out:

- Add a few drops of nitric acid while the suspension continues to boil.
- Add ammonia solution slowly (preferably from a burette), with continuous stirring, to the boiling solution until the sesquioxides are precipitated and the red litmus paper is turned to blue by the liquid.
- Filter the suspension through a hardened filter paper into a 500 mL conical beaker. Wash the filter paper with distilled water until the washings are free from chloride, as indicated by an absence of turbidity when a drop is added to a small volume of silver nitrate.
- Carefully remove the filter paper with the precipitate and replace it in the original beaker. A 10% solution of hydrochloric acid is added and the content stirred until the sesquoixides have gone into solution (20 mL of 10% hydrochloric acid should be sufficient). Bring the contents to boil and repeat the previous two steps as described above.

9.3.5.2 The preparation of soil and its water extract shall be carried out as follows:

(i) Prepare a sample of soil passing the 2 mm test sieve, as described in Clauses 9.3.5.1 (i) to (v).

(ii) Divide the soil passing the 2 mm sieve by successive riffling through the 15 mm divider to produce a sample weighing approximately 60 g.

(iii) Pulverise, dry and cool this sample in accordance with Clauses 9.3.5.1 (vii), (ix) and (x) respectively.

(iv) Weigh a specimen of 50 g directly in a dry extraction bottle.

(v) Add exactly 100 mL of distilled water to the extraction bottle, stopper it tightly and place it in the shaker and agitate for 16 h.

(vi) Filter the soil suspension into a clean and dry flask through a suitable filter paper, e.g. Whatman No. 50, on the Buchner funnel.

Note: If a centrifuge is available, it will probably be more convenient to use a centrifuge tube for the extraction. The suspension can then be centrifuged instead of filtered and 25 mL of the clear supernatant liquid is used for the analysis.

(vii) Transfer 50 mL of filtered extract to a 500 mL beaker. Add distilled water to about 300 mL and proceed to Clause 9.3.6.

9.3.5.3 The preparation of groundwater samples shall be carried out as follows:

(i) Filter the water through a suitable filter paper, such as Whatman No. 44, into a clean flask to remove any particles in suspension.

(ii) Transfer 50 mL of the filtered water to each of the two clean and dried 500 mL beakers, and add approximately 100 mL of distilled water to each beaker.

9.3.6 Test Procedures

9.3.6.1 Analyse each filtrate specimen obtained in Clauses 9.3.5.1 (x) to (xiv) or from the water extract procedure in Clauses 9.3.5.2 (iv) to (vii), or in Clause 9.3.5.3, as described in the following steps.

9.3.6.2 Test the solution with a litmus paper and, if necessary, make it slightly acidic by adding 20 drops of hydrochloric acid.

9.3.6.3 Dilute it to 300 mL if necessary, bring the solution to boiling and add 10 mL barium chloride solution drop by drop with continuous stirring. Continue the boiling gently until the precipitate is properly formed.

9.3.6.4 Allow the solution to stand at just below the boiling point for a least 30 min, and then leave it to cool to room temperature.

Note: This digestion period is necessary to enable the precipitate to form particles large enough to be retained by filtration.

9.3.6.5 Transfer the liquid and precipitate of barium sulphate with extreme care to previously ignited and weighed sintered silica filter crucible using suction. Alternatively, transfer the precipitate with extreme care to a suitable filter paper, e.g. Whatman No. 42, in the glass filter funnel and filter. In either case, wash the precipitate several times with hot distilled water until the washings are free from chloride as indicated by the absence of turbidity when a drop is tested with the solution of silver nitrate.

9.3.6.6 If a sintered silica filter crucible is used, remove it from the filter flask and dry at 105°C to 110°C for approximately 30 min and gradually raise the temperature to 800°C, either in an electric muffle furnace or by other suitable means until no further loss in mass occurs.

9.3.6.7 If the precipitate is filtered through a filter paper, transfer the filter paper and precipitate to a previously ignited and weighed crucible. If an electric muffle furnace is used, place the crucible together with its contents in the furnace at room temperature and gradually raise the temperature to red heat. If a Bunsen burner or other burner is used, first dry the filter paper and precipitate slowly over a small flame, taking care to char the filter paper slowly rather than to allow it to burn, otherwise some of the precipitate may be lost. Ignition for about 15 min at red heat is usually sufficient in either case.

9.3.6.8 Following either Clauses 9.3.6.6 or 9.3.6.7 above, cool the crucible to room temperature in the desiccator and weigh it to the nearest 0.001 g. Calculate the mass of the precipitate (m_4) from the increase in the recorded mass of the crucible.

9.3.7 Calculations

9.3.7.1 The calculation for soil in its acid extract shall be carried out as follows:

(i) Calculate the percentage of total sulphates (as SO_3) in the fraction of the soil sample finer than 2 mm for each determination from the equation:

$$SO_3 = \frac{34.3 \ m_4}{m_3}$$

where m_3 is the mass of each test specimen used (in g); and
m_4 is the mass of ignited precipitate (in g).

If more than one specimen has been tested and the individual results differ by no more than 0.2% (SO_3), calculate the mean result. If they differ by more than 0.2%, repeat the test starting with two new analytical portions of soil.

(ii) Calculate the percentage of the original soil sample passing the 2 mm test sieve from the equation in Clause 9.1.7.2 as for Test Method 9.1.

9.3.7.2 The calculation for soil in its water extract shall be carried out as follows:

(i) Calculate the percentage of water-soluble sulphates (as SO_3) in the fraction of the soil sample finer than 2 mm for each determination from the equation:

$$SO_3 = 1.372 \ m_4$$

Note: This calculation is based on a mass of soil of exactly 50 g being used for the analysis. If the mass m differs from 50 g, the percentage of sulphates (SO_3) is equal to 68.6 m_4/m, where m is the mass of soil sample and m_4 is the mass of ignited precipitate.

Alternatively, the sulphates (as SO_3) in the 2:1 water-soil extract (in g/L) can be calculated from the equation:

$$SO_3 = 0.686\ m_4$$

If individual results differ by no more than 0.2% or 0.2 g/L (SO_3), calculate the mean result. If they differ by more than 0.2% or 0.2 g/L, repeat the test starting with two new analytical portions of the soil.

(ii) Calculate the percentage of the original soil sample passing the 2 mm test sieve from the equation in Clause 9.1.7.2 as for Test Method 9.1.

9.3.7.3 The calculation for groundwater samples shall be carried out as follows:

(i) For each determination, calculate the sulphate content (as SO_3) of the groundwater (in g/L) from the equation:

$$SO_3 = 6.86\ m_4$$

Note: This calculation is based on a volume of groundwater of exactly 50 mL being used for the analysis.

(ii) If individual results differ by no more than 0.2 g/L (SO_3), calculate the mean result. If they differ by more than 0.2 g/L, repeat the test starting with two new 50 mL samples of filtered groundwater.

9.3.7.4 If the total sulphate content exceeds 0.5%, the water-soluble sulphate content of a 2:1 water-soluble extract shall be determined (see Clause 3.5).

9.3.8 Report

The test report shall affirm that the test was carried out in accordance with this method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) for soil samples:

- the average sulphate content, to the nearest 0.01% as (SO_3) of the oven-dry mass of the fraction of soil passing a 2 mm test sieve,
- whether the result represents total sulphates (as obtained by the acid-extraction method in Clause 9.3.5.1), or water-soluble sulphates (as obtained by the water-extraction method in Clause 9.3.5.2), and

- the percentage by dry mass of the original sample passing a 2 mm test sieve, to the nearest 1%, and

(c) for groundwater samples:

- the average sulphate content, to the nearest 0.01 g/L.

9.4 Determination of Water-soluble Chloride Content

9.4.1 Scope

This test method is used for the determination of water-soluble chloride salt content of soil. The procedure is based on Volhard’s method.

9.4.2 General

The guidance given in Clause 9.1.2 as for Test Method 9.1 shall be noted.

For the determination of water-soluble chlorides, the chlorides are extracted from a dry soil sample in a suspension of water. The mass of water used should be twice the mass of the soil sample. The results are expressed as the chloride ion content.

A qualitative test for checking for the presence chlorides is included, which if negative obviates the need for the quantitative analysis.

The water-extraction method is applicable to soils in which the chloride content is derived from recent contact with, or immersion in, saline water.

9.4.3 Apparatus

The following apparatus are required:

(a) a balance, readable to 1 g and accurate to 3 g,

(b) a balance, readable to 0.001 g and accurate to 0.005 g,

(c) a 1 L volumetric flask,

(d) a 10 mL graduated glass measuring cylinder,

(e) a 500 mL graduated measuring cylinder,

(f) a 100 mL pipette,

(g) a 25 mL pipette,

(h) two 50 mL burettes,

(i) at least four stoppered conical flasks, 500 mL capacity each,

(j) a wash bottle, preferably made of plastics, containing distilled water complying with Clause 5.1 of BS 1377 : Part 1 : 1990,

(k) an amber-coloured glass reagent bottle,

(l) a wide mouth screw-capped plastics or metal bottle, of 2 L capacity, with a watertight cap,

(m) mechanical shaking apparatus, capable of keeping 500 g of soil and 500 mL of water in the bottles in continuous suspension,

(n) drying oven, capable of maintaining the temperatures of 105 ± 5°C and 150 ± 5°C,

(o) a desiccator containing anhydrous silica gel,

(p) a filter funnel, of approximately 100 mm diameter,

(q) filter papers, of diameter appropriate to the size of the funnel and of medium grade (e.g. Whatman No. 40) and fine grade (e.g. Whatman No. 42),

(r) a test sieve, of 2 mm aperture size, with a receiver,

(s) sample dividers of multiple-slot type (riffle boxes), having widths of opening of 7 mm and 15 mm,

(t) a pestle & mortar, or a suitable mechanical crusher,

(u) a 500 mL volumetric flask, and

(v) two beakers, of about 250 mL capacity each.

9.4.4 Reagents

The following reagents, which shall be of recognised analytical reagent quality, are required:

(a) silver nitrate solution ($AgNO_3$, 0.100 mol/L),

Note: The solution can be prepared as follows:
(1) Dry about 20 g of silver nitrate at not more than 150°C for 1 hour to 2 hour and allow it to cool in the desiccator.
(2) Weigh 16.987 g of the dried silver nitrate, dissolve it in distilled water and diluted to 1 L in a volumetric flask.
(3) Store the solution in the amber-coloured glass reagent bottle and protect it from prolonged exposure to sunlight.

(b) thiocyanate solution (NH_4SCN or KSCN, approximately 0.1 mol/L),

Note: The solution can be prepared by dissolving 10.5 g of potassium thiocyanate or 8.5 g of ammonium thiocyanate in distilled water to 1 L in a volumetric flask.

(c) nitric acid solution (HNO_3, approximately 6 mol/L), Note: The solution can be prepared by diluting 100 mL of nitric acid (70% HNO_3, 1.42 g/mL) with distilled water to 250 mL and boil the diluted acid until it is colourless.

(d) 3,5,5-Trimethylhexan-1-ol, and

(e) ferric alum indicator solution.

Note: The solution can be prepared by adding 60 g of water to 75 g of ammonium ferric sulphate, warm to dissolve it, and add 10 mL of nitric acid (Clause 9.4.4(c), 6 mol/L). Allow it to cool and store it in a glass bottle.

9.4.5 Sample Preparation

9.4.5.1 Obtain an initial soil sample in accordance with Clause 4 which satisfies the following minimum mass requirement for analysis:

Fine-grained	Medium-grained	Coarse-grained
500 g	2 kg	30 kg

9.4.5.2 Dry this sample in an oven at 105°C to 110°C, and allow it to cool to room temperature in the desiccator.

9.4.5.3 Sieve the sample on a 2 mm test sieve (if appropriate, guarded by a test sieve of large aperture) and the crush retained particles other than stones to pass through the 2 mm test sieve.

9.4.5.4 Reject the stones, ensuring that no fines adheres to them, e.g. by brushing. Record the mass m_2 (in g) of sample passing the 2 mm test sieve to the nearest 0.1%. Throughout these and subsequent operations ensure that there is no loss of fines.

9.4.5.5 Divide the soil passing the 2 mm test sieve by successive riffling through the 15 mm divider to produce the following:

(i) a test specimen of about 500 g, and

(ii) a specimen of about 50 g for a qualitative check test to determine whether chlorides are present.

9.4.5.6 Dry the specimens in the oven at 105°C to 110°C. The specimens are deemed to be dry when the differences in successive weighings carried out at intervals of 4 h, do not exceed 0.1% of the original mass of the sample.

9.4.5.7 Allow the specimens to cool to room temperature in the desiccator.

9.4.6 Test Procedures

9.4.6.1 Standardisation of thiocyanate solution shall be carried out as follows:

(i) Transfer 25 mL of the silver nitrate solution into a 250 mL conical flask, using a pipette, and add 5 mL of the nitric acid solution and 1 mL of ferric alum indicator solution.

(ii) Add thiocyanate solution from a burette until the first permanent colour change occurs, that is from colourless to pink.

(iii) Record the volume of thiocyanate solution added V_1 (in mL).

(iv) Calculate the concentration C (in mol/L) of the solution from the following equation:

$$C = \frac{2.5}{V_1}$$

9.4.6.2 A qualitative check for chlorides shall be carried out as follows:

(i) Place the 50 g check specimen in a 500 mL conical flask and add to it an approximately equal mass of distilled water.

(ii) Agitate the contents intermittently for 4 h, allow it to settle and pour off some of the supernatant solution into a beaker.

(iii) Obtain about 25 mL of clear solution by filtering, if necessary, through a medium grade filter paper (e.g. Whatman No. 40).

(iv) Acidify the liquid with nitric acid, add about five drops of silver nitrate solution and allow it to stand for 10 min.

(v) If no turbidity is apparent after this time the soluble chloride ion content of the soil is negligible and the test for chloride content is not necessary.

9.4.6.3 The preparation of water-soluble chloride extract shall be carried out as follows:

(i) Weigh a clean and dry screw-capped bottle to 1 g, and record its mass.

(ii) Place the test specimen in the bottle and weigh the bottle together with its contents to 1 g.

(iii) Calculate the mass of soil by difference m (in g).

(iv) Add to the bottle distilled water of mass (m_w) equal to twice the mass of the test specimen. Fasten the watertight caps securely.

Note: For non-cohesive soils, a 1:1 extract may be more convenient, in which case a different factor is used for the calculation in Clause 9.4.7.

(v) Secure the bottle to the shaking apparatus and shake it for at least 16 h. When convenient, the soil can be left shaking overnight.

(vi) Filter the suspension through a medium-grade filter paper into a clean beaker until at least 100 mL of clear filtrate is collected. If the filtrate is not completely clear, filter it through a fine-grade filter paper.

Note: If the suspended particles settle quickly and the supernatant liquid is clear, the excess water can be carefully poured off.

9.4.6.4 The analysis of extract shall be carried out as follows:

(i) Take 100 mL of the filtered extract by means of the pipette and transfer it to the 500 mL conical flask.

(ii) Add 5 mL of the nitric acid solution to the flask followed by silver nitrate solution from a burette until all the chloride has been precipitated, and then add a little more silver nitrate solution.

(iii) Record the total volume V (in mL) of silver nitrate solution added.

(iv) Add 2 mL of 3,5,5-trimethylhexan-1-ol, fit the stopper, and shake the flask vigorously to coagulate the precipitate.

(v) Carefully loosen the stopper, avoiding any loss of solution, rinse it with distilled water, and collect the washings in the solution.

(vi) Add 5 mL of the ferric alum indicator solution, followed by the standardised thiocyanate solution from a burette until the first permanent colour changes occurs, that is from colourless to brick-red, and is the same depth of colour as observed during the standardisation described in Clause 9.4.6.1.

(vii) Record the volume V_3 (in mL) of thiocyanate solution added.

9.4.7 Calculations

9.4.7.1 Calculate the amount of chloride ions present in each water extract, as a percentage by dry mass of soil, from the equation:

$$\text{chloride ion content} = 0.007092\,(V_2 - 10\,CV_3)$$

where V_2 is the volume of the silver nitrate solution added (in mL);
V_3 is the volume of the standardised thiocyanate solution added (in mL); and
C is the concentration of the standardised thiocyanate solution (in mol/L).

Note: If the water-soil ratio is 1:1 instead of 2:1, the constant 0.007092 in this equation is replaced by 0.003546.

9.4.7.2 If more than one specimen has been tested, and if the individual results differ by no more than 0.1% of chloride ion content, calculate the mean result. If they differ by more than 0.1%, repeat the test starting with two new test specimens.

9.4.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the average percentage of chloride ions in the soil sample, to the nearest 0.01%, and

(c) the water to soil ratio used for preparing the soluble extract.

9.5 Determination of the pH Value

9.5.1 Scope

This test method is used for determining the pH value, by the electrometric method, which gives a direct reading of the pH value of a soil suspension in water. This test method can also be used for determining the pH value of a sample of groundwater.

9.5.2 General

The guidance given in Clause 9.1.2 as for Test Method 9.1 shall be noted.

9.5.3 Apparatus

The apparatus for preparation of test specimens are as follows:

(a) a balance, readable to 0.001 g and accurate to 0.005 g,

(b) a pestle and mortar, or a suitable mechanical crusher,

(c) a test sieve, of 2 mm aperture size, with a receiver,

(d) a non-corrodible tray, and

(e) a thermometer to cover the temperature range from 0°C to 40°C, accurate to 0.5°C.

The apparatus for determining the pH value by the electrometric method are as follows:

(f) a pH meter, fitted with a glass electrode and a calomel or a combined electrode (which may be incorporated in one probe) of range pH 3.0 to pH 10.0,

Note: The scale shall be readable and accurate to 0.05 pH units.

(g) glass or plastics beakers, 100 mL, with cover glasses and stirring rods,

(h) volumetric flasks, 500 mL each, and

(i) a wash bottle, preferably made of plastics, containing distilled water.

9.5.4 Reagents

The following reagents, which shall be of recognised analytical reagent quality, are required:

(a) buffer solution (pH 4.0),

Note: This buffer solution can be prepared by dissolving 5.106 g of potassium hydrogen phthalate in distilled water and dilute it to 500 mL with distilled water. Alternatively, a proprietary buffer solution of pH 4.0 may be used.

(b) buffer solution (pH 9.2),

Note: This buffer solution can be prepared by dissolving 9.54 g of sodium tetraborate (borax) in distilled water and dilute it to 500 mL. Alternatively, a proprietary buffer solution of pH 10.0 may be used.

(c) buffer solution (pH 7.0), such as a proprietary buffer solution of pH 7.0, and

(d) potassium chloride, a saturated solution for maintenance of the calomel electrode application.

9.5.5 Sample Preparation

9.5.5.1 Obtain an initial soil sample in accordance with Clause 4 which satisfies the following minimum mass requirements for analysis:

Fine-grained	Medium-grained	Coarse-grained
500 g	2 kg	30 kg

9.5.5.2 Allow the sample to air-dry by spreading it out on a tray at room temperature.

9.5.5.3 Sieve the sample on a 2 mm test sieve (if appropriate, guarded by a sieve of large aperture) and crush any retained particles other than stones to pass through the 2 mm test sieve.

9.5.5.4 Reject stones, ensuring that no fine material adheres to them by brushing. Record the mass m_2 (g) of the sample passing the 2 mm test sieve to the nearest 0.1%. Throughout these and subsequent operations ensure that there is no loss of fines.

9.5.5.5 Divide the soil passing the 2 mm test sieve by successive riffling through the 15 mm divider to produce a representative specimen of 30 g to 35 g.

9.5.6 Test Procedures

9.5.6.1 From the sample obtained as described in Clause 9.5.5.2, weigh 30 ± 0.1 g of soil and place it in a 100 mL beaker.

9.5.6.2 Add 75 mL of distilled water to the beaker, stir the suspension for a few minutes, cover it with a cover glass and allow it to stand for at least 8 h.

Note: The pH value of a soil suspension varies with the ratio of soil to water, an increase in dilution bringing the pH closer to 7.

9.5.6.3 Calibrate the pH meter by using the standard buffer solutions in accordance with the procedure recommended by the manufacturer.

9.5.6.4 Observe and record the temperature of the buffer solutions.

9.5.6.5 Stir the suspension of sample immediately before measurement.

9.5.6.6 Wash the electrode with distilled water and immerse it in the soil suspension. Take two or three pH readings of the suspension with slight stirring between each reading. These readings shall agree to within 0.05 pH units before they can be accepted.

Note: The pH readings of the soil suspension should reach a constant value in about 1 min. No readings should be taken until the pH meter has reach equilibrium.

9.5.6.7 Remove the electrodes from the suspension and wash them with distilled water. Recheck the calibration of the pH meter against one of the standard buffer solutions.

9.5.6.8 Observe and record the temperature of the suspension.

9.5.6.9 If the instrument is out of adjustment by more than 0.05 pH unit, set it to the correct adjustment and repeat the above Clauses 9.5.6.6 and 9.5.6.7 until consistent readings are obtained.

9.5.6.10 When not in use, leave the electrode standing in a beaker of distilled water.

9.5.7 Calculations

No calculations are required as this method is by direct reading from the pH meter.

9.5.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the pH value of the soil suspension to the nearest 0.1 pH unit, and

(c) state the temperature at which the pH value measurement is taken.

10 Determination of Dry Density/Moisture Content Relationship

10.1 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Not Susceptible to Crushing (Using 1000 cc Mould and 2.5 kg Rammer)

10.1.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are non-crushable. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a standard 1000 cc compaction mould.

10.1.2 General

The guidance given in Clause 3.7 shall be noted.

The Specifiers should be consulted about which sample preparation method to follow before proceeding to the test. If the alternative method is adopted, this shall be recorded as a Remark in the Worksheet.

10.1.3 Apparatus

The following apparatus are required:

(a) test sieves, with aperture sizes 63 mm, 37.5 mm, 20 mm, with a receiver,

(b) a balance, readable to 5 g and accurate to 10 g,

(c) a balance, readable to 1 g and accurate to 3 g,

(d) a corrosion-resistant metal or plastics tray with sides, e.g. about 80 mm deep, of a size suitable for the quantity of material to be used,

(e) a large metal scoop,

(f) a palette knife or spatula,

(g) watertight containers, e.g. strong polythene bags,

(h) apparatus for determination of moisture content as described in Clause 5,

(i) an implement for shredding stiff, cohesive soil,

(j) a straightedge, e.g. a steel strip about 300 mm long, 25 mm wide, and 3 mm thick, with one bevelled edge,

(k) apparatus for extracting specimens from the mould (optional),

(l) a cylindrical, corrosion-resistant metal mould i.e. the compaction mould, having a nominal internal volume of 1 L. The mould shall be fitted with a detachable baseplate and a removable extension. The essential dimensions are shown in Figure 10.1, which also indicates one suitable design of mould. The internal faces shall be smooth, clean and dry before each use, and

(m) a metal rammer having a 50 ± 0.5 mm diameter circular face, and weighing 2.5 kg ± 25 g. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to 300 ± 3 mm. One suitable form of the hand apparatus is shown in Figure 10.2.

Note: A motorised form of the apparatus may be used provided that the essential dimensions of the rammer and mould are adhered to, and provided that the density achieved is within ± 2% of the density achieved by using the hand rammer. The machine should be firmly supported on a heavy solid base such as a concrete floor or plinth.

10.1.4 Sample Preparation

10.1.4.1 Obtain an initial sample with a minimum mass of 10 kg so as to provide about 6 kg of soil passing through a 20 mm test sieve.

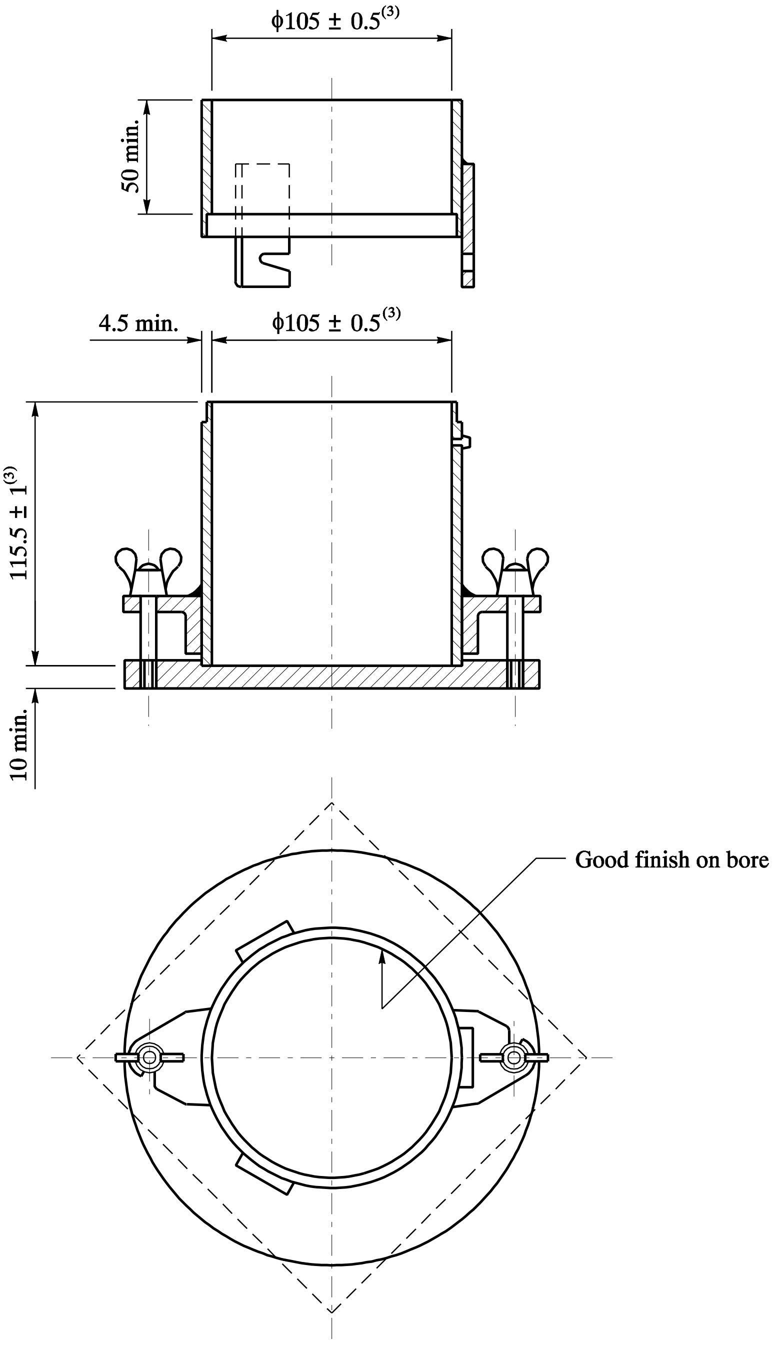
Note: One specimen only is required for this test for soils containing particles not susceptible to crushing and it can be used several times after progressively increasing the amount of water.

10.1.4.2 Assessment sieving shall be carried out in accordance with Clause 4.2. The soil may be mechanically processed in its as-received state using rubber pestle and mortar in accordance with Clause 4.5.1 such that, if the sample is sieved on a 5 mm test sieve, only individual particles are retained.

Note: For stiff, cohesive soils which need to be shredded or chopped into small lumps, the result of a compaction test depends on the size of the resulting pieces. Furthermore, the densities obtained in the test will not necessarily be directly related to densities obtained in-situ. The method used for breaking down cohesive soils, and the size of pieces obtained, should be recorded. Suggested methods are to shred the soil so that it can pass through 5 mm test sieve, or to chop it into pieces to pass a 20 mm test sieve.

10.1.4.3 Drying of soil, where necessary, may be carried out as specified in Clause 4.4 to provide the lowest moisture content required for compaction.

Note: Cohesive soil shall not become dry before testing, unless necessary. For saprolitic soils, oven-drying at 105 ± 5°C shall not be carried out. Where necessary, air-drying or oven-drying at temperature of ≤ 50°C is permitted prior to mechanical processing but only as much as is necessary to enable testing of the sample. The type of drying process, i.e. air-drying or oven-drying, shall also be recorded.



Notes:

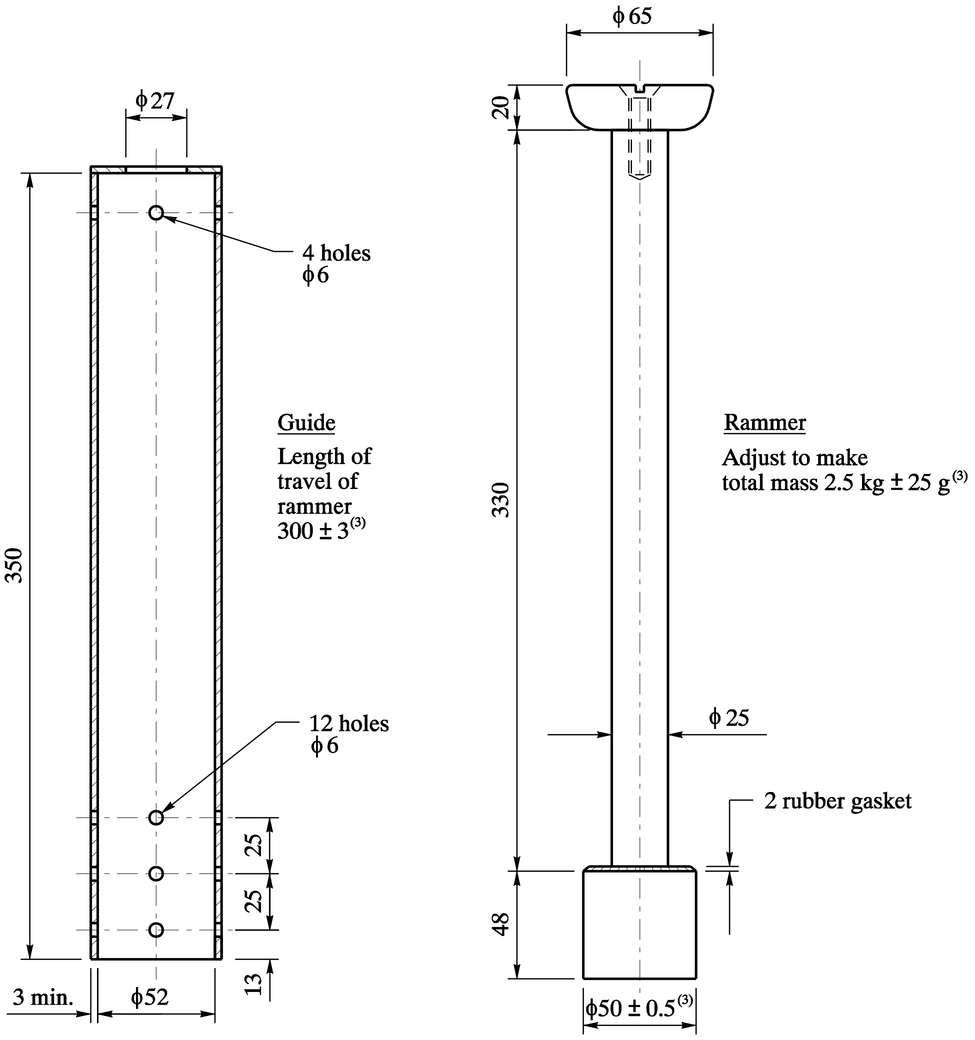
(1) All dimensions shown are in millimetres.

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

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 10.1 Mould for the Compaction Test (1L Mould)



Notes:

(1) All dimensions shown are in millimetres.

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

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 10.2 2.5 kg Rammer for the Compaction Test

10.1.4.4 The procedures to be used for sample preparation, the mass of samples required, and the type of mould for this test depend on the size of the largest particles present, and on whether or not the soil particles are susceptible to crushing during compaction. These are summarised in Table 10.1. The selection of methods is also shown in the form of a flow chart in Figure 10.4.

The assessment of these factors is covered as follows:

(i) Ascertain whether or not the soil particles are susceptible to crushing during compaction. If in doubt, assume that they are susceptible and follow Test Method 10.2.

(ii) Determine the approximate percentages (to an accuracy of ± 5%) by mass of particles in the soil sample passing the 20 mm and 37.5 mm test sieves. If the soil used for this assessment is to be used for the compaction test, it shall not be dried, and the dry mass of soil finer than 20 mm may be determined by measuring the moisture content using a representative portion. If enough soil is available to meet the requirements for the particle size distribution tests (Test Methods 8.1 and 8.2), a separate sample may be used for this sieving operation.

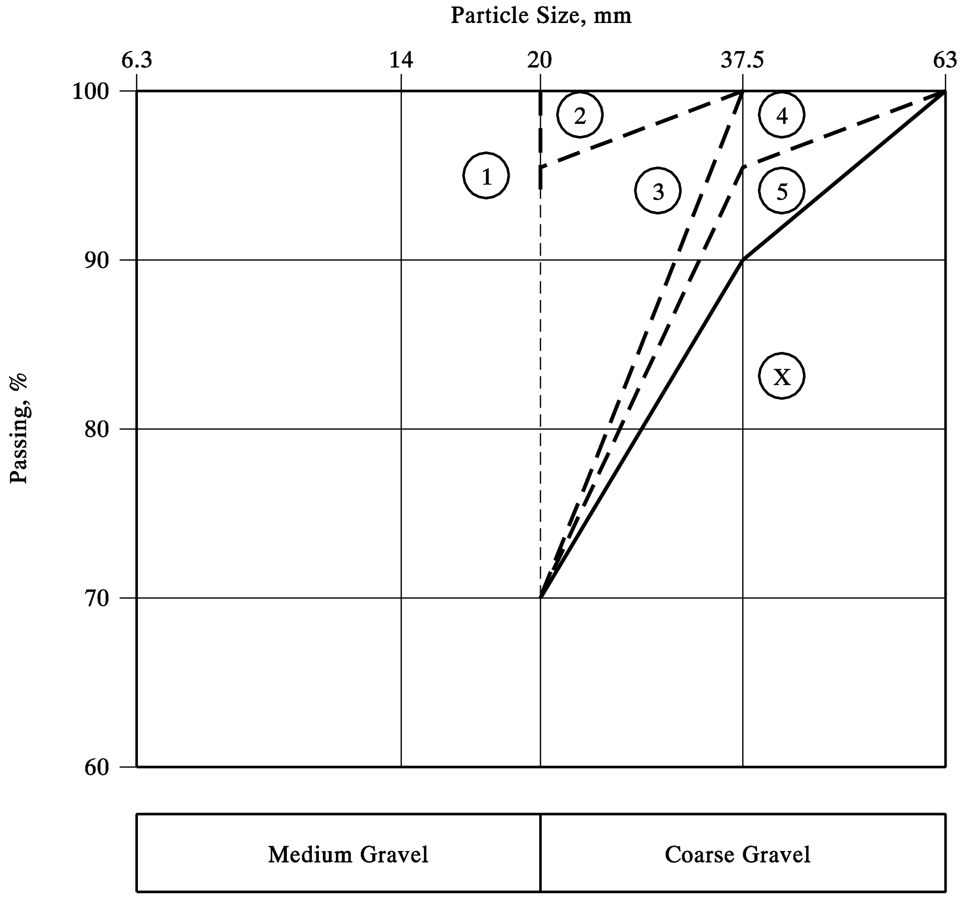
(iii) On the basis of these percentages, the soil can be assigned to one of the Grading Zones (1) to (5) in the following table, which are also shown diagrammatically in Figure 10.3. If a grading curve passes through more than one zone, the highest-numbered zone applies. A soil with a grading curve passing through zone X is not suitable for compaction tests.

Table 10.1 Summary of Sample Preparation Methods

Grading Zone	Minimum Percentage Passing Test Sieves (%)		Preparation Procedure Clause Reference		Minimum Mass of Prepared Soil Specimen Required		Type of Mould Used
	20 mm	37.5 mm	(a)	(b)	(a)	(b)	
(1)	100	100	10.1.4 10.1.4.5	10.2.4 10.2.4.3	6 kg	15 kg	1 L
(2)	95	100	10.1.4 10.1.4.6	10.2.4 10.2.4.4			
(3)	70	100	10.3.4 10.3.4.4	10.4.4 10.4.4.3	15 kg	40 kg	CBR
(4)	70	95	10.3.4 10.3.4.5	10.4.4 10.4.4.4			
(5)	70	90	10.3.4 10.3.4.6	10.4.4 10.4.4.5			
(X)	less than 70	less than 90	(← Tests not applicable →)				

Legend:

(a)	Soil particles not susceptible to crushing during compaction
(b)	Soil particles susceptible to crushing during compaction
1 L	One-litre compaction mould
CBR	CBR mould



Note: See Clauses 10.1.4.4 (iii) and Table 10.1.

Figure 10.3 Grading Limits Relating to Sample Preparation Procedure for Compaction Tests

10.1.4.5 Grading Zone (1): For soils passing the 20 mm test sieve, preparation shall be carried out as follows:

(i) Obtain the representative specimen of about 6 kg by subdividing the initial sample prepared.

(ii) Add a suitable amount of water depending on the soil type and mix thoroughly.

Note 1: The amount of water to be mixed with soil at the commencement of the test will vary with the type of soil under test. In general, with sandy and gravelly soils, a moisture content of 4% to 6% would be suitable, while with cohesive soils, moisture content about 8% to 10% below the plastic limit of the soil would usually be suitable.

Note 2: It is important that the water is mixed thoroughly and adequately with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with cohesive soils when adding a substantial quantity of water. With clays of high plasticity, or where hand mixing is used, storage of the mixed sample in a

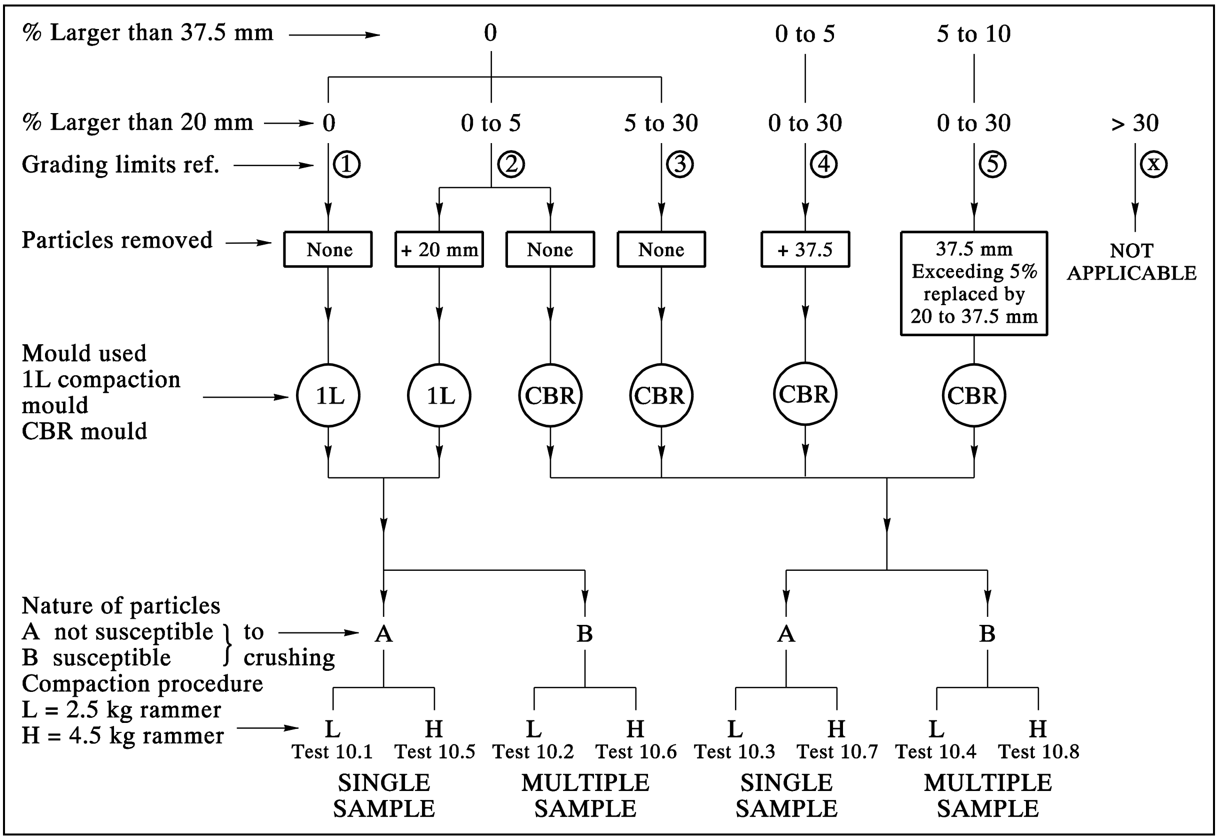


Figure 10.4 Flow Chart Representing Sample Preparation Methods for Compaction Tests

sealed container for a minimum period of 24 h before continuing with the test is the most satisfactory way of distributing the water uniformly.

Note 3: If the soil initially contains too much water, allow it to partially air-dry to the lowest moisture content at which the soil is to be compacted, and mix thoroughly.

(iii) If the soil is cohesive, seal it in an airtight container and store it for at least 24 h.

10.1.4.6 Grading Zone (2): For soils passing the 37.5 mm test sieve with at least 95% passing the 20 mm test sieve, preparation shall be carried out as follows:

(i) Weigh to 0.1% by mass the whole sample and record the mass.

(ii) Remove and weigh to 0.1% by mass the soil retained on the 20 mm test sieve.

Note: The removal of small amounts of stone (up to 5%) retained on a 20 mm test sieve is likely to affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density.

(iii) Subdivide the finer soil and proceed according to the above Clause 10.1.4.5 as for Grading Zone (1) soils. Alternatively, the whole sample can be prepared as described for Grading Zone (3) for compaction in a CBR mould, and the subsequent test procedures, calculations and reporting shall follow those for Grading Zone (3).

10.1.5 Test Procedures

10.1.5.1 Weigh the mould, with baseplate attached, to 1 g (m_1), and measure the internal dimensions to 0.1 mm (see also Clause 10.1.6.1).

Note: Measurement of the internal dimensions of the mould can be carried out yearly, provided that it has no damage.

10.1.5.2 Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.

10.1.5.3 Place a quantity of moist soil in the mould such that when compacted, it occupies a little over one-third of the height of the mould body.

10.1.5.4 Apply 27 blows from the rammer dropped from a height of 300 mm above the soil as controlled by the guide tube. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube.

10.1.5.5 Repeat the above Clauses 10.1.5.3 and 10.1.5.4 twice more, so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body.

Note: It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.

10.1.5.6 Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Replace any coarse particles removed in the levelling process, by finer soil from the sample, well pressed in.

10.1.5.7 Weigh the soil and mould with baseplate to 1 g (m_2).

10.1.5.8 Remove the compacted soil from the mould and place it on the metal tray. Take a representative specimen of the soil for determination of its moisture content in accordance with Test Method 5.1 or 5.2 as appropriate.

10.1.5.9 Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared soil.

10.1.5.10 Add a suitable increment of water and mix thoroughly into the soil.

Note: The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of

1% to 2% are suitable for sandy and gravelly soils, and of 2% to 4% for cohesive soils. To increase the accuracy of the test, it is often advisable to reduce the increments of water in the region of the optimum moisture content.

10.1.5.11 Repeat the above Clauses 10.1.5.2 to 10.1.5.10 to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

10.1.6 Calculations

10.1.6.1 Calculate the internal volume, V (in cm^3), of the mould.

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

$$\rho = \frac{m_2 - m_1}{V}$$

where m_1 is the mass of mould and baseplate (in g); and
m_2 is the mass of mould, baseplate and compacted soil (in g).

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

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

where w is the moisture content of the soil (in %).

10.1.6.4 Plot the dry densities obtained from a series of determinations as ordinates against the corresponding moisture contents as abscissa. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of dry density and moisture content, to three significant figures, corresponding to that point (see Figure 10.5).

Note: The maximum may lie between two observed points but when drawing the curve, care should be taken not to exaggerate its peak.

10.1.6.5 On the same graph, plot the curves corresponding to 0%, 5% and 10% air voids, calculated from the equation:

$$\rho_d = \frac{1 - \dfrac{V_a}{100}}{\dfrac{1}{\rho_s} + \dfrac{w}{100\,\rho_w}}$$

where ρ_d is the dry density (in Mg/m^3);
ρ_s is the particle density (in Mg/m^3) measured or assumed (if assumed, a value of 2.65 may be used);
ρ_w is the density of water (in Mg/m^3), assumed equal to 1;
V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil (equal to 0%, 5%, 10% for the purpose of this plot); and
w is the moisture content (in %).

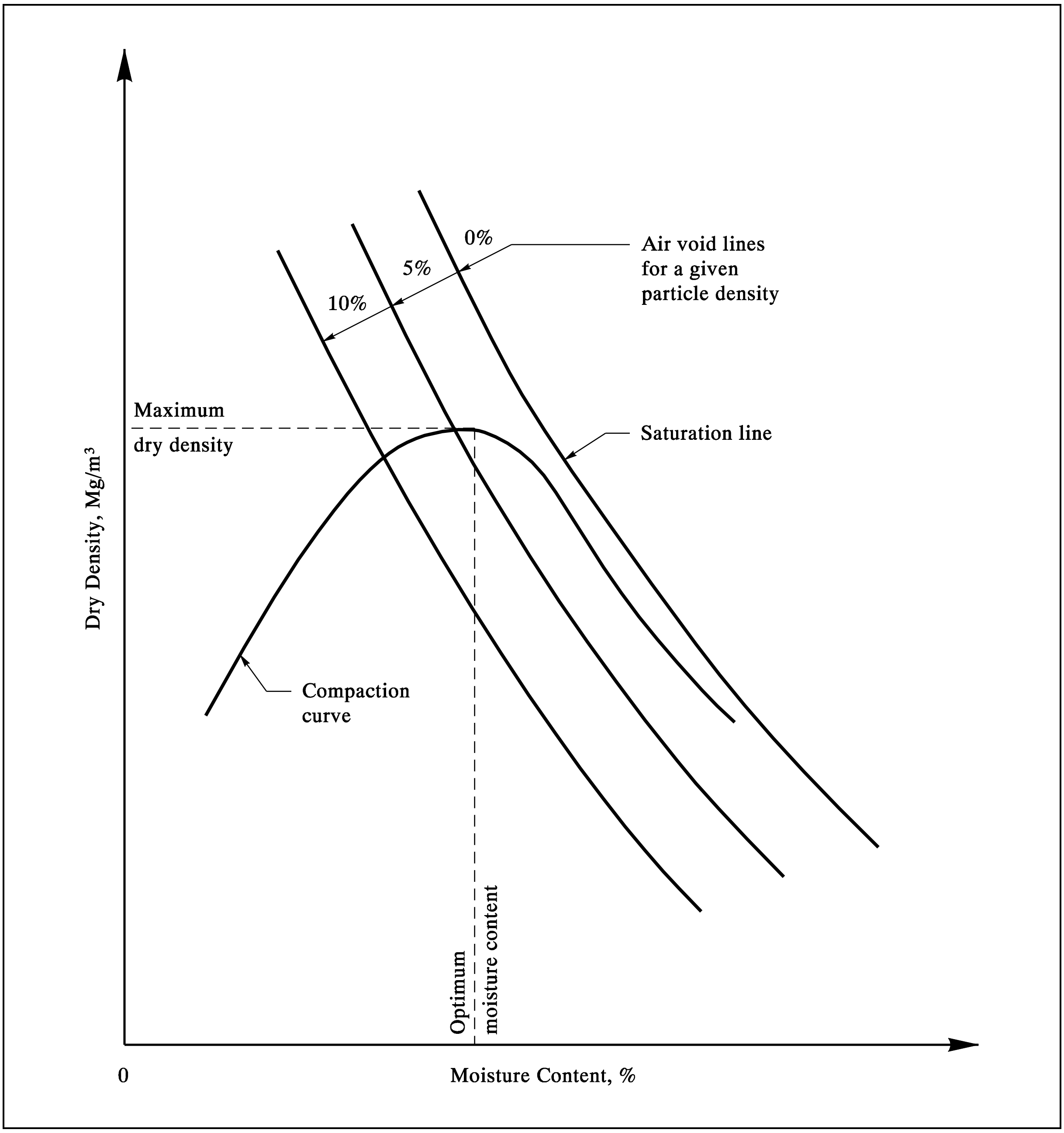


Figure 10.5 Dry Density/Moisture Content Relationship Curve

10.1.6.6 The particle density, ρ_s, may be measured or assumed as requested by the Specifier. If assumed, a value of 2.65 may be used. If determined, the test method shall be recorded and reported.

10.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) the sample preparation procedure, and whether a single sample or separate samples were used (in the case of stiff, cohesive soil, the size of pieces to which the soil was broken down shall be stated),

(c) the experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density,

(d) the dry density corresponding to the maximum dry density on the moisture content/dry density curve, reported as the maximum dry density to the nearest 0.01 (in Mg/m^3),

(e) the percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve reported as the optimum moisture content to two significant figures,

(f) the amount of stone retained on the 20 mm and 37.5 mm test sieves reported to the nearest 1% by dry mass, and the Grading Zone (1) to (5) or (X),

(g) the particle density and whether measured (if so the test method used) or assumed, and

(h) for saprolitic, residual or colluvial soils, the type of drying process adopted, including air-drying or oven-drying, if drying has been carried out during sample preparation.

10.2 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Susceptible to Crushing (Using 1000 cc Mould and 2.5 kg Rammer)

10.2.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are crushable. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a standard 1000 cc compaction mould.

10.2.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.2.3 Apparatus

The apparatus as listed in Clause 10.1.3 for Test Method 10.1 shall be used.

10.2.4 Sample Preparation

10.2.4.1 Obtain an initial sample of soil with a minimum mass of 25 kg so as to provide about 15 kg of soil passing through a 20 mm test sieve.

Note: Separate batches of soil at different moisture contents are required for this test for soils containing particles that are susceptible to crushing. Each batch of soil should be used for compacting once only, otherwise the characteristics of the material will progressively change after each application of compaction. Consequently, a much larger sample is required.

10.2.4.2 Prepare and assess the initial soil sample following Clauses 10.1.4.2 to 10.1.4.4 as for Test Method 10.1.

10.2.4.3 Grading Zone (1): For soils passing the 20 mm test sieve, preparation shall be carried out as follows:

(i) Subdivide the initial sample to produce five or more representative specimens, each of about 2.5 kg.

(ii) Mix each specimen thoroughly with a different amount of water to give a suitable range of moisture contents (see Notes 1 to 3 to Clause 10.1.4.5 (ii) of Test Method 10.1). The range of moisture contents shall be such that at least two values lie on either side of the optimum at which the maximum dry density occurs.

Note: The water added to each specimen should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1% to 2% are suitable for sandy and gravelly soils and of 2% to 4% for cohesive soils. To increase the accuracy of the test, it might be desirable to prepare specimens with smaller increments of water in the region of the optimum moisture content.

(iii) If the soil is cohesive, seal each specimen in an airtight container and store for at least 24 h.

10.2.4.4 Grading Zone (2): For soils passing the 37.5 mm test sieve with at least 95% passing 20 mm test sieve, preparation shall be carried out as follows:

(i) Weigh to 0.1% by mass the whole sample and record the mass.

(ii) Remove and weigh the soil retained on the 20 mm test sieve as described in Clause 10.1.4.6 (ii) of Test Method 10.1 with note.

(iii) Subdivide the finer soil, and proceed to the above Clause 10.2.4.3 as for Grading Zone (1) Soils. Alternatively, the whole sample can be used as described for compaction in a CBR mould, and the subsequent test procedures, calculations and reporting shall follow those compaction tests using the CBR mould. The Specifiers shall be consulted which sample preparation method to follow before proceeding further.

10.2.5 Test Procedures

10.2.5.1 Follow Clauses 10.1.5.1 to 10.1.5.8 as for Test Method 10.1.

10.2.5.2 Discard the remainder of the compacted specimen.

10.2.5.3 Repeat Clauses 10.1.5.2 to 10.1.5.8 for each of the prepared specimen. Discard the remainder of the compacted specimen every time. At least five determinations shall be achieved.

10.2.6 Calculations

Calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.2.7 Report

The test report shall include all the information as listed in Clause 10.1.7 as for Test Method 10.1.

10.3 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Not Susceptible to Crushing (Using CBR Mould and 2.5 kg Rammer)

10.3.1 Scope

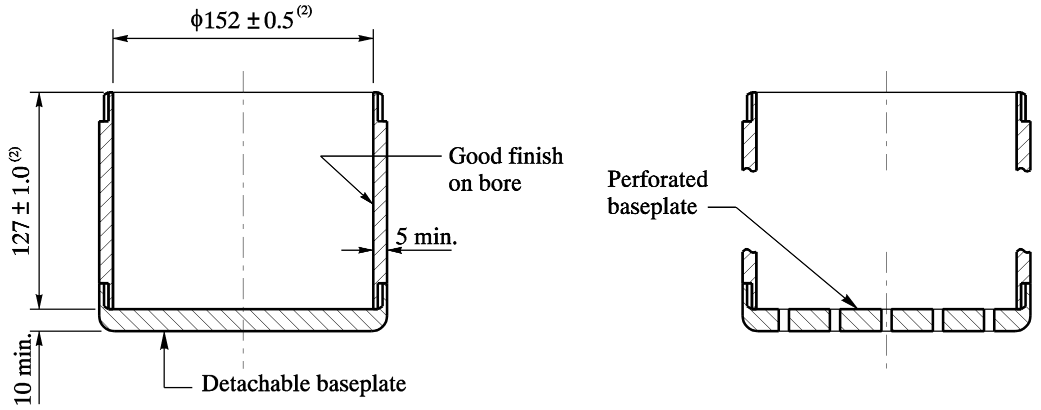
This test method is used for the determination of the dry density/moisture content relationship of a soil containing particles that are non-crushable, for which no more than 30% by mass of soil retained on the 20 mm test sieve (which may include some particles retained on the 37.5 mm test sieve). In this test, a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into the standard CBR mould.

10.3.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.3.3 Apparatus

The apparatus as listed in Clause 10.1.3 for Test Method 10.1 shall be used, except that the 1 L mould shall be replaced by a CBR mould. The CBR mould shall fulfil the same requirements as for the 1 L mould, but with a nominal diameter of 152 ± 0.5 mm. The essential dimensions and the suitable design of the mould are shown in Figures 10.6 and 10.7.

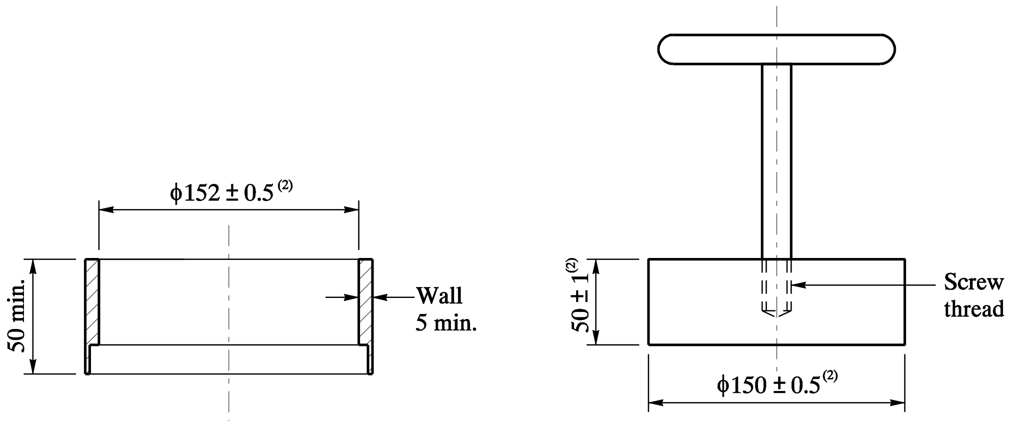


Notes: (1) All dimensions shown are in millimetres.

(2) These are manufacturing tolerances or limits on the essential dimensions.

(3) All other dimensions are given for guidance only.

Figure 10.6 Cylindrical Mould for the Determination of California Bearing Ratio



Notes: (1) All dimensions shown are in millimetres.

(2) These are manufacturing tolerances or limits on the essential dimensions.

(3) All other dimensions are given for guidance only.

Figure 10.7 Plug and Collar Extension for Use with Cylindrical Mould for the Determination of California Bearing Ratio

10.3.4 Sample Preparation

10.3.4.1 Obtain an initial sample of soil with a minimum mass of 50 kg so as to provide about 15 kg of soil passing a 37.5 mm test sieve.

Note: One specimen only is required for this test for soils containing particles not susceptible to crushing and it can be used several times after progressively increasing the amount of water.

10.3.4.2 Assessment sieving shall be carried out in accordance with Clause 4.2. The soil may be mechanically processed in its as-received state using rubber pestle and mortar in accordance with Clause 4.5.1 such that, if the sample is sieved on a 20 mm test sieve, only individual particles are retained. For cohesive soils, suggested methods are to shred the soil so that it can pass through the 20 mm test sieve.

Note: See Note to Clause 10.1.4.2 for Test Method 10.1.

10.3.4.3 Prepare and assess the sample according to Clauses 10.1.4.3 and 10.1.4.4 as for Test Method 10.1.

10.3.4.4 Grading Zone (3): For soils passing the 37.5 mm test sieve with 70% to 95% passing the 20 mm test sieve, preparation shall follow Clause 10.1.4.5 as for Grading Zone (1) in Test Method 10.1, except that the representative specimen shall weigh about 15 kg.

10.3.4.5 Grading Zone (4): For soils with at least 95% passing the 37.5 mm sieve and at least 70% passing the 20 mm sieve, preparation shall be carried out as follows:

(i) Weigh to 0.1% by mass the whole sample and record the mass.

(ii) Remove and weigh to 0.1% by mass the material retained on the 37.5 mm test sieve.

Note: The exclusion of the large proportion of particles coarser than 20 mm from this type of soil could have a large effect on the density obtained in the compaction mould compared with that obtainable with the soil as a whole, and the optimum moisture content would also be affected. The larger CBR mould is therefore specified for this type of material.

(iii) Subdivide the finer material to produce a 15 kg specimen and proceed to Clauses 10.1.4.5 (ii) to (iii) as in Test Method 10.1.

10.3.4.6 Grading Zone (5): For soils with 90% to 95% passing the 37.5 mm test sieve and at least 70% passing the 20 mm test sieve, preparation shall be carried out as follows:

(i) Weigh to 0.1% by mass the soil sample.

(ii) Remove and weigh to 0.1% by mass the material retained on the 37.5 mm test sieve.

(iii) Replace this material by the same quantity of material of similar characteristics which passes the 37.5 mm test sieve and is retained on the 20 mm test sieve.

Note: The substitution of large particles by smaller, similar particles is generally considered to give dry densities in the laboratory test which compare reasonably well with those obtained in the field.

(iv) Subdivide the finer material to produce a 15 kg specimen and proceed to Clauses 10.1.4.5 (ii) to (iii) as in Test Method 10.1.

10.3.5 Test Procedures

The test procedures shall follow Clause 10.1.5 as for Test Method 10.1, except for the following:

(i) Clause 10.1.5.1: For this test, this step shall be replaced by "Weigh the CBR mould with baseplate attached to 5 g (m_1), and measure the internal dimensions to 0.5 mm (see also Clause 10.1.6.1 in Calculations for Test Method 10.1)."

(ii) Clause 10.1.5.4: For this test, apply 62 blows instead of 27 blows.

(iii) Clause 10.1.5.7: For this test, weigh the soil and mould to 5 g (m_2), instead of

1 g.

(iv) Clause 10.1.5.9: For this test, the remaining soil can be rubbed through the 20 mm or the 37.5 mm test sieve.

10.3.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.3.7 Report

The test report shall include all the information as listed in Clause 10.1.7 as for Test Method 10.1.

10.4 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Susceptible to Crushing (Using CBR Mould and 2.5 kg Rammer)

10.4.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil containing particles that are crushable, for which no more than 30% by mass of soil retained on the 20 mm test sieve (which may include some particles retained on the 37.5 mm test sieve). In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into the standard CBR mould.

10.4.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.4.3 Apparatus

The apparatus used for Test Method 10.3 as stated in Clause 10.3.3, shall be used for this test.

10.4.4 Sample Preparation

10.4.4.1 Obtain an initial sample of soil with a minimum mass of 80 kg so as to provide about 40 kg of soil passing a 37.5 mm test sieve.

Note: See Note to Clause 10.2.4.1 in Sample Preparation for Test Method 10.2.

10.4.4.2 Prepare and assess the initial soil sample following Clauses 10.1.4.2 to 10.1.4.4 as for Test Method 10.1.

10.4.4.3 Grading Zone (3): For soils passing the 37.5 mm test sieve with 70% to 95% passing the 20 mm test sieve, preparation shall follow Clause 10.2.4.3 as for Grading Zone (1) in Test Method 10.2, except that each specimen shall weigh about 6 kg.

10.4.4.4 Grading Zone (4): For soils containing at least 95% passing the 37.5 mm sieve at least 70% passing the 20 mm sieve, preparation shall be carried out as follows:

(i) Follow Clauses 10.3.4.5 (i) and (ii) as for Grading Zone (4) in Test Method 10.3.

(ii) Subdivide the finer material to produce five or more representative specimens, each of about 6 kg, and proceed to Clauses 10.2.4.3 (ii) and (iii) as for Grading Zone (1) in Test Method 10.2.

10.4.4.5 Grading Zone (5): For soils with 90% to 95% passing the 37.5 mm test sieve and at least 70% passing the 20 mm test sieve, preparation shall be carried out as follows:

(i) Follow Clauses 10.3.4.6 (i) to (iii) as for Grading Zone (5) in Test Method 10.3.

(ii) Subdivide the material to produce five or more representative specimens, each of 6 kg, and proceed to Clauses 10.2.4.3 (ii) and (iii) as for Grading Zone (1) in Test Method 10.2.

10.4.5 Test Procedures

The test procedures shall follow Clause 10.3.5 as for Test Method 10.3, except that the test shall be repeated for each prepared specimen and the compacted specimen shall be discarded every time.

10.4.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.4.7 Report

The test report shall include all the information as listed in Clause 10.1.7 as for Test Method 10.1.

10.5 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Not Susceptible to Crushing (Using 1000 cc Mould and 4.5 kg Rammer)

10.5.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are non-crushable. In this test, the compactive effort is greater than that in Test Method 10.1: a 4.5 kg rammer falling through a height of 450 mm is used to compact the soil in five layers into a standard 1000 cc compaction mould.

10.5.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.5.3 Apparatus

The apparatus as listed in Clause 10.1.3 for Test Method 10.1 shall be used, except that the metal rammer shall be replaced by a heavier rammer. The rammer used in this test shall fulfil the same requirements as for Test Method 10.1, but shall weigh 4.5 kg ± 50 g, and shall be equipped with a suitable arrangement for controlling a greater height of drop of 450 ± 4 mm. One suitable hand apparatus is shown in Figure 10.8.

10.5.4 Sample Preparation

The sample preparation shall follow Clause 10.1.4 as for Test Method 10.1.

10.5.5 Test Procedures

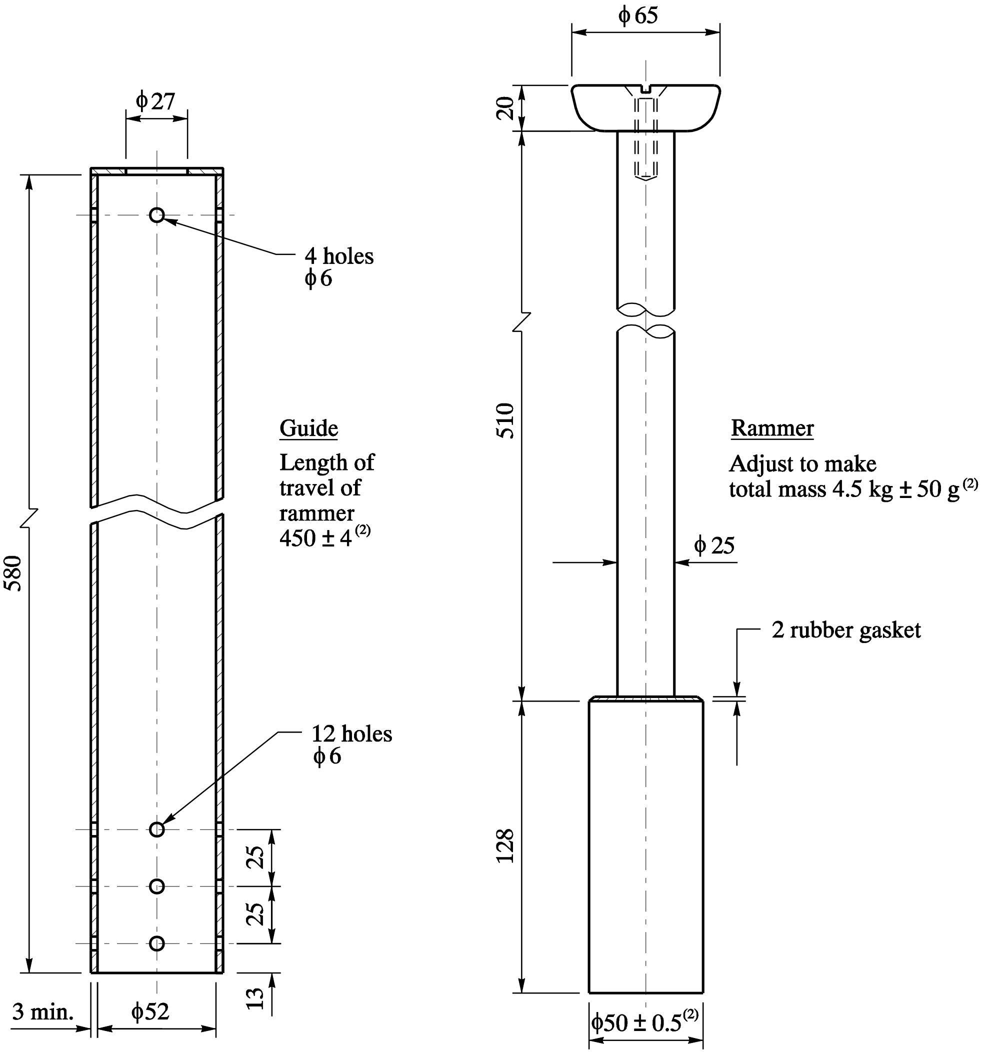
The test procedures shall follow Clause 10.1.5 as for Test Method 10.1, except that a 4.5 kg rammer shall be used and it shall be dropped from a height of 450 mm above the soil. The soil shall be compacted into the mould in five layers.

10.5.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.5.7 Report

The test report shall include all the information listed in Clause 10.1.7 as for Test Method 10.1.



Notes:

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

(2) These are manufacturing tolerances or limits on the essential dimensions.

(3) All other dimensions are given for guidance only.

Figure 10.8 4.5 kg Rammer for the Compaction Test

10.6 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Susceptible to Crushing (Using 1000 cc Mould and 4.5 kg Rammer)

10.6.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are crushable. In this test, the compactive effort is greater than that in Test Method 10.2: a 4.5 kg rammer falling through a height of 450 mm is used to compact the soil in five layers into a standard 1000 cc compaction mould.

10.6.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.6.3 Apparatus

The apparatus as listed in Clause 10.5.3 for Test Method 10.5 shall be used.

10.6.4 Sample Preparation

The sample preparation shall follow Clause 10.2.4 as for Test Method 10.2.

10.6.5 Test Procedures

The test procedures shall follow Clause 10.2.5 as for Test Method 10.2, except that a 4.5 kg rammer shall be used and it shall be dropped from a height of 450 mm above the soil. The soil shall be compacted into the mould in five layers.

10.6.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.6.7 Report

The test report shall include all the information listed in Clause 10.1.7 as for Test Method 10.1.

10.7 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Not Susceptible to Crushing (Using CBR Mould and 4.5 kg Rammer)

10.7.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are non-crushable. In this test, the compactive effort is greater than that in Test Method 10.3: a 4.5 kg rammer falling through a height of 450 mm is used to compact the soil in five layers into a standard CBR compaction mould.

10.7.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.7.3 Apparatus

The apparatus as listed in Clause 10.3.3 for Test Method 10.3 shall be used, except that the metal rammer shall be replaced by a heavier rammer. The rammer used in this test shall fulfil the same requirements as for Test Method 10.1, but shall weigh 4.5 kg ± 50 g, and shall be equipped with a suitable arrangement for controlling a greater height of drop of 450 ± 4 mm. One suitable hand apparatus is shown in Figure 10.8.

10.7.4 Sample Preparation

The sample preparation shall follow Clause 10.3.4 as for Test Method 10.3.

10.7.5 Test Procedures

The test procedures shall follow Clause 10.3.5 as for Test Method 10.3, except that a 4.5 kg rammer shall be used and it shall be dropped from a height of 450 mm above the soil. The soil shall be compacted into the mould in five layers.

10.7.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.7.7 Report

The test report shall include all the information listed in Clause 10.1.7 as for Test Method 10.1.

10.8 Determination of Dry Density/Moisture Content Relationship of Soils Containing Particles Which Are Susceptible to Crushing (Using CBR Mould and 4.5 kg Rammer)

10.8.1 Scope

This test method is used for the determination of the dry density/moisture content relationship of a soil passing a 20 mm test sieve, and containing particles that are crushable. In this test, the compactive effort is greater than that in Test Method 10.4: a 4.5 kg rammer falling through a height of 450 mm is used to compact the soil in five layers into a standard CBR compaction mould.

10.8.2 General

The guidance given in Clause 10.1.2 as for Test Method 10.1 shall be noted.

10.8.3 Apparatus

The apparatus as listed in Clause 10.7.3 for Test Method 10.7 shall be used.

10.8.4 Sample Preparation

The sample preparation shall follow Clause 10.4.4 as for Test Method 10.4.

10.8.5 Test Procedures

The test procedures shall follow Clause 10.4.5 as for Test Method 10.4, except that a 4.5 kg rammer shall be used and it shall be dropped from a height of 450 mm above the soil. The soil shall be compacted into the mould in five layers.

10.8.6 Calculations

The calculations shall follow Clause 10.1.6 as for Test Method 10.1.

10.8.7 Report

The test report shall include all the information listed in Clause 10.1.7 as for Test Method 10.1.

11 Determination of In-situ Bulk Density, In-situ Dry Density and Relative Compaction

11.1 Determination of In-situ Bulk Density and In-situ Dry Density of Soils by Sand Replacement Method Suitable for Fine- and Medium-grained Soils (with Small Pouring Cylinder)

11.1.1 Scope

This test method is used for the determination of the in-situ bulk density and in-situ dry density of fine- and medium-grained soils. The method is based on the sand replacement principle and uses a “small pouring cylinder”.

11.1.2 General

The guidance given in Clause 3.8 shall be noted.

11.1.3 Apparatus

The following apparatus are required:

(a) a pouring cylinder, similar in detail to that shown in Figure 11.1,

(b) suitable tools for excavating holes in soil e.g. a bent spoon dibber and a scraper tool, similar to that shown in Figure 11.2, to make a level surface,

(c) a cylindrical, metal, calibrating container, with an internal diameter of 100 ± 2 mm and an internal depth of 150 ± 3 mm of the type illustrated in Figure 11.3, fitted with a lip 50 mm wide and about 5 mm thick surrounding the open end,

(d) a balance, readable to 1 g, and accurate to 3 g,

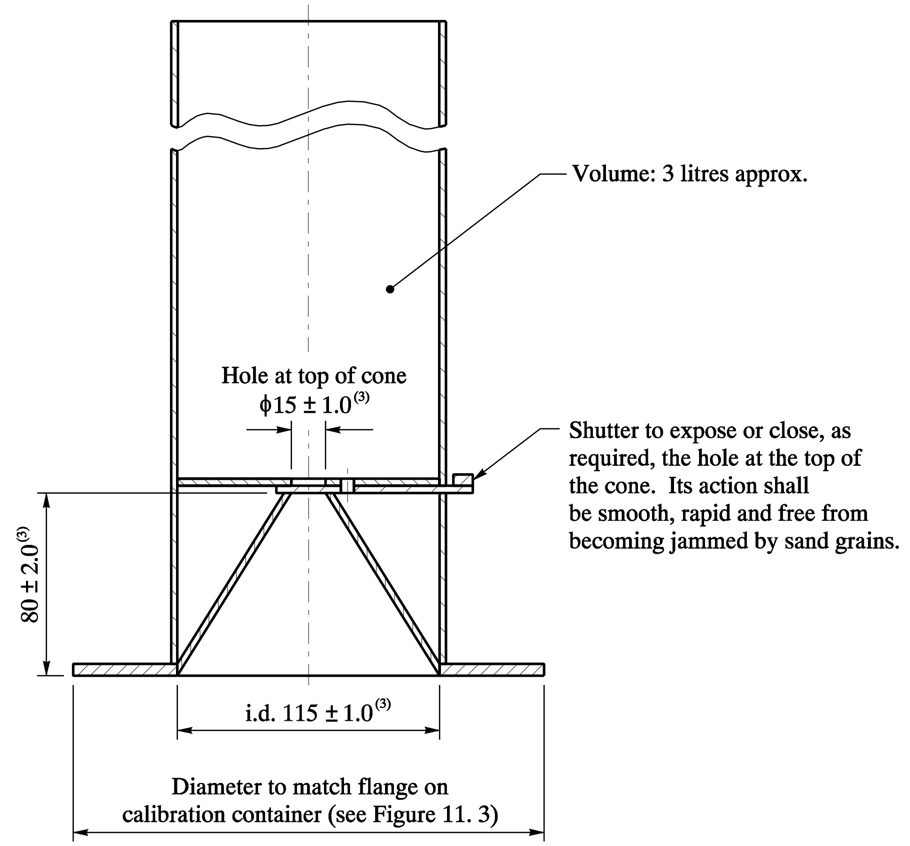
(e) a metal tray or container, to take excavated soil, a convenient size being one about 300 mm in diameter and about 40 mm deep,

(f) a cylindrical, steel core cutter (for fine-grained cohesionless soils). The cutter should be 130 mm long and 100 ± 2 mm internal diameter, with a wall thickness of 3 mm bevelled at one end. One suitable type is illustrated in Figure 11.4. This cutter shall be kept lightly greased,

(g) apparatus for moisture content determination as specified in Clause 5,

(h) a metal tray about 300 mm square and about 40 mm deep with a 100 mm diameter hole in the centre,

(i) BS test sieves having aperture sizes of 20 mm and 37.5 mm, with a receiver, and



Shutter to expose or close, as required, the hole at the top of the cone. Its action shall be smooth, rapid and free from becoming jammed by sand grains.

Notes:

(1) All dimensions shown are in millimetres.

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

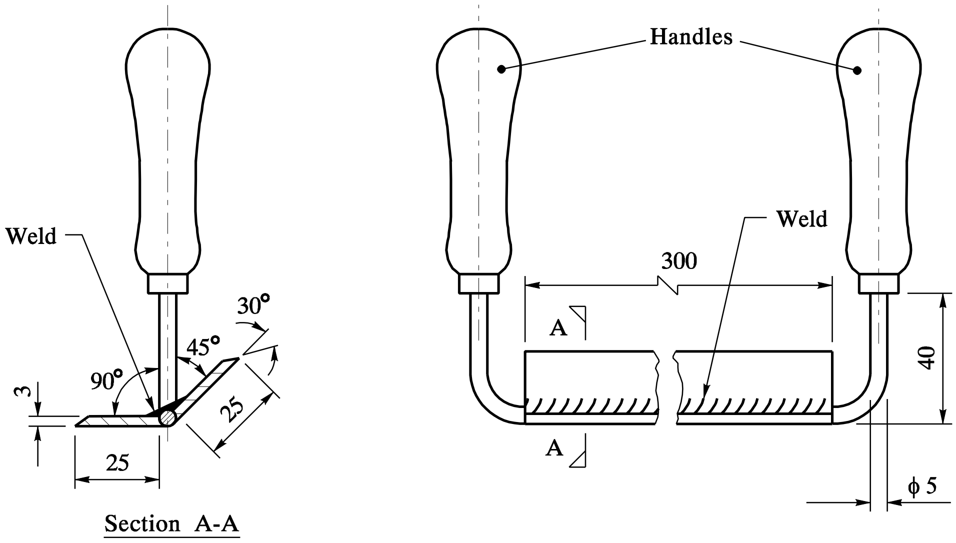
(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 11.1 Small Pouring Cylinder for the Determination of the Density of Fine- and Medium-grained Soils

(j) replacement sand, which shall be a clean closely graded silica sand having a bulk density that is reasonably consistent. The grading of the sand shall be such that 100% passes a 600 μm test sieve and 100% is retained on the 63 μm test sieve. In addition it shall be free from flaky particles, silt, clay and organic matter. Before using, it shall have been oven-dried and stored in a loosely covered container to allow its moisture content to reach equilibrium with atmospheric humidity.

Note: After oven-drying, a storage period generally of about 7 days is sufficient for the moisture content of the sand to reach equilibrium with the atmospheric humidity. The sand should not be stored in airtight containers and should be mixed thoroughly before use. If sand is salvaged from holes in compacted soils after carrying out this test, it is advisable to sieve, dry and store this sand again before it is used in further sand replacement tests.



Notes:

(1) All dimensions shown are in millimetres.

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

(3) All other dimensions are given for guidance only.

Figure 11.2 Scraper for Levelling the Surface of Soil

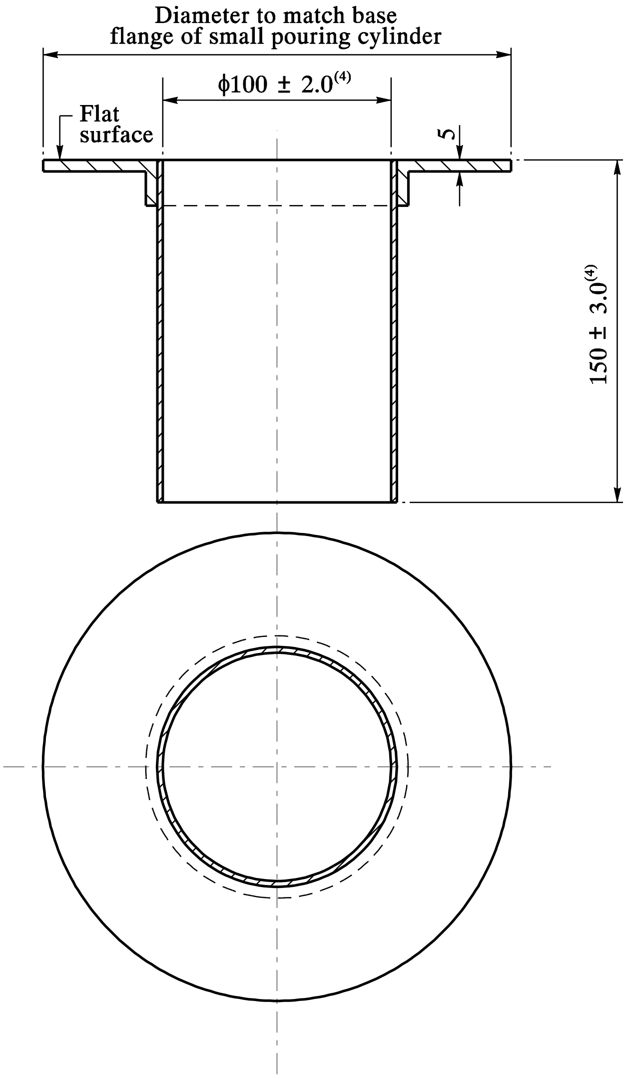
11.1.4 Calibration

11.1.4.1 The mass of sand in the calibrating container shall be determined as follows:

Note: The determination of the volume of the calibration container may be carried out yearly, provided that it has not been damage.

(i) Fill the pouring cylinder so that the level of sand in the cylinder is within about 15 mm of the top. Determine this initial mass of sand, m_1, to the nearest 1 g, and always use the same initial mass for every calibration. Maintain this mass constant throughout the tests for which the calibration is used. Place the calibrating container on a flat and level surface. Then place the pouring cylinder concentrically on top of the calibrating container with the metal tray sandwiched between the pouring cylinder and the calibrating container, and with the circular opening of the metal tray also placed concentrically with the cylinder. The metal tray used for the calibration shall be identical to the one to be used for the in-situ density tests. Keep the shutter of the pouring cylinder closed during the above operations.

(ii) Open the shutter on the pouring cylinder and allow the sand to run out. Do not tap the pouring cylinder or otherwise vibrate it during this period.



Notes:

(1) It is important that metal joints within the calibrating container do not form crevices because these will affect the accuracy of the calibration.

(2) All dimensions shown are in millimetres.

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

(4) These are manufacturing tolerances or limits on the essential dimensions.

(5) All other dimensions are given for guidance only.

Figure 11.3 Calibrating Container for Use with the Small Pouring Cylinder

When no further movement of sand takes place in the cylinder, close the shutter. Remove the pouring cylinder and the metal tray carefully.

(iii) With the help of a straight edge, carefully scrape off and collect the cone of sand left on top of the calibrating container so that the top surface of the sand left in the calibrating container is flat and level with the top of the container. Determine the mass of sand, m_3, remaining in the pouring cylinder and also the mass of sand, m_a, left in the calibrating container.

(iv) Repeat the measurements of m_a and m_3 at least three times and calculate their mean values.

11.1.4.2 The bulk density of sand (ρ_a) shall be determined as follows:

A convenient and accurate method for determining the internal volume, V (in mL), of the calibrating container is by determining the mass of water required to fill it. The procedure is described here.

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 modelling clay or similar material. Note the mass of the container, together with any modelling clay, to the nearest 1 g (m_5). Then fill the calibrating container almost completely with water, taking care not to spill water upon the pan of the balance or the outside of the container. Lay a straightedge across the top of the container and add water slowly and carefully by means of a dropping rod until the water just touches the straightedge. Remove the straightedge and note the mass of the container plus water to the nearest 1 g (m_6). Repeat the measurement a number of times to obtain an accurate mean value of m_6. For repeating the measurement, 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 straightedge. The volume of the calibrating container, V (in mL), is given by the equation:

$$V = m_6 - m_5$$

Note 1: If there is no visible damage to the calibrating container, the volume calibration can be carried out once a year.

Note 2: Since variations in atmospheric humidity affect the moisture content of the sand, and hence its bulk density, the calibration should 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 should be sampled and calibrated.

11.1.5 Test Procedures

11.1.5.1 Expose a flat area, approximately 450 mm square, of the soil to be tested and trim it down to a level surface, preferably with the aid of the scraper tool. Brush away any loose extraneous material.

11.1.5.2 Lay the metal tray on the prepared surface with the hole over the portion of the soil to be tested and ensure that no gap shall be left between the metal tray and the prepared surface so as to avoid trapping any sand within the gap during testing. Using this hole as a pattern, excavate a round hole, approximately 100 mm in diameter and the depth of the layer to be tested up to a maximum of 150 mm deep. Do not leave loose material in the hole and do not distort the immediate surround to the hole. Carefully collect all the excavated soil from the hole into an airtight bag or container and determine its mass, m_w, to the nearest 1 g. The metal tray is left in place throughout the test.

Note: Take care in excavating the hole to see that the hole is not enlarged by levering the excavating tool against the side of the hole, as this will result in lower densities being recorded.

11.1.5.3 For fine-grained cohesionless soils when a cylindrical hole cannot be formed using the above procedure in Clause 11.1.5.2 because of the instability of the sides of the hole, excavation of hole shall be carried out as described below:

Without using the metal tray, press the steel core cutter (Figure 11.4) evenly and carefully into the soil until its top edge is flush with the levelled surface. Excavate the soil to a depth of about 120 mm within the core cutter by means of suitable tools. Carefully collect the excavated soil and determine its mass, m_w, to the nearest 1 g. Keep the core cutter in position during the remainder of the testing procedure.

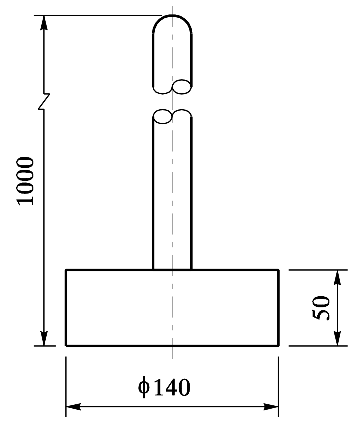
Note: The use of the core cutter will produce some disturbance in the soil and, where this procedure is necessary, due allowance should be made for a lower standard of accuracy than would normally be expected with the sand replacement method.

11.1.5.4 Place a representative specimen of the excavated soil in an airtight container and determine its moisture content, w, in accordance with Test Method 5.1 or 5.2, as appropriate. Alternatively, the whole of the excavated soil shall be dried and its mass, m_d, determined.

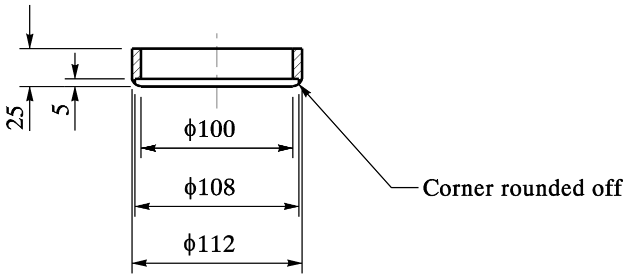
11.1.5.5 Place the pouring cylinder, filled with sand of an initial mass of m_1, as in Clause 11.1.4.1 (i) so that the base of the cylinder covers the hole concentrically. Ensure the shutter on the pouring cylinder is closed during this operation. Open the shutter and allow sand to run out; during this period do not vibrate the cylinder or the surrounding area. When no further movement of the sand takes place, close the shutter. Remove the cylinder and determine the mass of sand remaining in the cylinder after pouring as mass m_4, to the nearest 1 g.

11.1.5.6 When encountering large excavated particles, follow the procedures described below:

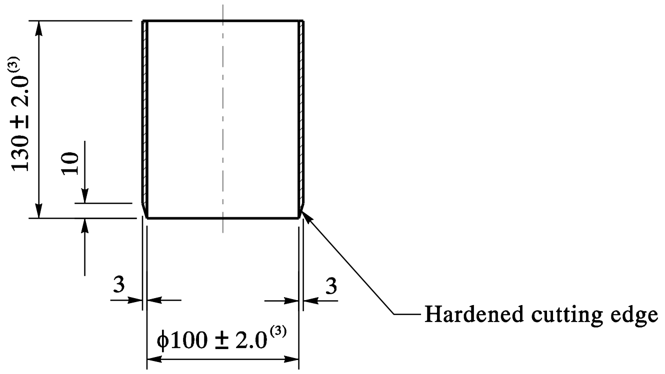
(i) If particles of concrete, brick or rock (Grade III or better), of a size which can be retained on a 20 mm BS sieve, are encountered in the excavated material, these particles should be picked out from the excavated material after determining the total mass m_w of the excavated material.



Rammer



Dolly



Core Cutter

Notes:

(1) All dimensions shown are in millimetres.

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

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 11.4 Core Cutter Apparatus for Soil Density Determination

(ii) The particles shall then be grouped according to their type, e.g. concrete in one group, brick fragments in another. The mass of each group of particles (m_1', m_2', m_3' etc.) retained on a 20 mm BS sieve shall be determined. The mass retained on a 37.5 mm BS sieve shall also be determined.

(iii) If wood or material other than concrete, brick or rock (Grade III or better), of a size which can be retained on a BS 20 mm sieve, is encountered in the test hole, this shall be reported and the test shall be aborted and relocated to a new position.

Note: The practice of putting large pieces of excavated material (i.e. large particles such as stones, brick and rock fragments etc.) back into the test hole before sand is poured into the test hole is not permitted.

11.1.5.7 All weighings for this test shall be carried out in a laboratory but not on site.

11.1.6 Calculations

11.1.6.1 Calculate the mass of sand in the cone and circular opening of the metal tray, m_2 (in g), from the equation:

$$m_2 = m_1 - m_3 - m_a$$

where m_1 is the mass of sand in cylinder before allowing sand to run into the calibrating container (in g);

m_3 is the mean value of the mass of sand remaining in the pouring cylinder after allowing sand to run into the calibrating container (in g); and

m_a is the mean value of mass of sand left in the calibrating container (in g).

11.1.6.2 Calculate the bulk density of the sand, ρ_a (in Mg/m^3), from the equation:

$$\rho_a = \frac{m_a}{V}$$

where V is the volume of the calibrating container (in mL).

11.1.6.3 Calculate the mass of sand required to fill the excavated hole, m_b (in g), from equation:

$$m_b = m_1 - m_4 - m_2$$

where m_1 is the mass of sand in cylinder before allowing sand to run into the hole (in g);

m_2 is the mass of sand in the cone and circular opening of the metal tray (in g); and

m_4 is the mass of sand remaining in the pouring cylinder after allowing sand to run into the hole (in g).

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

$$\rho = \left(\frac{m_w}{m_b}\right)\rho_a$$

where m_w is the whole mass of soil excavated (in g);
m_b is the mass of sand required to fill the hole (in g); and
ρ_a is the bulk density of sand (Mg/m^3).

11.1.6.5 Calculate the dry density, ρ_d (in Mg/m^3), from either one of the two equations below:

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

where w is the moisture content of a representative soil specimen from the whole mass of soil excavated (in %), or

$$\rho_d = \left(\frac{m_d}{m_b}\right)\rho_a$$

where m_d is the mass of all dry soil from the hole (in g); and
m_b is the mass of sand required to fill the hole (in g).

11.1.6.6 Correction for large excavated particles shall be carried out as follows:

(i) The material excavated from the test hole consists of large particles of brick, concrete, rock etc. of masses m_1', m_2', m_3' etc. and soil of mass m_0 such that:

$$m_w = m_0 + m_1' + m_2' + m_3' + \ldots\ldots$$

(ii) The volume v_i' of each group of large particles is determined from the equation:

$$v_i' = \frac{m_i'}{\mu_i\ \ (i = 1, 2, 3, \ldots\ldots)}$$

where μ_i is the density of each type of material. Suggested values of μ_i for concrete and Grade III (or better) rock are 2.45 Mg/m^3 and 2.65 Mg/m^3 respectively but other values of μ_i for different materials are acceptable as long as they are clearly reported with the test results.

(iii) The total volume of excavated large particles (V') can be expressed as an "excess" mass of replacement sand m_a' by the equations:

$$V' = \Sigma v_i' \ (i = 1, 2, 3, ...)$$

$$m_a' = V'\rho_a$$

where ρ_a is the bulk density of the replacement sand.

(iv) The corrected expression for the bulk density of the soil (ρ_c) is given by the equation:

$$\rho_c = \left(\frac{m_w - \Sigma m_i'}{m_b - m_a'} \right) \rho_a$$

where m_b is the total mass of replacement sand required to fill the test hole.

11.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in Clauses B.1 and B.2 of Appendix B, as appropriate,

(b) the in-situ bulk and dry densities of the soil (in Mg/m^3) to the nearest 0.01 Mg/m^3,

(c) the corrected bulk density of the soil (in Mg/m^3) to the nearest 0.01 Mg/m^3 (if applicable),

(d) the moisture content, as a percentage to two significant figures,

(e) the percentage of particles retained on the 20 mm and 37.5 mm sieves,

(f) whether alternative method has been employed for fine-grained cohesiveless soils,

(g) whether the whole excavated soil mass or a representative soil specimen has been used for the moisture content determination, and

(h) the densities of the large particles such as concrete, brick or rock.

11.2 Determination of In-situ Bulk Density and In-situ Dry Density of Soils by Sand Replacement Method Suitable for Fine-, Medium- and Coarse-grained Soils (with Large Pouring Cylinder)

11.2.1 Scope

This test method is used for the determination of the in-situ bulk density and in-situ dry density of fine-, medium- and coarse-grained soils. The method is based on the sand replacement principle and uses a “large pouring cylinder”.

11.2.2 General

The guidance given in Clause 11.1.2 as for Test Method 11.1 shall be noted.

11.2.3 Apparatus

The following apparatus are required:

(a) a pouring cylinder, similar in detail to that shown in Figure 11.5,

(b) suitable tools for excavating holes in compacted soil, e.g. a bent spoon dibber, large screwdriver and/or pointed steel rod about 250 mm long and 7 mm to 10 mm in diameter with a handle,

(c) a cylindrical metal calibrating container with an internal diameter of 200 ± 5 mm and an internal depth of 250 mm (see Note), of the type shown in Figure 11.6, fitted with a lip about 75 mm wide and about 5 mm thick surrounding the open end,

Note: If for any reason it is necessary to excavate holes other than 250 mm, the calibrating container should be replaced by one with the same depth as the hole excavated, or its effective depth reduced to that of the hole excavated.

(d) a balance, readable to 10 g and accurate to 20 g,

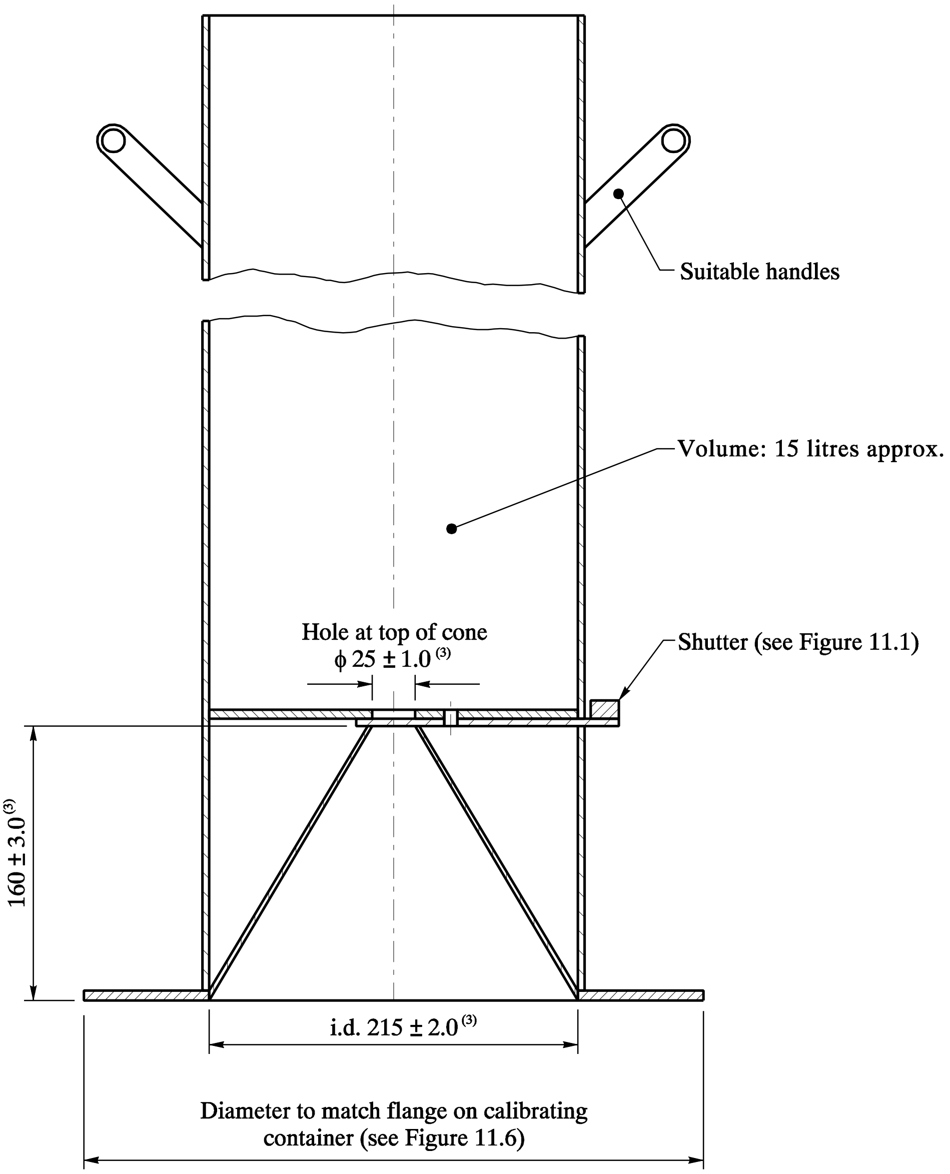
(e) metal trays or containers to take the excavated soil and to take the supply of sand to fill the pouring cylinder,

(f) apparatus for moisture content determination as specified in Clause 5,

(g) a metal tray about 500 mm square and about 50 mm deep with a 200 mm diameter hole in the centre,

(h) BS test sieves having aperture sizes of 20 mm and 37.5 mm, with a receiver, and

(i) replacement sand, specified and prepared as Clause 11.1.3 (k) for Test Method 11.1.



Notes:

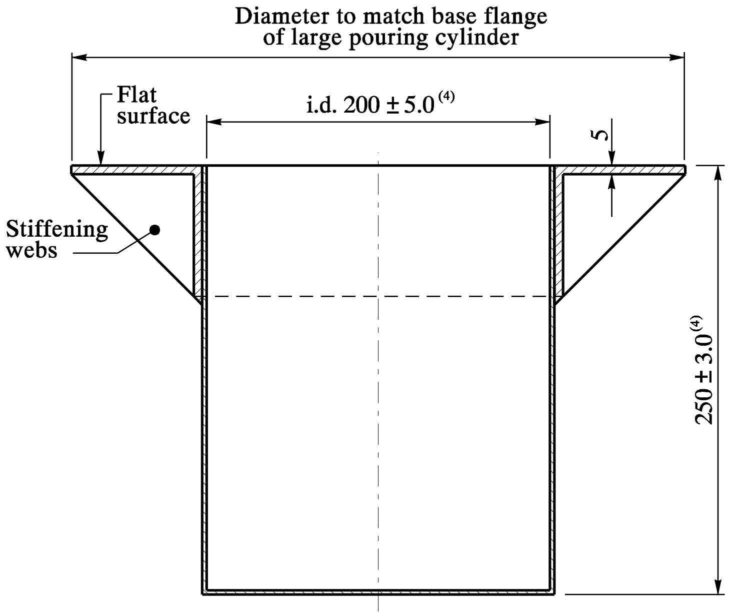
(1) All dimensions shown are in millimetres.

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

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 11.5 Large Pouring Cylinder for the Determination of the Density of Fine-, Medium- and Coarse grained Soils



Notes:

(1) It is important that metal joints within the calibrating container do not form crevices because these will affect the accuracy of the calibration.

(2) All dimensions shown are in millimetres.

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

(4) These are manufacturing tolerances or limits on the essential dimensions.

(5) All other dimensions are given for guidance only.

Figure 11.6 Calibrating Container for Use with the Large Pouring Cylinder

11.2.4 Calibration

11.2.4.1 The determination of the mass of sand in the calibrating container shall follow similar procedures described in Clause 11.1.4.1 as for Test Method 11.1 using the corresponding apparatus listed in Clause 11.2.3 for this test, except that the initial mass of sand shall be determined to the nearest 10 g instead.

11.2.4.2 The bulk density of sand (ρ_a) shall be determined as follows:

A convenient and accurate method for determining of the internal volume, V (in mL), of the calibrating container is by determining the mass of water required to fill it. The procedure is described here:

Note: The procedure described is a little different from that in Clause 11.1.4.2 as for Test Method 11.1 because the total mass of the pouring cylinder and water is so large that the method of filling and weighing is to weigh the water in two or three containers before tipping it into the pouring cylinder. Similarly, the method of filling and weighing sand is to weigh the sand in two or three containers and tip it into the pouring cylinder before using. Take care to see that the same constant initial mass as is used in calibrating the apparatus is used for each density measurement. Sufficient sand should be used so that about 4 kg to 5 kg of sand is left in the pouring cylinder after the test is completed.

Place the empty calibrating container on a flat surface, ensuring that its upper rim is horizontal, if necessary by embedding the base in modelling clay or similar material. Fill a suitable container (or containers) with water and weigh (m_5) to the nearest 10 g and then fill the calibrating container almost completely with water for the weighed container. Lay a straightedge across the top of the calibrating container and add more water slowly and carefully from the weighed container by means of a dropping rod until the water just touches the straightedge. Take care that no water is spilled during these operations. Then reweigh the water container (or containers) (m_6). Repeat the measurement a number of times to obtain an accurate mean value of m_6. For repeating the measurement, it is only necessary to remove a small amount of water from the filled calibrating container by means of the dropping rod, return it to the weighed container, and to refill the calibrating container to the level of the straightedge. The volume of the calibrating container, V (in mL), is given by the following equation:

$$V = m_5 - m_6$$

Note: see Note to Clause 11.1.4.2 (i) as in Test Method 11.1.

11.2.5 Test Procedures

11.2.5.1 Expose a flat area, approximately 600 mm square, of the soil to be tested and trim it down to a level surface, using the technique described in Clause 11.1.5.1 as for Test Method 11.1.

11.2.5.2 Applying similar technique described in Clause 11.1.5.2 as for Test Method 11.1, excavate a round hole, approximately 200 mm in diameter and the depth of the layer to be tested upto a maximum of 250 mm. Carefully collect the excavated soil from the hole and determine its mass, (m_w) to the nearest 10 g. Keep the metal tray in place throughout the test.

Note: If for any reason it is necessary to excavate holes other than 250 mm, the calibrating container should be replaced by one with the same depth as the hole excavated, or its effective depth reduced to that of the hole excavated.

11.2.5.3 Follow similar procedures described in Clauses 11.1.5.4 to 11.1.5.7 as for Test Method 11.1 using the corresponding apparatus for this test, except that all the masses shall be determined to the nearest 10 g instead.

11.2.6 Calculations

The calculations shall follow Clause 11.1.6 as for Test Method 11.1.

11.2.7 Report

The report shall contain all the information listed in Clause 11.1.7 as for Test Method 11.1.

11.3 Determination of In-situ Bulk Density and In-situ Dry Density of Soils by Nuclear Densometer Method Suitable for Fine- and Medium-grained Soils

11.3.1 Scope

This method covers the determination of the in-situ bulk density of fine-grained and medium-grained soils in field by the attenuation of gamma rays and calculation of the in-situ dry density using a moisture content determined in accordance with Clause 5.

11.3.2 General

The guidance given in Clause 3.8 shall be noted. The follow licensing and safety precautions shall be closely observed:

(a) The possession and use of radioactive substance are governed by the Radiation Ordinance of the Hong Kong Special Administrative Region. Any person who contravenes any of the provisions of this Ordinance shall be guilty of an offence and shall be liable to a fine or imprisonment or both. Please follow the Radiation (Control of Radioactive Substance) Regulations (Section 13 of Chapter 303) (Hong Kong Government, 1965) for details on licensing, conveyance, storage, workplace, precaution for workers and supervision. Advice regarding the Radiation Ordinance, licensing and monitoring services may be obtained from the Radiation Health Unit of the Department of Health.

(b) The nuclear equipment used in this test method utilises radioactive materials emitting ionising radiation which may be hazardous to health unless proper precautions are taken. Therefore before testing commences, it is essential that users of this equipment are aware of the potential hazards and comply with all applicable government regulations concerning the precautions to be taken and routine procedures to be followed with this type of equipment. Keep time spent near the nuclear device to a minimum in order to minimise radiation exposures.

(c) Anyone working with or near the radioactive device is required to complete a certain amount of training and be registered with the Department of Health in order to be designated as an authorised user. As an authorised user, an individual is required to wear a personnel radiation monitoring device approved by the Authority. This device should be worn only during that time the worker will be on the job and should not be taken home or worn during medical X-rays. Personnel monitoring devices are issued to a specific individual and must not be transferred to another person. The management on the control of radiation exposure shall be followed in accordance with the relevant Government regulations.

11.3.3 Apparatus

The following apparatus are required:

(a) a calibrated nuclear device for the measurement of density (densometer). The details of construction of the densometer may vary but the following general requirements shall apply:

  (1) The probe shall be an adjustable probe containing a gamma source which can be readily positioned in a preformed hole. The probe assembly shall be graduated in increments not exceeding 50 mm and shall be constructed in such a manner that it will be securely held in the test depth position.

  (2) The instrumentation shall display the results directly in metric units.

  Note: The calibration of the densometer shall be based on the principle stated in the ASTM D2922-96 (ASTM, 1996).

(b) a reference standard of suitable material having a uniform and constant density to establish the background count and count reproducibility,

(c) site preparation equipment, such as spades, straight-edges, scoops and brushes, required to prepare a suitably cleared and level surface to accommodate the densometer,

(d) a hole forming device, such as an auger or steel pin, to form a hole to accommodate the probe. The device shall have a nominal diameter which exceeds the probe diameter by not more than 3 mm and shall be graduated to indicate the depth of the hole. The device shall have a guide which will ensure that the hole is formed normal to the prepared surface,

(e) sampling equipment, such as augers, spades, picks, small digging tools, scoops, airtight containers and bags, to obtain samples of the tested soil, and

(f) apparatus for the determination of moisture content in accordance with Test Method 5.1 or 5.2, as appropriate.

11.3.4 Verification

11.3.4.1 Comparability of this test method shall be carried out as follows:

  (i) Before using the densometer on soil for which it has not previously been used, the results of determinations of in-situ bulk density using the densometer shall be compared with those results obtained using Test Method 11.2. The location of each determination in accordance with Test Method 11.2 shall correspond to the midpoint of the densometer probe and the gamma sensor. A minimum of ten pairs of determinations shall be carried out.

  (ii) If the difference between any pair of results does not exceed 0.08 Mg/m^3 and if the densometer produces results which are both higher and lower than those produced by Test Method 11.2, the densometer may be used without correction.

(iii) If either of the criteria stated in (ii) above is not met, the densometer shall not be used.

11.3.4.2 Routine densometer check shall be carried out as follows:

(i) The densometer shall be warmed up in accordance with the manufacturer's recommendations.

(ii) A standard count shall be carried out in accordance with the manufacturer's recommendations or the standard count shall be carried out by placing the reference standard on a hard, level surface consisting of material with a density of at least 1.6 Mg/m^3. The reference standard shall be placed at a distance of at least 10 m from any other nuclear device and at least 3 m from any large object.

(iii) The standard count reading for the day shall be compared with the mean of the last four standard count readings. If the difference is greater than that recommended by the manufacturer or where no recommendation is made and the difference is greater than 1%, the densometer shall be recalibrated.

(iv) The densometer shall be left switched on with the probe in the locked position. If the densometer is switched off, a further standard count shall be carried out in accordance with the above Clauses (ii) and (iii).

11.3.5 Test Procedures

11.3.5.1 A level surface of sufficient size to accommodate the densometer shall be prepared and cleared of all disturbed and loose materials. The depth of any depression below the densometer shall not exceed 3 mm. Depressions exceeding 3 mm in depth shall be filled using fine sand or material taken from the adjacent soil which passes a 600 μm BS test sieve.

11.3.5.2 A suitable hole for the probe shall be prepared using the hole-forming device. The hole shall be normal to the prepared test area and at least 50 mm deeper than the intended test depth. If a driven pin is used to form the hole, the pin shall be rotated every two or three blows to facilitate its removal.

11.3.5.3 The test depth shall be the same as the maximum depth required for determination of the in-situ bulk density in accordance with Test Method 11.1 or 11.2 as appropriate to the grain size of the soil.

11.3.5.4 The probe shall be positioned and inserted into the hole in such a manner that the gamma source is shielded at all times. The probe shall be seated firmly against the side of the hole nearest to the back of the densometer by gently pulling the densometer backwards until contact is achieved. The operator shall ensure that the densometer is correctly seated and the depth setting on the control panel is the same as the probe depth.

11.3.5.5 The operator shall ensure that there are no other radioactive sources within 10 m of the densometer.

11.3.5.6 Three readings of the in-situ bulk density shall be taken in accordance with the manufacturer's recommendations and the mean determined. If any one reading differs from any other reading by more than 0.015 Mg/m^3, additional readings shall be taken until three consecutive readings which do not differ by more than 0.015 Mg/m^3 are obtained and the mean determined. The mean of the three readings shall be taken as the in-situ bulk density, ρ. If the above criterion is not met after six readings, the densometer shall not be used. The densometer shall be recalibrated.

11.3.5.7 The densometer shall be removed and a minimum of 500 g sample of the soil directly beneath the densometer position shall be taken for the determination of moisture content. The sample shall be obtained by augering or digging to the test depth. The sample shall be placed in a moisture tight container and the lid replaced. The moisture content (w) shall be determined in accordance with Test Method 5.1 or 5.2, as appropriate.

11.3.5.8 If a sample of soil at the same location as the densometer test is required for the determination of the maximum dry density, it shall be obtained by digging to the test depth, keeping the sides of the excavation vertical and the bottom flat and level. The appropriate quantity of soil required for the test shall be taken, placed in a moisture tight container and sealed.

11.3.6 Calculations

The in-situ dry density of the material, ρ_d (Mg/m^3), shall be calculated from the equation:

$$\rho_d = \frac{\rho}{1 + \frac{w}{100}}$$

where ρ_d is the in-situ bulk density of the material (Mg/m^3) obtained from the densometer readings; and

w is the moisture content of the material (%) determined in accordance with Clause 5.

11.3.7 Report

The test report shall contain all the information listed in Clause 11.1.7 as for Test Method 11.1, as appropriate.

11.4 Determination of Relative Compaction of Fill Material

11.4.1 Scope

This method sets out the standard procedures for the determination of the relative compaction of fill material.

11.4.2 General

The guidance given in Clause 3.8 shall be noted.

11.4.3 Standard Procedures

11.4.3.1 The in-situ bulk density and in-situ dry density of fill material shall be determined in accordance with one of the following methods:

(i) Sand replacement methods described in Test Method 11.1 or 11.2 as appropriate to the grain size of the fill material.

(ii) Nuclear densometer method as stated in Test Method 11.3.

Note: The sand replacement method shall be used unless otherwise permitted by the Specifiers.

11.4.3.2 The maximum dry density of the fill material shall be determined as stated in Test Methods 10.1 to 10.8 as appropriate to the grain size of the fill.

11.4.4 Calculations

The relative compaction, R_c, of fill material shall be calculated from the equation:

$$R_c = \left(\frac{\rho_d}{\rho_{max}}\right)100$$

where ρ_d is the in-situ dry density of a soil determined by Test Method 11.1, 11.2 or 11.3; and

ρ_{max} is the maximum dry density of the same type of soils determined by Test Methods 10.1 to 10.8 as appropriate.

11.4.5 Report

The report shall affirm that the determination was carried out in accordance with this method and shall contain the following information:

(a) the general information listed in Clauses B.1 and B.2 of Appendix B, as appropriate,

(b) the laboratory maximum dry density to the nearest 0.01 Mg/m^3 and the method of determining the in-situ dry density,

(c) the optimum moisture content to two significant figures,

(d) the in-situ dry density to the nearest 0.01 Mg/m^3 and the method of determining the in-situ dry density,

(e) the relative compaction to the nearest 0.1%,

(f) the test certificate numbers for the laboratory maximum dry density determination ((b) above) and in-situ dry density determination ((d) above), and

(g) a statement whether or not the maximum dry density determination was carried out on same batch of soil type and source corresponding to the test location of the in-situ density test.

12 Determination of the California Bearing Ratio

12.1 Determination of the California Bearing Ratio (CBR)

12.1.1 Scope

This test method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil.

12.1.2 General

The guidance given in Clause 3.9 shall be noted.

The CBR test shall be carried out on material passing the 20 mm test sieve. If the soil contains particles larger than this, the fraction retained on the 20 mm test sieve shall be removed and weighed before preparing the test sample. If this fraction is greater than 25%, the test is not applicable.

Six methods are described for the preparation of disturbed samples for the CBR test (see the following Clause 12.1.4 for Sample Preparation). In Methods (1) and (2), static compaction is used to achieve a specified density. In the other methods, dynamic compaction by hand or mechanical rammer, or by vibrating hammer, is used, either to achieve a specified density as in Methods (3) and (4), or to provide a specified compactive effort as in Methods (5) and (6). The selection of methods is illustrated in Figure 12.1.

When applying a standard compactive effort, the compactive procedures described in Test Method 10.3 or 10.7 can be used.

A method for the preparation of undisturbed samples for the laboratory CBR test (whether of natural soil or compacted fill) is also described in Clause 12.1.4.

12.1.3 Apparatus

The following apparatus are required for sample preparation:

(a) test sieves, of aperture sizes 20 mm and 5 mm,

(b) a cylindrical, corrosion-resistant, metal mould, i.e. the CBR mould, having a nominal internal diameter of 152 ± 0.5 mm. The mould shall be fitted with a detachable baseplate and a removable extension. The essential dimensions are shown in Figures 10.6 and 10.7, which also indicate one suitable design of mould. The internal faces shall be smooth, clean and dry before each use,

(c) a compression device for static compaction, (for Methods (1) and (2) in the following Clause 12.1.4, Sample Preparation). The horizontal platens of the device shall be large enough to cover a 150 mm diameter circle and capable of a separation of not less than 300 mm. The device shall be capable of applying a force of at least 300 kN,

(d) metal plugs, 150 ± 0.5 mm in diameter and 50 ± 1.0 mm thick, for static compaction of a soil specimen (for Methods (1) and (2)). A handle, which can be screwed into the plugs to facilitate removal after compaction, may be used. The essential dimensions are shown in Figure 10.7. One is required for Method (1) and three are required for Method (2),

(e) a metal rammer, (for Methods (3) and (5)). The rammer shall be either the 2.5 kg rammer as specified in Test Methods 10.1 to 10.4, or the 4.5 kg rammer as specified in Test Methods 10.5 to 10.8, depending on the degree of compaction required. A mechanical compacting apparatus may be used provided that it complies with Clause 10,

(f) an electric, vibrating hammer having a power consumption of between 600 W and 800 W operating at a frequency between 25 to 60 Hz. and a tamper for attachment to the vibrating hammer, (for Methods (4) and (6)). Essential dimensions of the hammer are shown in Figure 12.2, which also indicates one suitable design of tamper,

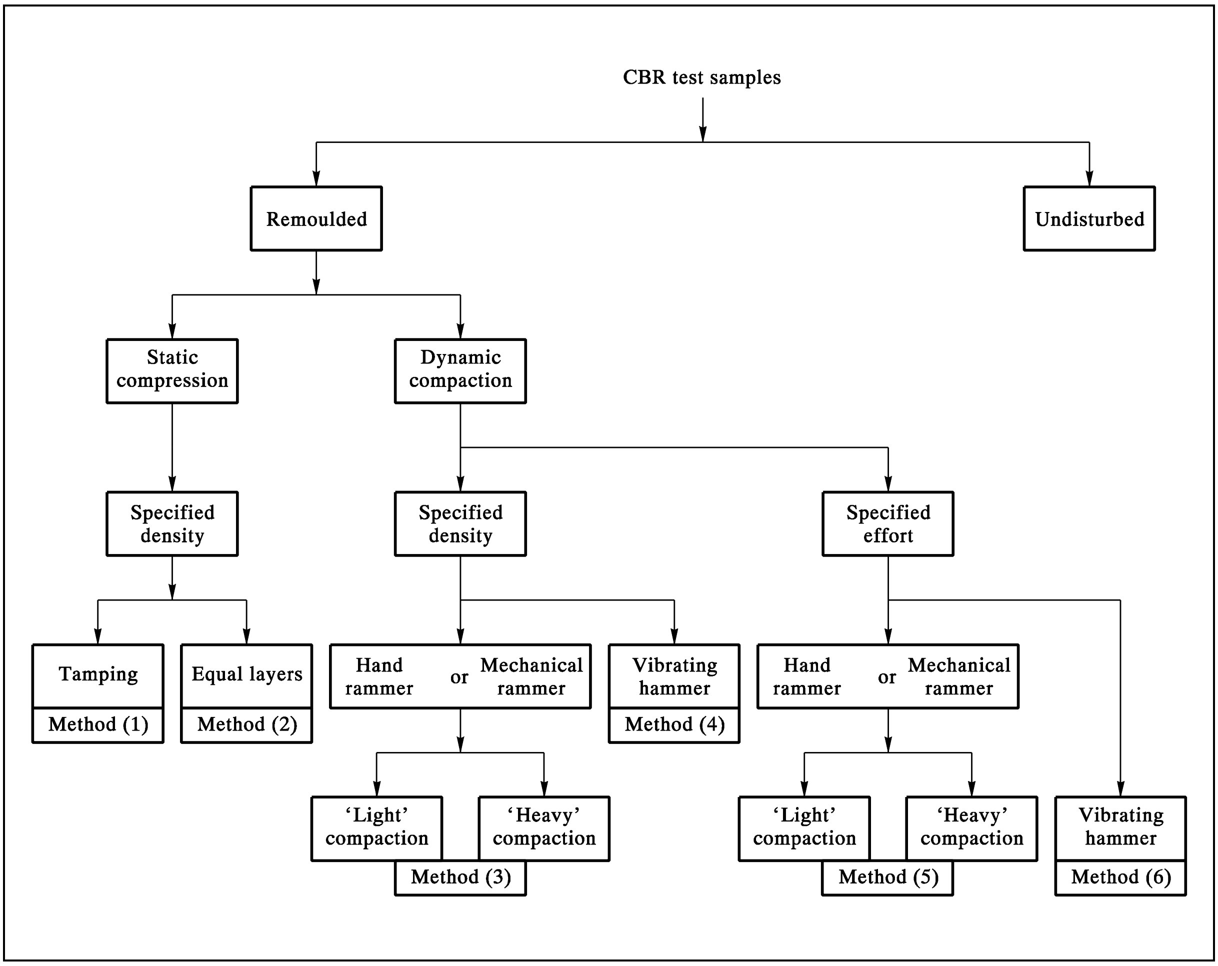
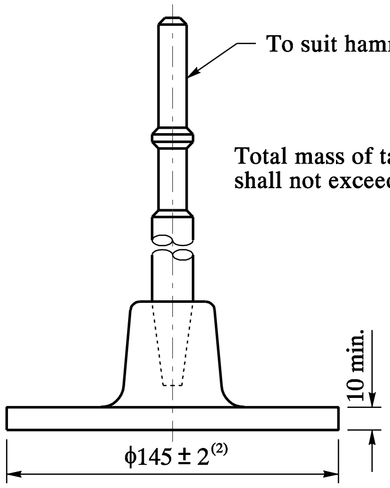


Figure 12.1 Flow Chart Representing Sample Preparation Methods for the CBR Test



Notes: (1) All dimensions shown are in millimetres.

(2) These are manufacturing tolerances or limits on the essential dimensions.

(3) All other dimensions are given for guidance only.

Figure 12.2 Tampers for the Vibrating Hammer Compaction Test

(g) a steel rod, about 16 mm in diameter and 600 mm long,

(h) a steel straightedge, e.g. a steel strip about 300 mm long, 25 mm wide and 3 mm thick, with one bevelled edge,

(i) a spatula,

(j) a balance, capable of weighing up to 25 kg, readable to 5 g and accurate to 10 g,

(k) apparatus for moisture content determination, as described in Clause 5, and

(l) filter papers, 150 mm in diameter, e.g. Whatman No. 1 or equivalent.

The following additional items are required if soaking of sample is specified:

(m) a perforated baseplate, fitted to the CBR mould in place of the normal baseplate (see Figure 10.6),

(n) a perforated swell plate, with an adjustable stem to provide a seating for the stem of a dial gauge (see Figure 12.3),

(o) a tripod, mounting to support the dial gauge (see Figure 12.3),

(p) a dial gauge, having a travel of 25 mm, and readable to 0.01 mm,

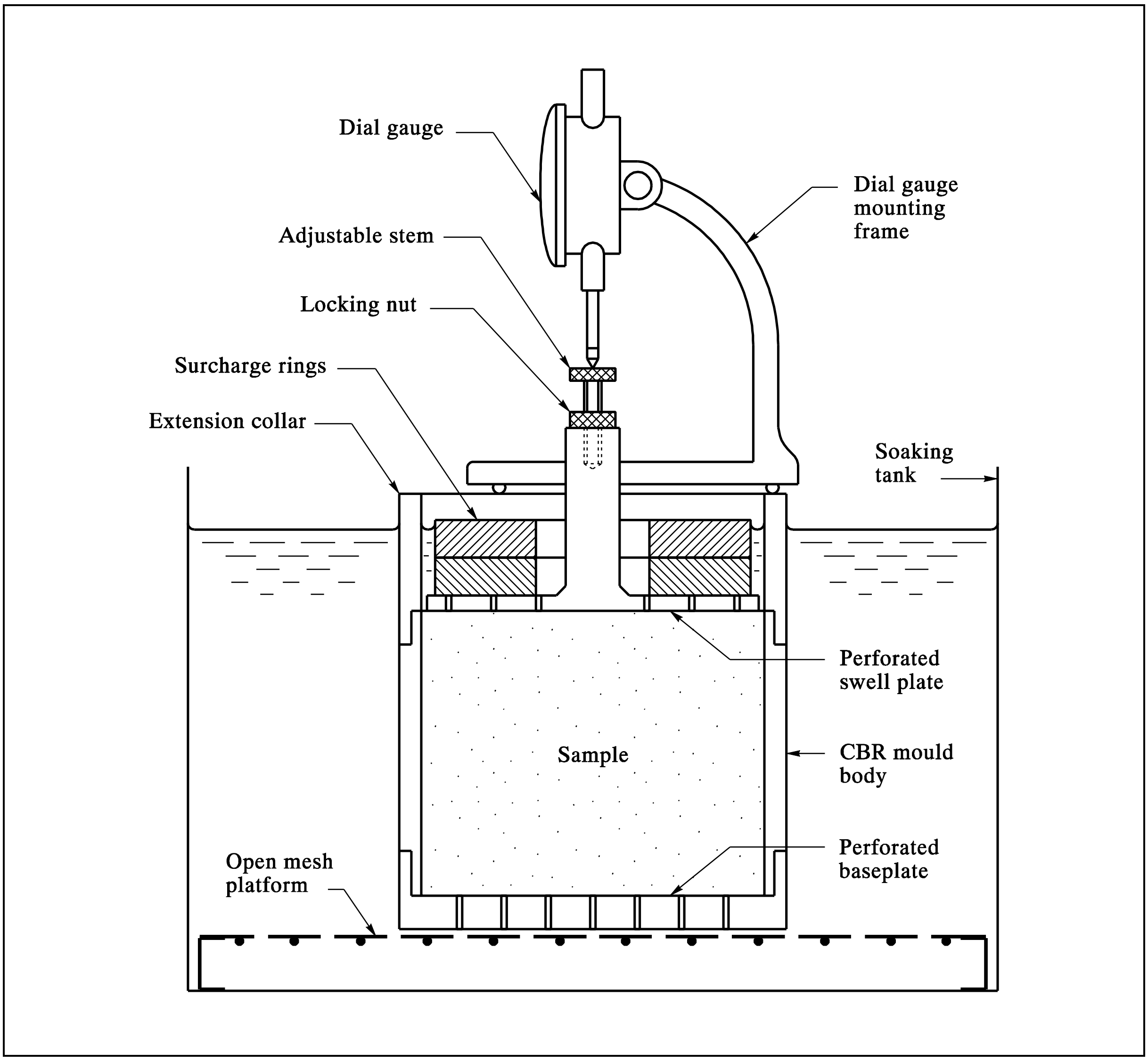


Figure 12.3 Apparatus for Measuring the Swelling of a Sample during Soaking for the CBR Test

(q) a soaking tank, large enough to allow the CBR mould with the baseplate to be submerged, preferably supported on an open mesh platform,

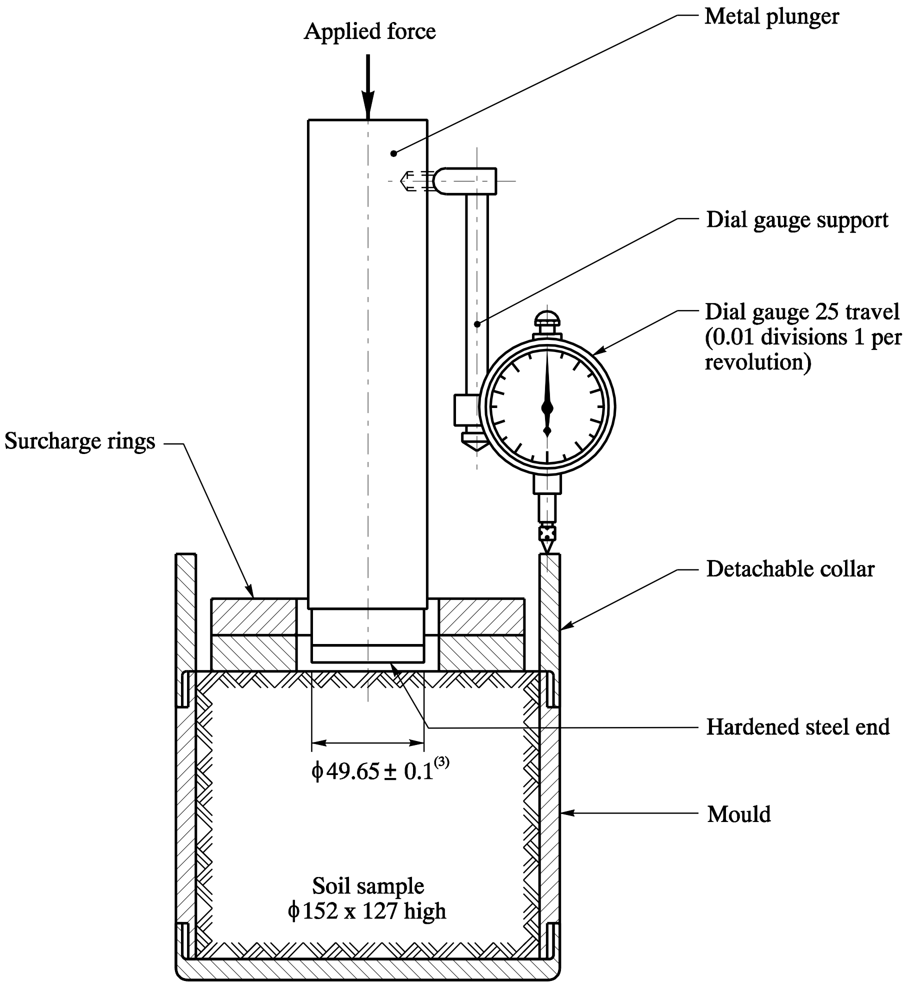
(r) annular surcharge discs. Each disc shall have a mass known to ± 50 g, an internal diameter of 52 mm to 54 mm and an external diameter of 145 mm to 150 mm. Alternatively half-circular segments may be used, and

(s) petroleum jelly.

The following apparatus are required for penetration test:

(t) a cylindrical metal plunger. The lower end of the plunger shall be of hardened steel and have a nominal cross-sectional area of 1935 mm^2, corresponding to a specified diameter of 49.65 ± 0.10 mm. A convenient size would be approximately 250 mm long (see Figure 12.4),

(u) a machine for applying the test force through the plunger, having a means for applying the force at a controlled rate. The machine shall be capable of applying at least 45 kN at a rate of penetration of the plunger of 1 mm/min to within ± 0.2 mm/min,



Notes:

(1) All dimensions shown are in millimetres.

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

(3) These are manufacturing tolerances or limits on the essential dimensions.

(4) All other dimensions are given for guidance only.

Figure 12.4 General Arrangement of Apparatus for the CBR Test

(v) a calibrated force-measuring device of appropriate operational accuracy. The device shall be supported by the crosshead of the compression machine so as to prevent its own weight being transferred to the test specimen,

Note: At least three force-measuring devices should be available, having the following ranges:

(1) 0 to 2 kN readable to 2 N, accurate to 5 N, for values of CBR up to 8%,
(2) 0 to 10 kN readable to 10 N, accurate to 20 N, for values of CBR from 8% to 40%, and
(3) 0 to 50 kN readable to 50 N, accurate to 100 N, for values of CBR above 40%.

(w) a means of measuring the penetration of the plunger into the specimen, to within 0.01 mm. A dial gauge with 25 mm travel, readable to 0.01 mm and accurate to 0.05 mm and fitted to a bracket attached to the plunger is suitable. A general arrangement is shown in Figure 12.4, and

Note: A dial gauge indicating 1 mm/r is convenient since the specified rate of penetration of 1 mm/min can be controlled conveniently by keeping the hand of the dial gauge in step with the second hand of a clock or watch.

(x) a stopclock or stopwatch readable to 1 s.

12.1.4 Sample Preparation

12.1.4.1 Sample preparation of disturbed samples shall follow Clauses 12.1.4.2 to 12.1.4.13 below. Sample preparation of undisturbed samples shall follow Clause 12.1.4.14. If soaking of sample is specified, it shall be carried out as described in Clause 12.1.4.15.

12.1.4.2 When the density or air voids content of a compacted sample is specified, the exact amount of soil required for the test can be calculated as follows:

The dry density, ρ_d (in Mg/m^3), corresponding to an air voids content of V_a (in %) is given by the equation:

$$\rho_d = \frac{1 - \frac{V_a}{100}}{\frac{1}{\rho_s} + \frac{w}{100\,\rho_w}}$$

where V_a is the air voids expressed as a percentage of the total volume of soil;
ρ_s is the particle density (in Mg/m^3);
w is the soil moisture content (in %); and
ρ_w is the density of water (in Mg/m^3), assumed equal to 1.

The corresponding mass of soil, m_1 (in g), to just fill the CBR mould of volume V_m (in cm^3) is given by the equation:

$$m_1 = \frac{V_m}{100} (100 + w) \rho_d$$

where V_m is the volume of the CBR mould determined in accordance with Clause 12.1.4.7.(i) (in m^3);
w is the moisture content of the soil (in %); and
ρ_d is the specified dry density (in Mg/m^3).

12.1.4.3 When a compactive effort is specified, the mass of soil can only be estimated. In principle, the sample shall be large enough to provide about 6 kg of material passing a 20 mm test sieve for each test. Suggested minimum masses required are as follows:

Fine-grained	Medium-grained	Coarse-grained
6 kg	6 kg	12 kg

Note: Preliminary trials may be necessary to ascertain the required mass more closely.

The initial mass shall be measured to the nearest 5 g so that the mass used for the test sample can be determined after compaction by difference, as a check.

12.1.4.4 Obtain the above quantity of soil from site and sealed in a container to prevent loss of moisture until required for testing.

12.1.4.5 Rub the soil through a 20 mm test sieve, weigh the retained material and determine its proportion of the total sample.

12.1.4.6 Bring the sample to the required moisture content and mix the soil thoroughly. The sample shall normally be sealed and stored for at least 24 hours before compaction into the test mould.

Note 1: The moisture content of the soil shall be chosen to represent the design conditions for which the test results are required. Alternatively, where a range of moisture contents is to be investigated, water shall be added to or removed from the natural soil after disaggregation.

Note 2: With cohesiveless soils, it may be possible to reduce or omit the curing period if trial tests indicate that this has negligible influence on the results.

12.1.4.7 Initial preparation of the mould shall be carried out as follows:

(i) Weigh the mould with baseplate attached to the nearest 5 g (m_2). Measure the internal dimensions to 0.5 mm.

Note: The determination of the internal dimensions and hence the volume of the CBR mould can be carried out yearly, provided that the mould has not been damaged (see also Clause 12.1.6.3(i)).

(ii) Attach the extension collar to the mould and cover the baseplate with a filter paper.

(iii) Measure the depth of the collar as fitted, and the thickness of the spacer plug or plugs, to 0.1 mm.

12.1.4.8 Method (1): Sample preparation by static compression with tamping shall be carried out as follows:

(i) Pour the weighed soil slowly into the mould while tamping it with the steel rod. Avoid segregation of particle sizes and ensure that the largest particles are uniformly distributed within the mould.

(ii) When all the soil is added, level off its surface, which should then be about 5 mm to 10 mm above the top of the mould body if the correct amount of tamping has been applied.

(iii) Place a filter paper on the soil surface, followed by the 50 mm thick spacer plug.

(vi) Place the mould assembly in the compression device and apply a load to the sample until the top of the plug is flush with the collar. Hold the load constant for at least 30 s.

(v) Release the load. If rebound occurs, reapply the load for a longer period.

(vi) Remove the spacer plug, filter paper and collar. Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(vii) Unless the sample is to be tested immediately, seal the sample (by screwing on the top plate if appropriate) to prevent loss of moisture. With clay soils, or soils in which the air content is less than 5%, allow the sample to stand for at least 24 h before testing to enable excess pore pressures set up during compression to dissipate.

12.1.4.9 Method (2): Sample preparation by static compression in layers shall be carried out as follows:

(i) Divide the soil into three portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

(ii) Place one portion of soil in the mould and level the surface.

(iii) Place the three spacer plugs on top of the soil and compress the soil using the compression device until the thickness of the soil, after removal of the load, is about one-third of the depth of the mould.

Note: The correct level of the soil surface can be ascertained easily if the corresponding projection of the top spacer plug above the top of the collar is determined and recorded in advance.

(iv) Repeat the above Clauses 12.1.4.9 (ii) and (iii) using two plugs and then one plug. During the last operation, compress the soil until the top surface of the plug is level with the top of the collar.

(v) Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(vi) Seal and store the sample as in Clause 12.1.4.8 (vii).

12.1.4.10 Method (3): Sample preparation by dynamic compaction - Rammer compaction to a specified density shall be carried out as follows:

(i) Divide the prepared soil into five portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

(ii) Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.

(iii) Place the first portion of soil into the mould and compact it using either the 2.5 kg rammer or the 4.5 kg rammer, until the layer occupies about one-fifth of the height of the mould. Ensure that the blows are evenly distributed over the surface. Alternatively the mechanical compacting apparatus may be used.

(iv) Repeat the above Clause 12.1.4.10 (iii) using the other four portions of soil in turn, so that the final level of the fifth layer is just above the top of the mould.

Note: Preliminary trials may be necessary to judge the amount of compaction needed for each layer.

(v) Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

(vi) Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(vii) Seal and store the sample as in Clause 12.1.4.8 (vii).

12.1.4.11 Method (4): Sample preparation by dynamic compaction - Vibrating compaction to a specified density (suitable for granular soils) shall be carried out as follows:

(i) Divide the prepared quantity of soil into three portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

(ii) Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.

(iii) Place the first portion of soil into the mould and compact it using the vibrating hammer. Continue the compaction until the thickness of the layer is about one-third of the height of the mould.

(iv) Repeat the above Clause (iii) using the other two portions of soil in turn, so that the final level of the third layer is just above the top of the mould. (see Note to Clause 12.1.4.10 (iv)).

(v) Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

(vi) Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(vii) Seal and store the sample as in Clause 12.1.4.8 (vii).

12.1.4.12 Method (5): Sample preparation by dynamic compaction - Rammer compaction with specified effort shall be carried out as follows:

(i) The specified effort of compaction shall correspond to the 2.5 kg rammer method (see Test Method 10.3 or 10.4) or to the 4.5 kg rammer method (see Test Method 10.7 or 10.8) or to an intermediate value (see Note). When the 2.5 kg rammer method is used, the procedure is as described. When the 4.5 kg rammer method or the intermediate compaction effort is used, the procedure is similar except that the soil is placed and compacted in five layers instead of three (as shown in brackets and marked * in Clauses (ii) to (v)).

Note: In certain circumstances, it is required to obtain an intermediate density between that given by the 2.5 kg rammer method and the 4.5 kg rammer method at a given moisture content. This can be obtained by using an intermediate compactive effort between these two levels of compaction. In order to reduce the variations in compactive effort to a minimum, it is suggested that this intermediate effort should be obtained by compacting the specimen in five equal layers, giving each layer 30 blows of a 4.5 kg rammer falling through 450 mm.

(ii) Divide the prepared quantity of soil into three (five*) portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

(iii) Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.

(iv) Place the first portion of soil into the mould and compact it, so that after 62 blows of the appropriate rammer the layer occupies about or a little more than one-third (one-fifth*) of the height of the mould. Ensure that the blows are evenly distributed over the surface. Alternatively the mechanical compacting apparatus may be used.

(v) Repeat the above Clause (iv) using the other two (four*) portions of soil in turn, so that the final level of the soil surface is not more than 6 mm above the top of the mould body.

Note: Preliminary trials may be necessary to judge the amount of soil required for each layer.

(vi) Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

(vii) Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(viii) Seal and store the sample as in Clause 12.1.4.8 (vii).

12.1.4.13 Method (6): Sample preparation by dynamic compaction - Vibrating compaction with specified effort (suitable for granular soils) shall be carried out as follows:

(i) Divide the prepared quantity of soil into three portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

(ii) Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.

(iii) Place the first portion of soil into the mould and compact it using the vibrating hammer fitted with the circular steel tamper. Compact for a period of 60 ± 2 s, applying a total downward force on the sample of between 300 N and 400 N. The compacted thickness of the layer shall be about equal to or a little greater than one-third of the height of the mould.

Note 1: Apply pressure combined with vibration to ensure the required degree of compaction. A downward force on the sample surface of 300 N to 400 N shall be applied, this being greater than the force needed to prevent the hammer bouncing on the soil.

Note 2: The required pressure shall be assessed by applying the vibrating hammer, without vibration, to a platform scale. The required force is applied when a mass of 30 kg to 40 kg is indicated. The operator can usually judge the required pressure to apply with sufficient accuracy after first carrying out the above check.

Note 3: A disc of polyethylene sheet may be placed immediately beneath the tampered plate to prevent sand particles moving up through the annular gap.

(iv) Repeat the above Clause (iii) using the other two portions of soil in turn, so that the final level of the soil surface is not more than 6 mm above the top of the mould (see Note to Clause 12.1.4.10 (iv)).

(v) Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

(vi) Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

(vii) Seal and store the sample as in Clause 12.1.4.8 (vii).

12.1.4.14 Preparation of undisturbed sample shall be carried out as follows:

(i) Take an undisturbed sample from natural soil or from compacted fill by using a weighed CBR mould fitted with a cutting shoe. Expose a small area, approximately 300 mm square, of the soil layer to be tested and level it. Remove loose extraneous material. Lay the steel dolly on top of the cutter, and ram the latter down into the soil layer until only about 10 mm of the dolly protrudes above the surface, care being taken not to rock the cutter. Dig the cutter out of the surrounding soil taking care to allow some soil to project from the lower end of the cutter. Trim the ends of the core flat to the ends of the cutter by means of the straightedge.

Note: Where driving causes shortening of the sample in the cutter, or there is difficulty in digging out the cutter, it may be found preferable to remove the soil from around the outside of the cutter and slightly in advance of the cutting edge as it is driven down. Care needs to be taken not to cause voids inside the cutter by trimming away the soil a short distance outside the wall of the cutter. Jacking the cutter down against a fixed reaction instead of using the rammer may allow the cutter to be driven more precisely and straight.

(ii) After removing the cutting shoe from the mould, cut and trim the ends of the sample so that they are flush with the ends of the mould body. Fill any cavities with fine soil, well pressed in.

(iii) Attach the baseplate and weigh the sample in the mould to the nearest 5 g (m_3).

(iv) Unless the sample is to be tested immediately, seal the exposed face with a plate or an impervious sheet to prevent loss of moisture.

12.1.4.15 Soaking of sample, if specified, shall be carried out as follows:

(i) Remove the baseplate from the mould and replace it with the perforated baseplate.

(ii) Fit the collar to the other end of the mould, packing the screw threads with petroleum jelly to obtain watertight.

(iii) Place the mould assembly in the empty soaking tank. Place a filter paper on top of the sample, followed by the perforated swell plate. Fit the required number of annular surcharge discs around the stem on the perforated plate.

Note: One surcharge disc of 2 kg simulates the effect of approximately 70 mm of superimposed construction on the formation being tested. However, the exact amount of surcharge is not critical. Surcharge discs of any convenient multiples may be used.

(iv) Mount the dial gauge support on top of the extension collar, secure the dial gauge in place and adjust the stem on the perforated plate to give a convenient zero reading (see Figure 12.3).

(v) Fill the immersion tank with water to just below the top of the mould extension collar. Start the timer when the water has just covered the baseplate.

(vi) Record readings of the dial gauge at suitable intervals of time, depending on the rate of movement.

(vii) Record the time taken for water to appear at the top of the sample. (This may not necessarily indicate the end of the swelling stage). If this has not occurred within 3 days, flood the top of the sample and leave to soak for a further day, giving the normal soaking period of 4 days. A longer period may be necessary to allow swelling to reach completion.

(viii) Plot a graph of swelling (as indicated by the dial gauge movement) against elapsed time or square-root time. Flattening of the curve indicates when swelling is substantially complete.

(ix) Take off the dial gauge and its support, remove the mould assembly from the immersion tank and allow the sample to drain for at least 15 min. If the tank is fitted with a mesh platform, leave the mould there to drain after emptying the tank.

(x) Remove the surcharge discs, perforated plate and extension collar. Remove the perforated baseplate and refit the original baseplate.

(xi) Weigh the sample with mould and baseplate to the nearest 5 g if the density after soaking is required.

(xii) If the sample has swollen, trim it level with the end of the mould and reweigh.

(xiii) The sample is then ready for test in the soaked condition.

12.1.5 Test Procedures

12.1.5.1 Place the mould with baseplate containing the sample, with the top face of the sample exposed, centrally on the lower platen of the testing machine.

12.1.5.2 Place the appropriate annular surcharge discs on top of the sample.

12.1.5.3 Fit into place the cylindrical plunger and force-measuring device assembly with the face of the plunger resting on the surface of the sample.

12.1.5.4 Apply a seating force to the plunger, depending on the expected CBR value, as follows:

For CBR value	up to 5%	5% to 30%	above 30%
Apply Force	10 N	50 N	250 N

12.1.5.5 Record the reading of the force-measuring device as the initial zero reading (because the seating force is not taken into account during the test) or reset the force-measuring device to read zero.

12.1.5.6 Secure the penetration dial gauge in position. Record its initial zero reading, or reset it to read zero.

12.1.5.7 Start the test so that the plunger penetrates the sample at a uniform rate of 1 ± 0.2 mm/min. At the same instant, start the timer.

12.1.5.8 Record readings of the force gauge at intervals of penetration of 0.25 mm, to a total penetration not exceeding 7.5 mm.

Note: If the operator plots the force penetration curve as the test is being carried out, the test can be terminated when the indicated CBR value falls below its maximum value. Thus if the CBR at 2.5 mm were seen to be 6% but by 3.5 mm penetration it could be seen to have fallen below 6%, the test could be stopped and the result reported as:

CBR at 2.5 mm penetration = 6%
CBR at 5.0 mm penetration = < 6%

12.1.5.9 If no further test is to be made on the sample, determine its moisture content as described in Clause 12.1.5.13.

12.1.5.10 If a test is to be carried out on both ends of the sample, raise the plunger and level the surface of the sample by filling in the depression left by the plunger and cutting away any projecting material. Check for flatness with the straightedge.

12.1.5.11 Remove the baseplate from the lower end of the mould, fit it securely on the top end and invert the mould. Trim the exposed surface if necessary.

12.1.5.12 If the sample is to be soaked before carrying out a test on the base, follow Clause 12.1.4.15 and then repeat the above Clauses 12.1.5.1 to 12.1.5.9.

12.1.5.13 After completing the penetration test(s), determine the moisture content of the test sample as follows:

(i) For a cohesive soil containing no gravel-sized particles, take a sample of about 350 g from immediately below each penetrated surface, but do not include filling material used to make up the first end tested. Determine the moisture content of each sample as described in Test Method 5.1 or 5.2 as appropriate.

Note: If the sample has been soaked, the moisture content after soaking will generally exceed the initial moisture content. Because of the possibility of moisture gradients, the determination of dry density from the moisture content after soaking may have little significance. If required, the dry density after soaking can be calculated from the initial sample mass and moisture content and the measured increase in height due to swelling.

(ii) For a cohesionless soil or a cohesive soil containing gravel-sized particles, extrude the sample, break in half and determine the moisture contents of the upper and lower halves separately as described in Test Method 5.1 or 5.2 as appropriate.

12.1.6 Calculations

12.1.6.1 The Force-Penetration curve shall be plotted as follows:

(i) Calculate the force applied to the plunger from each reading of the force-measuring device observed during the penetration test.

Note: Alternatively, readings of the force-measuring device may be plotted directly against penetration readings. Forces are then calculated only at the appropriate penetration values as in Clause 12.1.6.2 below (after correction if necessary).

(ii) Plot each value of force as ordinate against the corresponding penetration as abscissa and draw a smooth curve through the points. The normal type of curve is convex upwards as shown by the curve labelled Test 1 in Figure 12.5, and needs no correction.

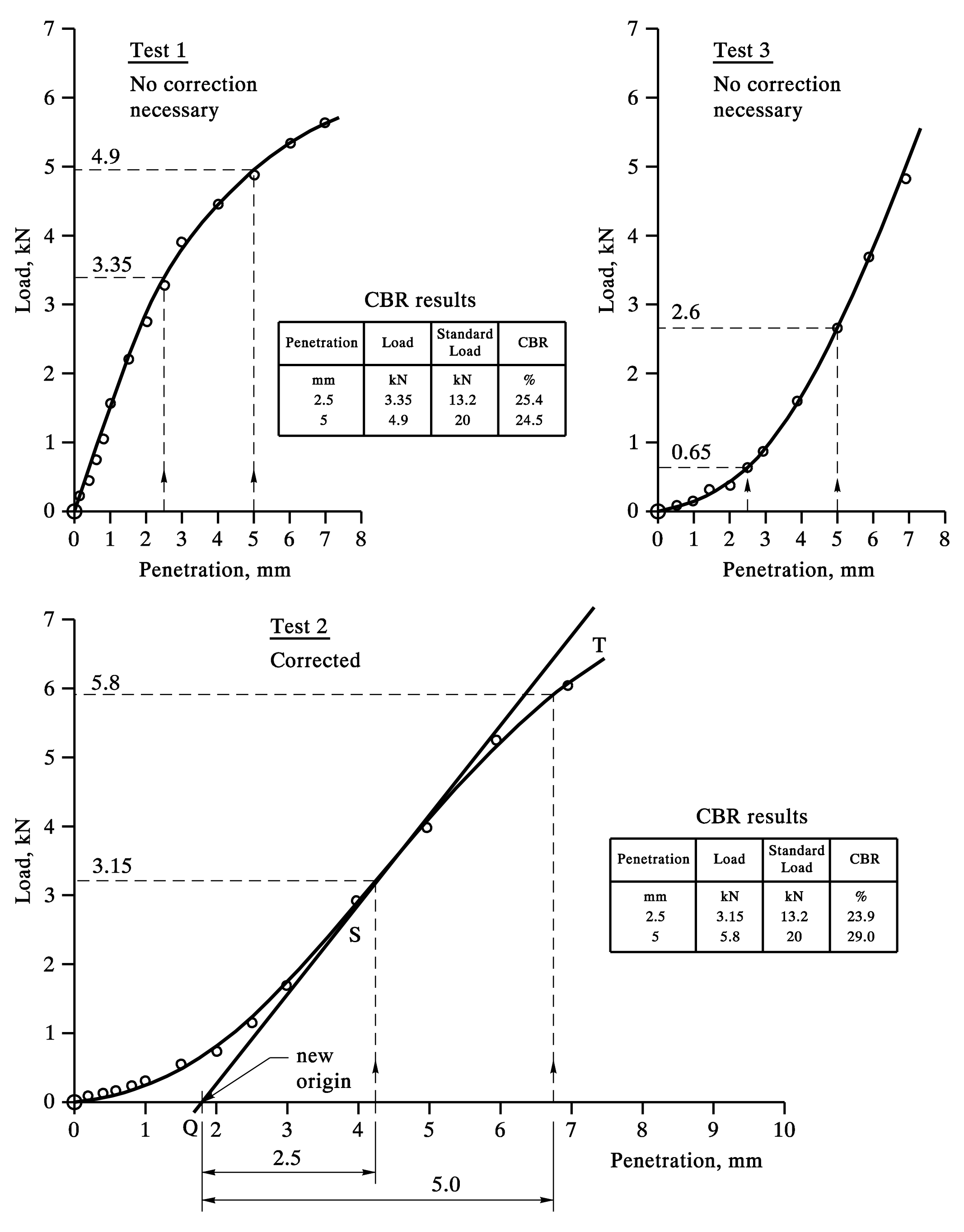
(iii) If the initial part of the curve is concave upwards as the curve labelled Test 2 (curve OST) in Figure 12.5, correction is necessary by drawing a tangent at the point of greatest slope (i.e. the point of inflexion, S) and producing it to intersect the penetration axis at Q. The corrected curve is represented by QST, with its origin at Q from which a new penetration scale can be marked.

(iv) If the graph continues to curve upwards as the curve labelled Test 3 in Figure 12.5, and it is considered that the penetration of the plunger is increasing the soil density and therefore its strength, the above correction in (iii) is not applicable.

12.1.6.2 Calculation of California Bearing Ratio shall be carried out as follows:

(i) The standard force-penetration curve corresponding to a CBR value of 100% is shown by the heavy curve in Figure 12.6, and forces corresponding to this curve are given in Table 12.1 below.

(ii) The CBR value obtained from a test is the force read from the test curve (after correction and calculation if necessary) at a given penetration expressed as a percentage of the force corresponding to the same penetration on the standard curve. Curves representing a range of CBR values are included in Figure 12.6.



CBR results

Penetration	Load	Standard Load	CBR
mm	kN	kN	%
2.5	3.35	13.2	25.4
5	4.9	20	24.5

CBR results

Penetration	Load	Standard Load	CBR
mm	kN	kN	%
2.5	3.15	13.2	23.9
5	5.8	20	29.0

Figure 12.5 Typical CBR Test Result Curves

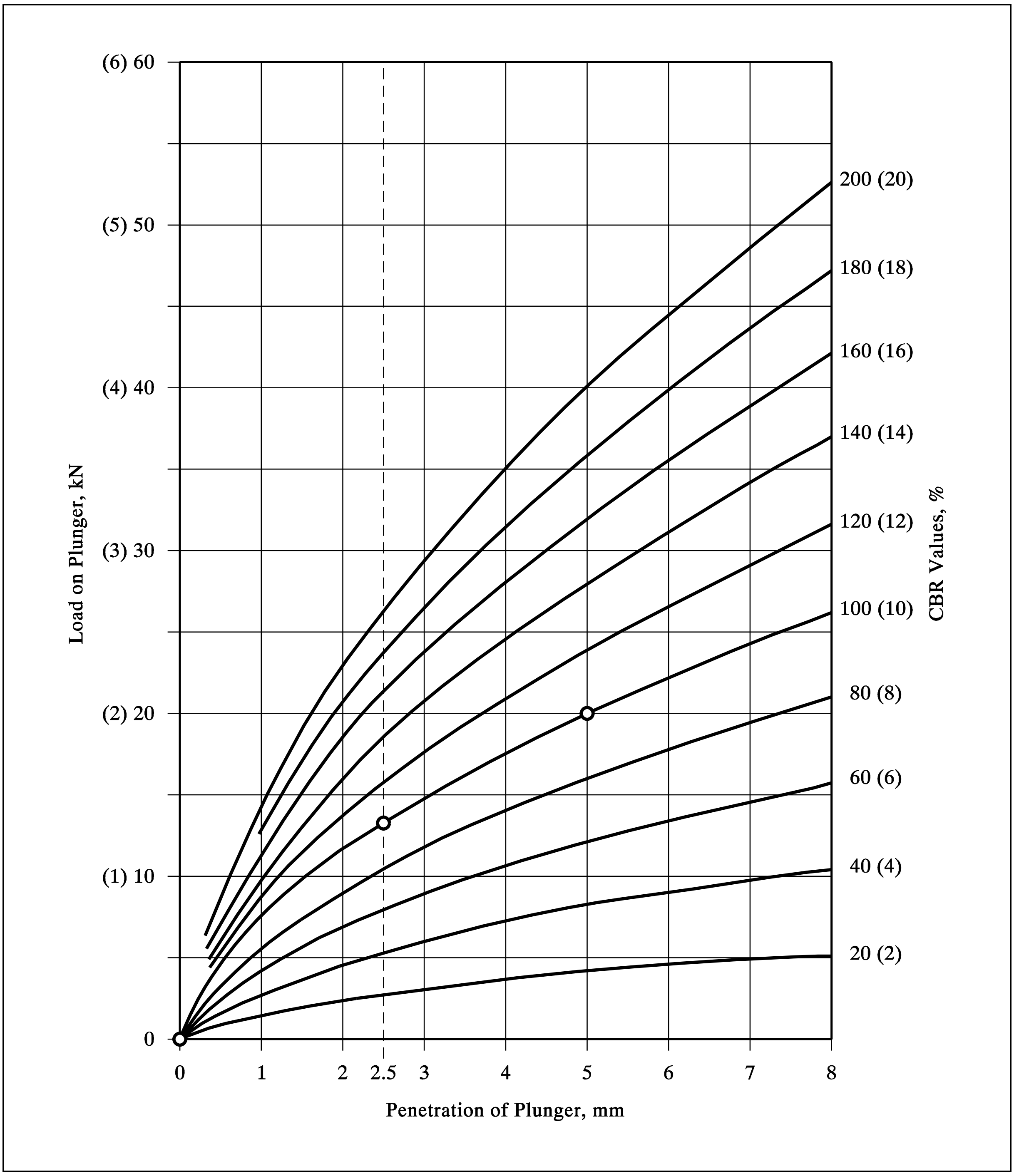


Figure 12.6 Force-penetration Curves for a CBR Value of 100% and Other CBR Values

Table 12.1 Standard Force-penetration Relationships for 100% CBR

Penetration (mm)	Force (kN)
2	11.5
2.5	13.2
4	17.6
5	20.0
6	22.2
8	26.3

(iii) Penetrations of 2.5 mm and 5 mm are used for calculating the CBR value. From the test curve, with corrected penetration scale if appropriate, read off the forces corresponding to 2.5 mm and 5 mm penetration. Express these as a percentage of the standard forces at these penetrations, i.e. 13.2 kN and 20 kN respectively. Take the higher percentage as the CBR value.

(iv) If the force-penetration curve is plotted on a diagram similar to Figure 12.6, the CBR value at each penetration can be read directly without further computation if the correction is not required. The same diagram can be used for small forces and low CBR values if both the force scale (ordinate) and the labelled CBR values (abscissa) are divided by 10 as shown in brackets in Figure 12.6.

12.1.6.3 Density of the sample shall be calculated as follows:

(i) Calculate the internal volume of the mould, V_m (in cm^3).

(ii) The initial Bulk Density, ρ (in Mg/m^3), of a sample compacted with specified effort (preparation Methods (5) and (6)), or of an undisturbed sample, is calculated from the equation:

$$\rho = \frac{m_3 - m_2}{V_m}$$

where m_3 is the mass of soil, mould and baseplate (in g);
m_2 is the mass of the mould and baseplate (in g); and
V_m is the volume of the mould body (in cm^3).

(iii) The initial Dry Density, ρ_d (in Mg/m^3), of the sample is calculated from the equation:

$$\rho_d = \left(\frac{100}{100 + w}\right)\rho$$

where w is the moisture content of the soil (in %).

The Dry Density, ρ_{ds} (in Mg/m^3), of the soaked sample is calculated from the equation:

$$\rho_{ds} = \frac{\rho_d}{1 + \dfrac{Ax}{1000\ V_m}}$$

where A is the area of cross section of the mould (in mm^2); and
x is the increase in sample height after swelling (in mm).

12.1.7 Report

The test report shall affirm that the test was carried out in accordance with this test method. The results of tests on the top and bottom ends of the sample shall be indicated separately, and the test report shall contain the following information:

(a) the general information as required in Clause B.1.1 of Appendix B,

(b) force-penetration curves, showing corrections if appropriate,

(c) the California Bearing Ratio (CBR) values, to two significant figures (if the results from each end of the sample are within ± 10% of the mean value, the average result may be reported),

(d) the initial sample density and the moisture content and dry density if required,

(e) the method of sample preparation,

(f) the moisture contents below the plunger at the end of each test, or the final moisture contents of the two halves of the sample,

(g) whether soaked or not, and if so the period of soaking, the amount of swell and the swelling-time curve (if required), and

(h) the proportion by dry mass of any over-size material removed from the original soil sample before testing.

Part III

13 General Procedures for Sample Preparation for Phase II Tests

13.1 General

The general procedures described in this Chapter shall be followed for all Phase II tests in this Geospec for preparation of test specimens, unless otherwise specified in the test procedures for individual tests.

The following pre-test assessment on received soil samples shall be carried out before preparation of specimen:

(i) For undisturbed samples, on removal from the sampling tube or container, the surfaces of the sample shall be carefully examined to assess whether it is possible to obtain a suitable specimen for testing. The specimen shall be such that the size of the largest particles shall not exceed one-fifth of the diameter of the test specimen, or the maximum particle size specified for an individual test, whichever the less. If there are any visible signs of bulging, cracking or disintegration on the specimen, these shall also be reported. Where necessary, the Specifiers shall be informed and requested to examine and assess the sample condition and its suitability for testing.

Note: The particle size assessment should be based on visual observation of the soil guided by a suitable length measuring device. A more rigorous assessment will need to be carried out at the end of the test.

(ii) For remoulded samples, if applicable, the samples shall be sieved where necessary to obtain a test specimen with particles not greater than the maximum size permitted as for undisturbed samples.

Clause 13.2 described the procedures for preparing remoulded test specimens from disturbed soil samples.

Clause 13.3 covers the preparation of test specimens from undisturbed samples of soil received from the field. Undisturbed soil specimens shall be prepared with minimum disturbance to the soil fabric and moisture content. The method of preparation shall depend on whether the sample received in the laboratory is contained in a tube of the same internal diameter as the soil specimen to be tested or in a tube of larger diameter, or is a block sample. Five procedures are described which depend on the type of undisturbed sample and the size or shape of the test specimen, as follows:

(a) cylindrical specimen of the same diameter as the tube sample,

(b) cylindrical specimen of smaller diameter than the tube sample,

(c) cylindrical specimen from a block sample,

(d) circular or square disc specimen from a tube sample, and

(e) circular or square disc specimen from a block sample.

The cylindrical specimens are used for tests employing the triaxial apparatus. Cylindrical specimen of fine-grained cohesive soil can be extruded from a large diameter tube sample with negligible disturbance.

The circular disc specimens are used for a consolidation or swelling test in an oedometer, while the square specimens are used for a direct shear test in the small shear box apparatus.

All prepared specimens not being used immediately should be wrapped in thin clinging plastic films to prevent loss of moisture.

13.2 Preparation of Remoulded Test Specimens from Disturbed Soil Samples

13.2.1 Apparatus

The following apparatus are required:

(a) the apparatus listed in Clause 4 as for the sample preparation for Phase I tests,

(b) cylindrical split moulds of various sizes to produce the required remoulded cylindrical specimens. The moulds shall be fitted with a clamping device capable of holding the component parts securely together and maintaining the cylindrical shape when the soil is subjected to compaction,

(c) cylindrical extension formers of the same diameter as the cylindrical split moulds. These formers shall be at least 40 mm high with suitable tolerances to fit to the top of the split mould to facilitate compaction of the soil specimen,

(d) circular plates of at least 10 mm thick and of the same diameter as the cylindrical remoulded specimens. The top end of the plates shall have a connection device for attachment to the compression machine,

(e) shear boxes and cutters of various sizes as described in Clause 16,

(f) extension formers having the same plan size as the shear boxes. These formers shall be at least 20 mm high with suitable tolerances to fit to the top of the shear box or cutter to facilitate compaction of the prepared soil in the shear box or cutter,

(g) square and circular plates of at least 5 mm thick and of the same plan dimensions as the square and circular shear box remoulded specimens. The top end of the plates shall have a connection device for attachment to the compression machine,

(h) compression machine, e.g. Universal Testing Machine, for compacting loose soil samples to form remoulded specimens,

(i) silicone grease or petroleum jelly, and

(j) tools such as wooden dolly for removing the remoulded specimen in the cutter into the shear box.

13.2.2 Procedures

13.2.2.1 Take a bulk representative soil sample with the minimum mass given in Table 13.1 below and determine its initial mass.

Table 13.1 Mass of Soil Required for Each Test Specimen from Disturbed Samples

Type of Test	Mass of Soil Required
Direct shear (small shear box, 20 mm thick specimens)	1.5 kg
Direct shear (small shear box, 44 mm thick specimens)	3 kg
Direct shear (large shear box)	50 kg
Triaxial (72-76 mm diameter specimen)	3.5 kg
Triaxial (100 mm diameter specimen)	8 kg

13.2.2.2 Unless otherwise specified, particles larger than the sizes given in Table 13.2 below shall be removed using an appropriate sieve (or the next size down) from the sample:

Table 13.2 Maximum Size of Particles Allowed in Test Specimens for Phase II Tests

Type of Test	Maximum Size of Particle
Direct shear (small shear box, 20 mm thick specimen)	4 mm
Direct shear (small shear box, 44 mm thick specimen)	10 mm
Direct shear (large shear box, 150 mm thick specimen)	25 mm
Consolidation (oedometer)	H/5
Consolidation (triaxial)	D/5
Triaxial	D/5

Note: H denotes height of specimen and D denotes diameter of specimen.

13.2.2.3 Initial preparation of soil, including assessment of soil classification, moisture content determination, drying of soil (where necessary), and mechanical processing shall follow Clause 4 as for Phase I tests, as appropriate.

Note: The method of drying (oven-drying or air-drying) and the drying temperature shall be specified by the Specifiers.

13.2.2.4 If drying has been carried out, determine the dry weight of the sample.

13.2.2.5 Determine the moisture content of the sample.

13.2.2.6 Bring the soil sample to the desired moisture content either by thoroughly mixing with the appropriate amount of water or by air-drying if it is too wet.

13.2.2.7 Repeat the above Clauses 13.2.2.5 and 13.2.2.6 until the desired moisture content is achieved.

13.2.2.8 Place the prepared soil in a sealed container and store it for at least 24 h before use.

13.2.2.9 Compact the soil at the specified moisture content (target value ± 2%) into a mould to achieve the specified dry density (to within ± 2% of the target dry density) as described below:

Note 1: Unless otherwise stated in the test procedures, static compaction using a suitable compression machine shall be used to achieve the required density.

Note 2: The mould shall be the shear box (or cutter) for the direct shear test, or a split mould for a cylindrical triaxial specimen. The plan size of the mould shall be the same as that of the test specimen to be formed.

(i) Weigh a mass of the above-prepared soil which will give the required bulk density when it just fills the mould. Compress the soil into the mould with an extension former, using the circular or square plate attached to the compression machine. The compression shall be such that the soil just fills the mould. Remove the extension former and level the surface of the formed specimen with a straightedge. Fill any small cavities by pressing in additional soils at the same moisture content.

(ii) The mass of soil to achieve the required density shall just fill the mould when uniformly compressed. If the volume of the excess or deficiency of the soil is more than 2% of the volume of the mould, the soil shall be removed from the mould, broken up, mixed with additional soil if necessary and recompressed without loss of moisture.

(iii) After satisfactory compaction, specimens of cohesive soils shall be sealed and stored for at least 24 h, to allow for dissipation of excess pore water pressures.

(iv) Final placement of the formed test specimen into the testing apparatus shall be as described in individual tests.

13.3 Preparation of Test Specimens from Undisturbed Soil Samples

13.3.1 Apparatus

The following apparatus are required:

(a) a sharp thin-bladed trimming knife,

(b) a spatula,

(c) a wire-saw,

(d) a saw, medium to coarse teeth,

(e) a metal straightedge trimmer, such as a steel strip about 300 mm long, 25 mm wide and 3 mm thick, with one bevelled edge,

(f) a straightedge such as an engineer's steel rule in good condition, graduated to 0.5 mm,

(g) a steel try-square,

(h) vernier calipers, readable to 0.05 mm and accurate to 0.1 mm, to be used for measuring the dimensions of a test specimen, and

(i) a flat glass plate, about 300 mm square and 10 mm thick.

The following additional apparatus are required for the preparation of a cylindrical specimen directly from a tube sample:

(j) an extruder to suit the sample tube, and to which it can be securely attached during extrusion,

(k) suitable supports, which are needed for certain soil samples to prevent their distortion during extrusion, and

(l) a split mould assembly.

The following additional apparatus are required for the preparation of cylindrical specimens of smaller diameter than the sampling tube:

(m) an extruder, as specified in (j) above,

(n) a thin-walled split mould for cutting the test specimen. The mould shall be smooth inside and out and turned at one end to form a cutting edge at the inner surface of the mould. The area ratio shall be kept as low as possible consistent with the strength requirements of the mould and shall not exceed 20%, Note: The area ratio, A, is defined as the volume of soil displaced by the sampler in proportion to the volume of the sample and is given by the equation:

$$A = \left(\frac{D_0^2 - D_1^2}{D_1^2} \right) 100$$

where D_0 is the outside diameter of mould; and
D_1 is the inside diameter of the cutting edge.

(o) a jig for holding the split mould securely on the sample tube while the sample is being extruded. The axis of the mould and the sample tube shall be maintained in visual alignment with the direction of extrusion, and

(p) an extruder to suit the split mould, and to which it can be securely attached during extrusion.

The following additional apparatus are required for the preparation of cylindrical specimen from an undisturbed block sample:

(q) a thin-walled split mould as specified in (n) above,

(r) a jig for firmly holding the thin-walled split mould in alignment with its direction of movement as it is pushed into the block sample (for specimens to be formed in a split mould),

(s) a soil lathe (for specimens to be hand trimmed), and

(t) a mitre box.

The following additional apparatus are required for the preparation of circular or square disc specimens from a sampling tube:

(u) a corrosion-resistant metal cutter for holding or forming the test specimen, provided with a sharp and externally-chamfered cutting edge and smooth internal surfaces. The cutter shall be circular or square in plan, and having the same internal dimensions as the size of specimen specified in the individual tests. The mould with a cutting edge into which the specimen is intruded is referred to as the cutting ring, whether it is circular or square,

(v) a jack and frame suitable for extruding the soil vertically from the sampling tube, and

(w) a jig for holding the circular or square cutter just above the top of the sampling tube. The jig shall be designed to allow the sample to pass through and project above the cutter. Alternatively a separate driving ring may be used for the same purposes.

The following additional apparatus are required for the preparation of circular or square disc specimen from block sample:

(x) a jig for firmly holding the plane of the cutter at right angle to its direction of movement as it is pushed into the block sample.

13.3.2 Preservation of Samples

The following measures shall be taken to preserve the as-received state of undisturbed samples, and to minimise the disturbance during specimen preparation:

(i) All tests shall be carried out as soon as possible on arrival in the laboratory, but if longer-term storage is necessary, samples shall be well sealed and stored in a room that is not subjected to vibration.

(ii) Tube samples shall be stored vertically on purpose-built racks, with an orientation the same as that for materials in the field.

(iii) Loss or gain of moisture of undisturbed samples shall be prevented during all stages of preparation and storage at the laboratory, e.g. the preparation operations shall be carried out as quickly as practicable and covered up between stages.

(iv) Cutting and trimming operations shall be carried out using cutting tools appropriate to the nature of the soil, and the reference straightedge used for checking flatness shall not be used for trimming.

13.3.3 Preparation of Cylindrical Specimen from Sample Tube of the Same Internal Diameter as the Required Specimen

13.3.3.1 Cut a suitable portion of the sampling tube using a saw, to facilitate the extrusion of the specimen. The sawing shall be done in such a way to avoid sample disturbance.

13.3.3.2 If the end of the protective coating (e.g. wax) or the soil surface exposed at the end of the cut out sample, against which the soil sample is to be extruded, is reasonably flat and perpendicular to the axis of the sample, no initial preparation is necessary. Otherwise remove any protective coating and loose or disturbed soil and trim the end of the sample to achieve that condition.

13.3.3.3 Place a paper or plastic disc next to the sample, or lightly oil the face of the extruder ram, to prevent adhesion between the soil and the extruder.

13.3.3.4 Extrude enough of the sample out of the tube to enable any loose and disturbed material to be cut away.

Note: Unless otherwise agreed by the Specifiers, the sample shall be pushed out of the tube in the same direction as it entered.

13.3.3.5 Extrude a length of sample long enough for testing. Then contain the sample within a split mould.

Note: The least disturbed portion of the sample will normally be at the bottom end of the tube, i.e. the end nearest to the cutting shoe when the sample was taken.

13.3.3.6 Cut off the surplus soil and trim the ends of the test specimen flat and flush with the ends of the split mould. Protect the ends from loss of moisture until the specimen is ready to be set up for the test.

13.3.4 Preparation of Cylindrical Specimen of Diameter Smaller Than Sampling Tube

13.3.4.1 Fit the sampling tube or a suitable portion of it obtained by careful sawing onto the extruder. Extrude enough of the sample from the tube to enable any loose and disturbed material to be cut off, leaving the end of the remaining sample flat and flush with the end of the tube.

13.3.4.2 Clamp the thin-walled split mould securely in the jig attached to the extruder with its cutting edges about 10 mm away from the end of the sample tube. The axis of the mould and the tube shall be in alignment with the direction of extrusion.

13.3.4.3 Extrude the sample directly into the split mould, maintaining a uniform speed. As extrusion proceeds, cut away excess soil from outside the split mould so that it does not impede the extrusion.

13.3.4.4 Cut off the extruded soil, remove the split mould from the jig.

13.3.4.5 Cut off the surplus soil and trim the ends of the test specimen flat and flush with the ends of the split mould. Protect the ends from loss of moisture until the specimen is ready to be set up for the test.

13.3.5 Preparation of Cylindrical Specimen from Undisturbed Block Sample

13.3.5.1 Initial Preparation shall be carried out as follows:

(i) Cut away at least 10 mm from the outside of the block sample, and cut out an approximately rectangular prism of soil slightly larger than the final dimensions of the specimen. The orientation of the axis of the prism shall be appropriate for the test to be carried out, when necessary, and shall be recorded.

(ii) Make the ends of the prism plane and parallel using the mitre box, or by carefully trimming and checking with a straightedge and try-square on the glass plate.

13.3.5.2 If a soil lathe is to be used, carry out the following steps:

(i) Place the specimen in a soil lathe and cut off the excess soil in thin layers. Rotate the specimen between each cut until a cylindrical specimen is produced. Take care to avoid disturbance due to torsional effects.

(ii) Contain the specimen within a split mould. Cut off the surplus soil and trim the ends of the test specimen flat and flush with the ends of the split mould. Protect the ends from loss of moisture until the specimen is ready to be set up for the test.

13.3.5.3 If a split mould with a cutting edge is to be used, carry out the following steps:

(i) Clamp the thin-walled split mould firmly in a holding jig.

(ii) Push the split mould into the soil, carefully trimming away most of the excess soil for a short distance in advance of the cutting edge. Ensure that the cutting edge itself always pares away the final sliver of excess material so that voids are not formed inside the mould. Maintain alignment of the axis of the mould with the direction of motion during this operation.

(iii) When the mould contains a length of specimen slightly in excess of the required trimmed length, undercut the specimen so that the mould can be extracted.

(iv) Trim the ends of the test specimen flat and flush with the ends of the split mould. Protect the ends from loss of moisture until the specimen is ready to be set up for the test.

13.3.5.4 With brittle soils for which the preceding methods are not practicable, the encapsulation method may be satisfactory to be used for an irregular lump of material as well as for a cylindrical or rectangular shape:

(i) Cover the piece of soil with paraffin wax, or wrap it with thin clinging film, to provide a waterproof coating.

(ii) Place the sample in a container, e.g. a one-litre compaction mould, and surround it with a suitable plaster, e.g. cellulose filler, mixed with water to a workable paste, so that the sample is completely encapsulated. Alternatively, pack damp sand around the sample.

(iii) Allow the plaster to set, but not to harden.

(iv) Jack a thin-walled split mould with a sharp cutting edge into the encapsulated sample with a continuous steady movement.

(v) Remove the split mould containing the test specimen from the container and trim the end of the specimen flat and flush with the ends of the split mould. Protect the ends from loss of moisture until the specimen is ready to be set up for the test.

13.3.6 Preparation of Circular or Square Disc Specimen from Sampling Tube

13.3.6.1 Fit the sampling tube or a suitable portion of it obtained by careful sawing onto the extruder. Extrude enough of the sample from the tube to enable any loose and disturbed material to be cut off, leaving the end of the remaining sample flat and flush with the end of the tube.

13.3.6.2 Extrude a further short length, e.g. 20 mm to 30 mm, of the soil sample from the tube for examination, after removing the protective covering.

13.3.6.3 Cut off and remove the extruded length of sample. Trim the end of the remaining sample flat and flush with the end of the tube.

13.3.6.4 Secure the cutter rigidly in the jig and mount the assembly on the sample tube so that the cutting edge of the cutter is 3 mm to 6 mm above the top of the tube.

13.3.6.5 Extrude the sample steadily direct into the cutter until the top surface projects slightly above the cutter. During this operation trim away the soil from the outside of the cutter to reduce friction and to prevent obstruction.

13.3.6.6 Cut off the sample in its cutter a little below the cutting edge and remove the cutter from the jig. For loose or soft soils, take care to ensure that the specimen does not slide in, or fall out of, the cutter.

13.3.6.7 Cut off the soil projecting above the upper end of the cutter and trim the surface flat and flush with the cutter, checking with the reference straightedge. Avoid excessive remoulding of the surface.

13.3.6.8 Place the trimmed surface on the flat glass plate and trim the other surface flush with the cutting edge. Ensure that no soil is left adhering to the outside of the cutter.

13.3.6.9 If during the above operation a small inclusion interferes with extrusion and trimming, remove it and fill the cavity with fine material from the parings.

13.3.7 Preparation of Circular or Square Disc Specimen from Block Sample

13.3.7.1 Procedure using a holding jig shall be carried out as follows:

(i) Clamp the cutter firmly in the holding jig.

(ii) Push the cutter steadily into the soil, carefully trimming away most of the excess soil for a short distance in advance of the cutting edge. Ensure that the cutting edge itself always pares away the last sliver of excess soil so that voids are not formed inside the cutter. Maintain the plane of the cutter at right angles to direction of motion during this operation.

(iii) When the top surface of the specimen protrudes slightly above the cutter, sever the soil slightly below the cutting edge so that the soil contained in the cutter can be removed intact.

13.3.7.2 Procedure using a driving ring shall be carried out as follows:

(i) Cut a roughly circular or square portion of soil from the sample of dimensions somewhat larger than the test specimen.

(ii) Prepare two plane faces on the portion so that they are flat and parallel to each other and orientated in the direction required for the test.

(iii) Place one prepared surface of the sample on the glass plate. Use the cutter, placed on the exposed face, as a template while carefully trimming the edges of the sample. Push the cutter down slowly and evenly without tilting, using a driving ring placed on top, allowing the cutting edge to pare away the last fraction of soil. Ensure that the specimen is a close fit in the cutter with no voids against the inner surface. Push the cutter down until the top surface of the specimen projects slightly above it. Remove the driving ring.

13.3.7.3 Proceed to Clauses 13.3.6.7 to 13.3.6.9.

14 Determination of Compressibility Characteristics of Soils

14.1 The One-dimensional Consolidation Test

14.1.1 Scope

This test, commonly referred to as the oedometer test, is used for the determination of the one-dimensional compression and consolidation properties of soils when subjected to changes in the applied effective stress. The method described is concerned mainly with the primary consolidation phase, but it can also be used for the determination of the secondary compression characteristics, upon request from the Specifiers.

14.1.2 General

The guidance given in Clause 3.10.1 shall be noted.

The environmental requirements are very important for all Phase II tests. Testing shall be carried out in an area free from significant vibrations and other mechanical disturbance and in a laboratory in which the temperature during the test is maintained at t°C ± 4°C, where t is a fixed value between 19 and 24 over the period of the test. The temperature control requirement related to calibration is given in Appendix A. The apparatus shall be sited away from the effects of local sources of heat, direct sunlight and draughts.

The daily maximum and minimum temperatures in the vicinity of the test apparatus shall be recorded to 0.5°C. The records shall commence on the day the specimen is mounted on the test apparatus and cover the period of the test. Where it is not feasible to record these temperatures over the weekend or public holidays, record the maximum and minimum temperatures over the whole period starting from the end of the last working day preceding the holidays to the start of the first working day after the holidays.

14.1.3 Apparatus

The following apparatus are required:

(a) the apparatus for specimen preparation and measurement described in Clause 13.3.1, as appropriate,

(b) the apparatus for moisture content determination as specified in Clause 5,

(c) the apparatus for particle density determination, if required,

(d) the consolidation apparatus, known as oedometer, which shall consist essentially of the following items:

- a corrosion-resistant metal consolidation ring:

(1) The ring shall be able to provide complete and rigid support and confine the soil specimen laterally. It shall be provided with a cutting edge to facilitate the preparation of the specimen. The inner surface of the ring shall be smooth and preferably coated with silicone grease or petroleum jelly.

(2) The diameter of the consolidation ring shall depend primarily on the nominal sizes of undisturbed tube samples received for the test, the nature of the soil and the maximum size of particles present in the sample. The internal diameter of the ring shall be not less than 50 mm and not greater than 105 mm. The height of the ring shall be not less than 18 mm and not more than 0.4 times its internal diameter.

Note: A consolidation ring of 70 mm diameter × 19 mm thick is commonly used.

- corrosion-resistant porous plates, to be placed on the top and beneath the bottom surface of the test specimen:

(1) The diameter of the top porous plate shall be 0.25 mm - 0.75 mm smaller than the internal diameter of the consolidation ring, in order to permit free compression of the soil specimen. A taper towards the upper edge is permissible to minimise the danger of binding, should tilting occur. The bottom porous plate shall be large enough to adequately support the consolidation ring and the soil specimen.

(2) The thickness of the plates shall be sufficient to prevent breaking under load, and the material shall be of negligible compressibility under the loads applied during the test. The upper and lower surfaces of the plates shall be plane, clean and undamaged. The porosity of the plates shall allow free drainage of water throughout the test but shall prevent intrusion of soil particles into their pores. The permeability of the plates shall be at least one order of magnitude greater than the estimated permeability of the soil specimen.

Note: Table 8 of Geoguide 1 (GEO, 1993) gives typical ranges of geotechnical parameters including permeability for selected Hong Kong soils other than marine clay. For marine clay, the typical range of permeability is 10^{-10}-10^{-11} m/s.

- a corrosion-resistant consolidation cell, to accept the consolidation ring containing the soil specimen with a push fit:

(1) The specimen shall be held between the top and bottom porous plates and shall rest centrally on the base of the cell. Load is applied to the specimen through a rigid, centrally mounted, and corrosion-resistant loading cap fitted with a central seating. The principal features of the cell are illustrated in Figure 14.1.

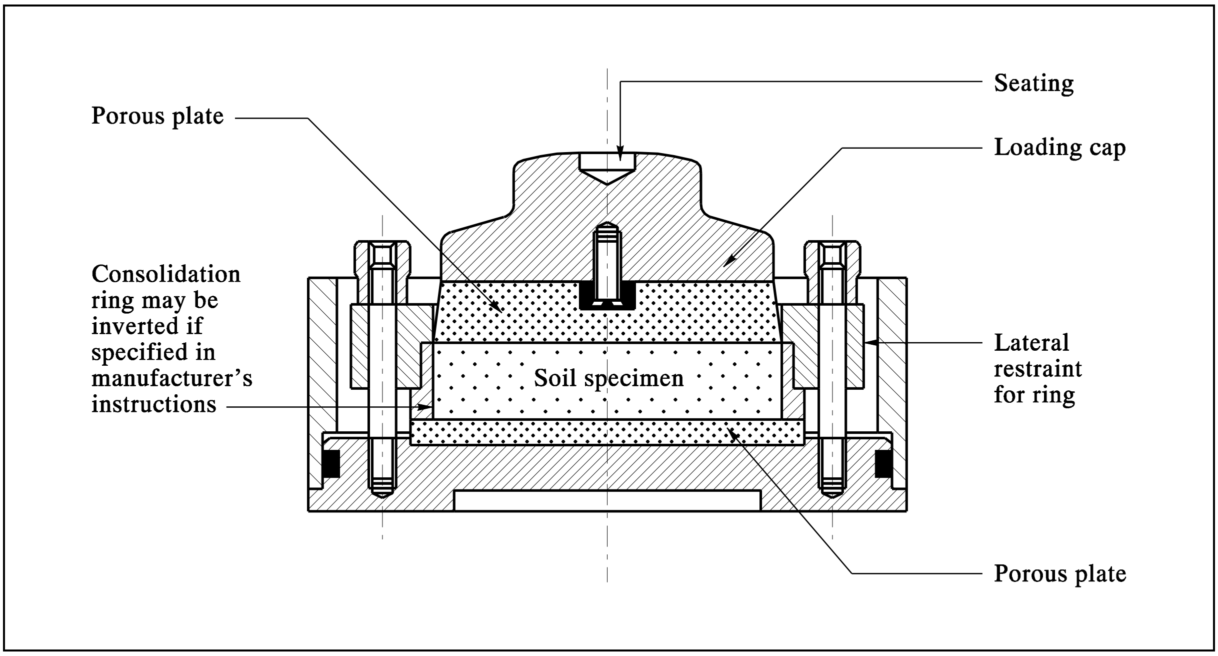


Figure 14.1 Section of a Typical Consolidation Cell

(2) The cell shall be capable of being filled with water to a level higher than the top of the upper porous plate. The materials comprising the cell and the fitted components shall not be corrodible by electro-chemical reaction with each other.

(e) a compression gauge, which may be a calibrated dial gauge or a displacement transducer. The gauge shall be supported for measuring the vertical compression or swelling of the specimen throughout the test. It shall be readable to 0.002 mm and accurate to 0.01 mm,

(f) a calibrated loading device, having a rigid bed for supporting the consolidation cell:

(1) The loading device shall be securely bolted onto the bench or supporting stand, which in turn shall be securely fixed to the floor or counterbalanced against overturning when fully loaded.

(2) The device shall enable a vertical load to be applied axially in increments to the test specimen through a loading yoke. The load applied to the test specimen shall be central to the loading cap covering the top porous plate through a central seating. The loading mechanism shall be capable of applying the load immediately and without impact.

(3) Calibrated hanger weights of a variety of combination shall be provided to enable the increments of load to be applied to the test specimen for achieving the required pressures. Each load increment shall be maintained constant by a stress-control method while permitting

increasing vertical compression of the test specimen during the consolidation test. The vertical load applied to the specimen shall be capable of applying pressure to 2 kPa, and accurate to 4 kPa or 2% of the applied pressure, whichever is greater. The apparatus shall be capable of accommodating a compression of at least 75% of the specimen thickness. A counterbalanced lever system, using calibrated weights in increments, is the method commonly employed for applying the vertical load to the test specimen.

(g) a metal disc, of steel, bronze or brass. The thickness of the disc shall equal to the height of the consolidation ring, with a diameter of 0.8 mm - 1.2 mm smaller than the internal diameter of the ring. The end faces shall be flat, smooth and parallel,

(h) a calibrated vernier calliper readable to 0.05 mm and accurate to 0.1 mm,

(i) a calibrated micrometer readable to 0.01 mm and accurate to 0.02 mm, and

(j) the following miscellaneous apparatus and materials:

- a calibrated timing device readable to 1 s and accurate to 1 s in 5 minutes,
- a calibrated maximum and minimum temperature measuring device readable to 0.5°C and accurate to 1°C,
- a calibrated balance readable to 0.01 g and accurate to 0.05 g,
- a watch glass or perspex plate, for holding the specimen and cutter,
- silicone grease or petroleum jelly, and
- distilled water at room temperature.

14.1.4 Calibration

14.1.4.1 Measurements of apparatus shall be carried out as follows:

(i) Clean and dry the consolidation ring and the watch glass or perspex plate. Ensure that the cutting edge is true and not damaged.

(ii) Weigh the ring and the watch glass or perspex plate separately to 0.01 g.

(iii) Lubricate the inside face of the ring with a thin smear of silicone grease or petroleum jelly.

Note: Great care should be exercised in the application of the silicone grease or petroleum jelly. Such material if smeared onto the porous plate will impede water flow and give erroneous rate of consolidation results.

(iv) Measure the height of the consolidation ring to 0.01 mm at four or more equally spaced points and calculate the mean height, H_0.

(v) Measure the internal diameter of the ring to 0.05 mm in two perpendicular directions. Calculate the mean diameter and the area, A, to 0.1 mm^2.

14.1.4.2 Deformation Characteristics of apparatus shall be determined as follows:

Note: The determination of the deformation characteristics of the apparatus shall be carried out before each test. However, where the individual items are each marked with a permanent identification and are to be used together as a set, the determination may be less frequent but shall be at least once a year. Record the identification numbers of all items, if the latter method is used.

(i) Assemble the consolidation apparatus as described in Clauses 14.1.6.2 and 14.1.6.3 but fit the metal disc in place of the soil specimen. Do not add water to the cell. Identify the orientation of each component with respect to the loading device by indelible marks.

Note: If a filter paper is to be placed against each face of the specimen during a test, similar filter papers should be placed at the top and bottom of the metal disc for the calibration. The filter papers shall be wetted prior to placing to simulate the test conditions.

(ii) Apply increments of load similar to those applied for a test up to the maximum working load of the apparatus. Each increment shall be sustained only as long as necessary to observe the resulting reading of the compression gauge.

(iii) Record the deformation to 0.002 mm under each load increment as indicated by the compression gauge.

(iv) Unload the apparatus in decrements corresponding to the loading increments and record the deformations as described in (iii) above.

(v) Tabulate or plot the deformations as the cumulative corrections, y, to be applied to the measured cumulative settlement of the specimen corresponding to each applied load (see Clause 14.1.6.5 (iv)).

14.1.5 Sample Preparation

14.1.5.1 Provide a description of the sample in accordance with Geoguide 3 (GCO, 1988), and carry out pre-test assessment as described in Clause 13.1.

14.1.5.2 Prepare the disc specimen of the appropriate size specified for the consolidation ring used from an undisturbed sample of soil in accordance with Clause 13.3, taken either from a tube sample as described in Clause 13.3.6, or a block sample as stated in Clause 13.3.7.

Note: Cutting and trimming operations shall be carried out using cutting tools appropriate to the nature of the soil. The reference straightedge used for checking flatness shall not be used for trimming.

14.1.5.3 Measure the height of the specimen to 0.01 mm (H_0) in its ring (omit this step if the height of the ring is equal to the height of the soil specimen).

14.1.5.4 Weigh the specimen in its ring together with a watch glass or perspex plate of known weight and determine the initial mass of the specimen, m_0, immediately and to 0.01 g.

14.1.5.5 Take separate specimen from the same sample for the determination of particle density, if required, and initial moisture content, w_i, in accordance with the test method specified for reference purpose.

14.1.6 Test Procedures

14.1.6.1 Prior to the test, prepare the porous plates as follows:

(i) Clean the surfaces of the plates using a natural bristle or nylon brush.

(ii) Check visually that there are no signs of cracks or damage on the plates. If found, the plates shall not be used.

(iii) Ensure that the pores are not clogged by soil particles, and that the plates are readily permeable to water.

(iv) Saturate the porous plates by boiling them in distilled water for at least 20 min, either over heat at atmospheric pressure, or in a vacuum desiccator in which the pressure has been reduced to about 20 ± 5 mm of mercury.

(v) For saturated soils or soils that do not exhibit an affinity for water, keep the plates saturated in a beaker of de-aired tap water inside a vacuum desiccator (in which the pressure is kept at below 760 mm of mercury) until required for the test. Immediately before assembly in the consolidation cell, remove free surface water with a tissue, ensuring that the pores remain saturated.

(vi) For soils that readily absorb water, dry the porous plates in air for at least 16 hours after saturation as described in (iv) above.

Note: To assess whether the soil absorbs water readily or not, trials may be carried out by putting drops of water on separate portions of soils from the sample and observe.

14.1.6.2 Assemble the consolidation cell as follows:

(i) Place the prepared bottom porous plate centrally in the consolidation cell.

(ii) Place the prepared specimen containing in its ring centrally on top of the porous plate.

Note: Filter papers (Whatman No. 54 or equivalent) which have been immersed in de-aired water can be placed at both the top and bottom of the soil specimen between the porous plates and the specimen to prevent fine soil particles clogging the pores of the porous plates.

(iii) Assemble the cell components so that the consolidation ring is laterally confined and in correct alignment.

(iv) Place the prepared top porous plate and loading cap centrally on top of the specimen.

(v) Record the type of porous plates used.

(vi) When assembling the apparatus for a test, ensure that each component is orientated as described in Clause 14.1.4.2.

14.1.6.3 Assemble the loading frame as follows:

(i) Place the consolidation cell in position on the bed of the loading apparatus.

(ii) Adjust the counterbalanced loading beam so that when the load-transmitting members just make contact with the loading cap and the beam is slightly above the horizontal position.

(iii) Add a small weight to the beam hanger, sufficient to maintain contact between the load-transmitting members while final adjustments are being made. The resulting seating pressure on the specimen shall be less than 5 kPa. Record the actual seating pressure.

(iv) Clamp the compression gauge securely into position so that it can measure the relative movement between the loading cap and the base of the cell. Position the gauge such that it can measure swelling as well as compression of the specimen. Record the initial reading of the gauge to 0.002 mm.

14.1.6.4 Soak the specimen as follows:

Note: In Hong Kong, marine or alluvial clays of low permeability are usually saturated or near saturated in their natural state. Therefore, soaking is not necessary. For saprolitic, residual or colluvial soils, which are generally of higher permeability ($k > 10^{-8}$ m/s) and are normally only partially saturated in their natural state, soaking for at least 12 hour is necessary. The aim of soaking is to prepare a specimen with a high degree of saturation, preferably 95% or more. If in doubt, trials should be carried out to determine the minimum soaking time.

(i) Fill the consolidation cell with water and soak the specimen for at least 12 hours.

(ii) On completion of soaking, record the amount of swelling or compression, if any.

14.1.6.5 After completion of soaking, load the specimen according to the loading sequence, specified by the Specifiers, as follows:

(i) Record the compression gauge reading as the initial reading for the load increment stage, d_i.

(ii) Apply the specified pressure to the specimen at a convenient moment (zero time) by adding the appropriate weights to the beam hanger without jolting. For the initial loading, the added pressure shall be the specified initial pressure subtracting the seating pressure.

(iii) For specimen where soaking has not been carried out, immediately fill the consolidation cell with water after applying the pressure. If the specimen begins to swell, proceed to the next higher pressure.

(iv) Take readings of the compression gauge at suitable time intervals.

Note: Suggested intervals for taking the compression readings are 0, 10, 20, 30, 40, 50 s, 1, 2, 4, 8, 15, 30 min, 1, 2, 4, 8, 24 h. More frequent readings at the initial stage may need to be taken for soils which compress very rapidly. Readings may be taken at other time intervals so long as they enable the curve to be plotted with sufficient accuracy.

(v) Plot the compression gauge readings against both the logarithm of time and square-root time, while the test is in progress, either manually or by means of an automatic recorder.

(vi) Maintain the pressure until such time that the end of primary consolidation can be identified. The end of primary consolidation shall be determined using the log time and the square-root time plots (see the following Clause 14.1.7); whichever gives a longer primary consolidation period. Record the compression gauge reading at the end of the primary consolidation.

Note 1: A period of 24 h under one pressure is generally adequate to reach the end of primary consolidation but this shall be verified from the plots.

Note 2: In some cases, the end of primary consolidation can be identified on only the square-root time plot or the log time plot. In such cases that shall be taken as the end of primary consolidation.

Note 3: If secondary consolidation is to be determined, refer to Clause 14.1.7.8.

(vii) Record the time and compression gauge reading, at the termination of the load increment stage. This reading becomes the initial reading for the next stage.

(viii) Increase the pressure to the next value in the selected sequence, as described in (ii) above and repeat Steps (iii) to (viii) until all loading stages in the sequence are completed.

(ix) If unloading curve is not required, dismantle the assembly as described in Clause 14.1.6.8.

14.1.6.6 Unload the specimen according to the unloading sequence, specified by the Specifiers, as follows:

(i) Reduce the pressure to the specified pressure in the unloading sequence, at a convenient moment (zero time).

(ii) Record readings of the compression gauge at convenient intervals such as those used in the loading stage.

(iii) Plot the readings so that the completion of swelling can be identified.

Note: The swelling is considered complete when the swelling curve based on the square-root time plot is virtually flattened.

(iv) Record the final reading of the compression gauge.

(v) Repeat Steps (i) to (v) for each unloading stage until all unloading stages in the sequence are completed.

14.1.6.7 If a second load-unload cycle is specified, repeat the above loading and unloading procedures.

14.1.6.8 After all loading and unloading stages are completed, dismantle the testing assembly as follows:

(i) Drain off the water from the cell. Allow it to stand for at least 15 min to enable free water to drain from the porous plates.

(ii) Mop up any excess water from within the cell.

(iii) Remove the load from the specimen and also the consolidation cell from the apparatus.

(iv) Dismantle the cell, and weigh the specimen in its ring together with a watch glass or perspex plate of known weight, and determine the final wet mass of the specimen (m_f) to 0.01 g.

(v) Dry the specimen to constant mass at the same temperature as that used for the determination of moisture content and determine the dry mass (m_d) to 0.01 g.

(vi) Soak the dried specimen in water until it is sufficiently soften for breaking up into individual particles. Break it up for inspection. If there are particles of size larger than one-fifth of the height of the consolidation ring, determine their percentage by mass and take photograph of them alongside a suitable scale and a colour chart.

14.1.7 Calculations

14.1.7.1 Calculate the initial and final moisture content of the specimen, w_0 and w_f (to 0.1%), from the following equations:

$$w_0 = \frac{100\,(m_0 - m_d)}{m_d}\,; \qquad w_f = \frac{100\,(m_f - m_d)}{m_d}$$

where m_0 is the initial wet mass of the specimen (in g);
m_f is the final wet mass of the specimen (in g); and
m_d is the final dry mass of the specimen (in g).

14.1.7.2 Calculate the initial and final bulk density, ρ_0 and ρ_f (to 0.01 Mg/m^3), from the following equations:

$$\rho_0 = \frac{1000\,m_0}{AH_0}\,; \qquad \rho_f = \frac{1000\,m_f}{AH_f}$$

where A is the area of the specimen (in mm^2);
H_0 is the initial height of the specimen (in mm); and
H_f is the final height of the specimen (in mm).

14.1.7.3 Calculate the initial and final dry density, ρ_{do} and ρ_{df} (to 0.01 Mg/m^3), from the following equations:

$$\rho_{do} = \frac{100\,\rho_0}{100 + w_0}\,; \qquad \rho_{df} = \frac{100\,\rho_f}{100 + w_f}$$

14.1.7.4 Calculate the initial and final void ratio, e_0 and e_f (to 0.01), from the following equations:

$$e_0 = \frac{\rho_s}{\rho_{do}} - 1\,; \qquad e_f = \frac{\rho_s}{\rho_{df}} - 1$$

where ρ_s is the particle density (in Mg/m^3) (a default value of 2.65 is to be assumed if it is not specified or determined separately).

14.1.7.5 Calculate the initial and final degree of saturation, S_0 and S_f (to 0.1%), from the following equations:

$$S_0 = \frac{w_0 \rho_s}{e_0 \rho_w} ; \qquad S_f = \frac{w_f \rho_s}{e_f \rho_w}$$

where ρ_w is the density of water = 1.0 Mg/m^3.

14.1.7.6 Illustrate the compressibility characteristics by plotting the compression of the specimen as the ordinate on a linear scale against the corresponding applied pressure, p (in kPa), as the abscissa on a logarithmic scale. Indicate the compression in terms of both void ratio, e, and strain, ε, expressed as a percentage reduction in the initial height of the specimen. The calculation and plotting of void ratio, strain and compressibility shall be carried out as follows:

(i) Calculate the equivalent height of solid particles, H_s (to 0.01 mm), from the following equation:

$$H_s = \frac{H_0}{1 + e_0}$$

(ii) Calculate the height of the specimen, H (to 0.01 mm), at the end of primary consolidation of each loading or the end of each unloading stage from the following equation:

$$H = H_0 - \delta H_0 - (\Delta H - y)$$

where δH_0 is the compression/swelling of the specimen due to soaking under the seating pressure (negative value for swelling);

ΔH is the cumulative compression of the specimen from the start of the initial loading stage up to the end of primary consolidation of the loading stage; and

Note: This is calculated from the difference between the initial compression gauge reading, d_i taken in Clause 14.1.6.5 (i) and the compression gauge reading recorded at the end of primary consolidation of the loading stage or the end of the unloading stage as defined in Clause 14.1.6.6 (iii).

y is the cumulative correction for the deformation of the apparatus under the pressure applied for the loading/unloading stage (refer to Clause 14.1.4.2 for its determination).

Note: For tests where y is less than 5% of the cumulative compression, correction may be omitted.

(iii) Calculate the void ratio, e (to 0.01), at the end of primary consolidation of each loading stage or the end of each unloading stage from the following equation:

$$e = \frac{H - H_s}{H_s}$$

(iv) Calculate the strain, ε (to 0.01%), at the end of primary consolidation of each loading stage or the end of each unloading stage from the following equation:

$$\varepsilon = \left(\frac{H_0 - H}{H_0} \right) 100$$

(v) Calculate the coefficient of volume compressibility, m_v (to 0.01 m^2/MN), for each loading increment from the following equation:

$$m_v = \left(\frac{H_1 - H}{H_1} \right) \left(\frac{1000}{p_2 - p_1} \right)$$

where H_1 is the height of the specimen at the end of primary consolidation of the previous loading stage (in mm);
p_1 is the pressure applied to the specimen for the previous loading stage (in kPa); and
p_2 is the pressure applied to the specimen for the loading stage under consideration (in kPa).

(vi) Plot values of void ratio, e, and strain, ε, calculated at the end of primary of each loading stage or the end of the unloading stage as the ordinate against the applied pressure on a logarithmic scale as the abscissa on two separate plots. Draw smooth curves through the points for both the loading and unloading portions. Indicate the value of the initial void ratio, e_0, and initial strain, ε_0, on the vertical axis respectively. Also, indicate the values of void ratio and strain corresponding to the end of secondary compression, if any, of each loading and unloading stage.

14.1.7.7 Determine the coefficient of consolidation using one of the two recognised curve fitting methods described as follows:

Note: Correction shall be made to the compression data prior to plotting and curve fitting, where appropriate.

Method (A) - Logarithm of time Curve-fitting Method (Figure 14.2)

(i) Locate the corrected zero point by marking off the difference in ordinates between any two points on the initial (convex-upwards) portion of the curve having times in the ratio 1:4, and laying off an equal distance above the upper point. Repeat this operation using two other pairs of points having times in the same ratio, and take the average of the compression readings so determined as the corrected zero compression point, denoted by d_0.

(ii) Draw and extend the tangents to the two linear portions of the laboratory curve, i.e. at the point of inflexion, and the secondary compression portion. Their intersection gives the compression corresponding to the theoretical 100% primary compression, denoted by d_{100}.

(iii) From the zero and 100% points, locate the 50% primary compression point, d_{50}, on the laboratory curve and obtain its time, t_{50} (in min).

(iv) Calculate the coefficient of consolidation, c_v (to 0.01 m^2/year), for this load increment from the following equation:

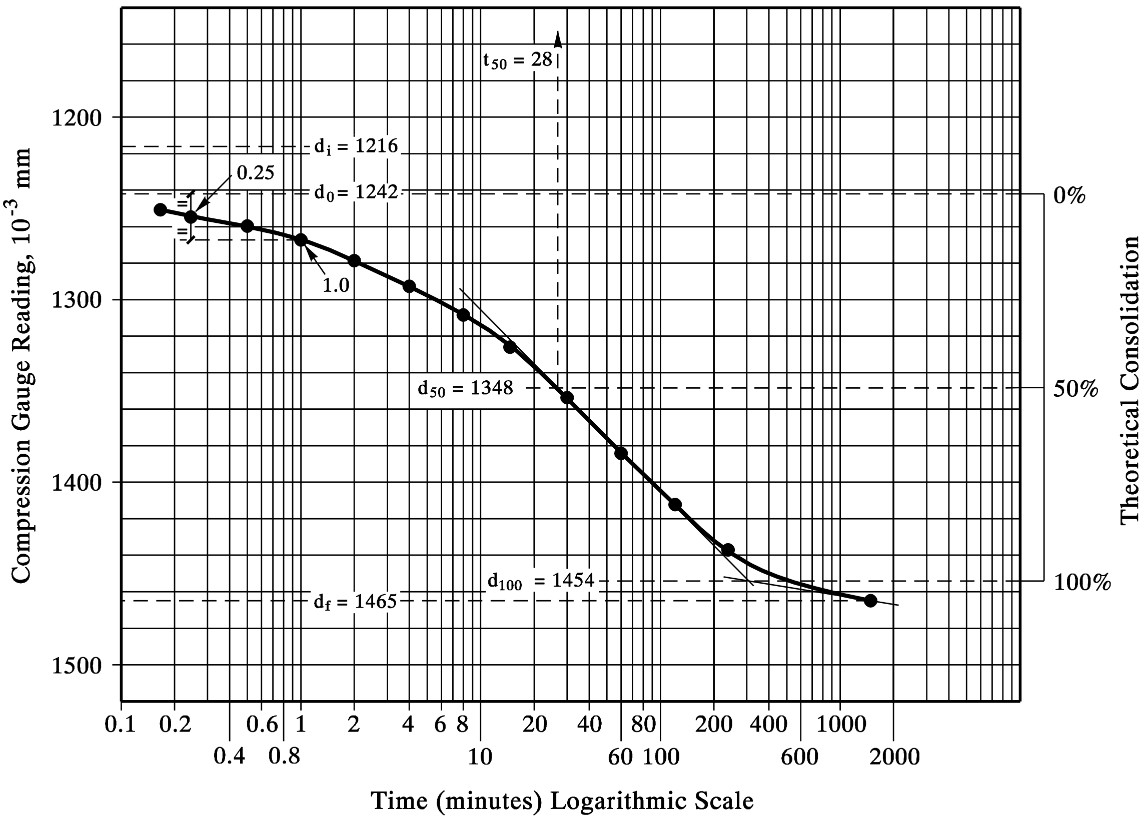


Figure 14.2 Laboratory Consolidation Curve: Logarithm of Time Fitting Method

$$c_v = \frac{0.026\,\overline{H}^2}{t_{50}} \quad \text{and} \quad \overline{H} = \frac{H_1 + H}{2}$$

where $\overline{H}$ is the average specimen height for the load increment (in mm); and

t_{50} is expressed in minutes.

(v) Repeat Steps (i) to (iv) for each load increment applied to the specimen.

Method (B) - Square-root Time Curve-fitting Method (Figure 14.3)

(i) Draw a straight line best fitting the early portion of the curve (usually within the first 50% of compression) and extend it to intersect the ordinate of zero time. This intersection represents the corrected zero point, denoted by d_0.

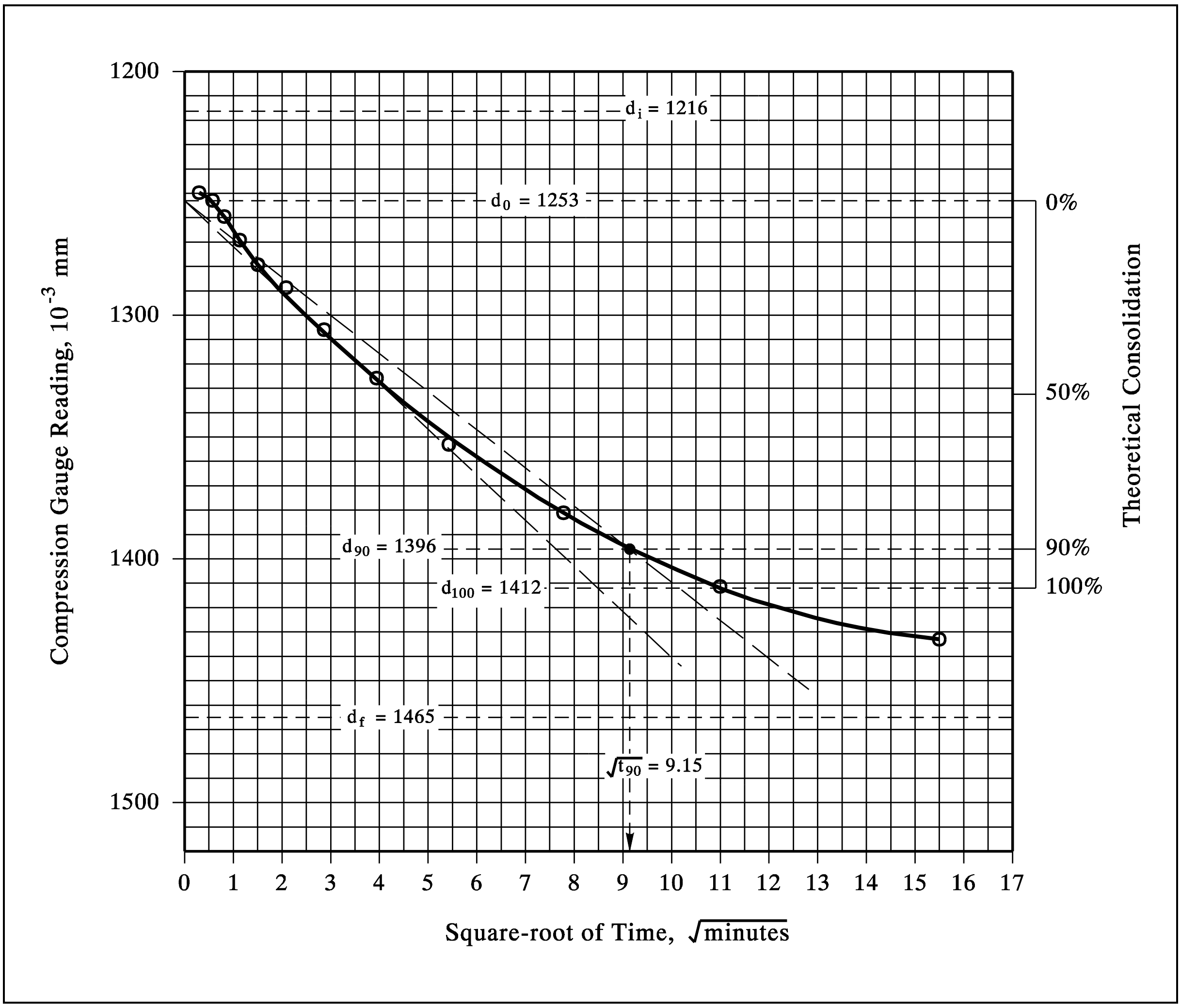


Figure 14.3 Laboratory Consolidation Curve: Square-root of Time Fitting Method

(ii) Draw another straight line through the d_0 point which at all points has abscissa 1.15 times as great as those on the best fit line drawn in Step (i) above. The intersection of this line with laboratory curve gives the 90% compression point, d_{90}. Determine the theoretical 100% primary compression point, d_{100}, from the two points d_0 and d_{90} by direct scaling.

(iii) Read off the value of t_{90} from the laboratory curve corresponding to the d_{90} point and calculate the value of c_v (to 0.01 m^2/year), from the following equation:

$$c_v = \frac{0.111\overline{H}^2}{t_{90}} \quad \text{and} \quad \overline{H} = \frac{H_1 + H}{2}$$

where t_{90} is expressed in minutes.

(iv) Repeat Steps (i) to (iii) for each load increment applied to the specimen.

14.1.7.8 Determine the coefficient of secondary compression at the selected loading stages if required by the Specifiers. This can be derived from the logarithm-of-time curve as follows:

(i) Extend the linear portion of the secondary compression portion of the curve, obtained as described in Clause 14.1.7.7, so that it covers at least one complete cycle of log time. It is necessary to prolong the duration of the load increment to establish a linear relationship.

(ii) Read off the compression gauge readings at the beginning and end of the cycle, e.g. at 1000 min and 10000 min, and calculate the difference, δH_{sec} (in mm), between them.

(iii) Calculate the coefficient of secondary compression, C_{sec}, to 0.001 for the loading stage from the following equation:

$$C_{sec} = \frac{\delta H_{sec}}{H_i}$$

where H_i is the initial height of the specimen at the start of the primary consolidation for the relevant loading stages.

(iv) Repeat Steps (i) to (iii) for each of the selected loading stages.

14.1.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in B.1.1 of Appendix B,

(b) the information as required in B.1.2 of Appendix B for Phase II tests,

(c) the actual seating pressure,

(d) the actual soaking time,

(e) the amount of swelling or compression upon completion of soaking,

(f) whether saturated or air-dried porous plates were used,

(g) the diameter, initial and final height, bulk density and dry density of the specimen,

(h) the initial and final moisture content (state the test method used for moisture content determinations, and if the minimum mass requirement for carrying out the moisture content tests cannot be followed, this shall be stated),

(i) the initial and final void ratio and degree of saturation of the specimen,

(j) plots of the void ratio and the vertical strain corresponding to the end of primary consolidation against the logarithm of applied pressure for the complete load-unload-reload cycle, with the end of secondary compression for each stage indicated,

(k) plots of compression gauge readings against time (log time and square-root time) for each load increment,

(l) the calculated values of the coefficient of volume compressibility, m_v (in m^2/MN), and the coefficient of consolidation, c_v (in m^2/year) based upon log time and square-root time plots, for each load increment, and

(m) values of the coefficient of secondary compression, C_{sec}, for each load increment (if required).

14.2 The Isotropic Compression Test in a Triaxial Cell

14.2.1 Scope

This test is used for the determination of the isotropic compression properties of soils when subjected to changes in the applied effective stress in a triaxial cell. The test is performed on a soil specimen in the form of a right cylinder with a nominal diameter of 70 mm to 110 mm and a height to diameter ratio of 1.9 to 2.1. A height to diameter ratio of down to 0.9 to 1.1 can also be accepted.

14.2.2 General

The guidance given in Clause 3.10.3 shall be noted.

The environmental requirements as described in Clause 14.1.2 shall be observed.

The consolidation is normally carried out in stages as specified by the Specifiers. Each stage of consolidation is carried out in two phases, an undrained phase and a drained phase. In the undrained phase, the cell confining pressure is increased so that it exceeds the back pressure by an amount equal to the desired effective stress for consolidation causing the pore pressure to build up to a steady value. In the drained phase, this excess pore pressure is allowed to dissipate against the back pressure until the pressures virtually equalise. The volume of water draining out of the soil specimen during this process and the pore water pressure are recorded at suitable time intervals so that the consolidation curves can be obtained.

The effective consolidation stresses shall be as specified by the Specifiers. The back pressure shall be maintained at a constant value throughout the consolidation process. The back pressure shall not be reduced below the pore pressure reached in the final step of the saturation stage, or 200 kPa, whichever is greater.

14.2.3 Apparatus

The following apparatus are required:

(a) the apparatus for specimen preparation and measurement described in Clause 13.2.1 or 13.3.1, as appropriate,

(b) the triaxial cell which shall be of dimensions appropriate to the size of the test specimen, and suitable for use with de-aired tap water at the internal working pressures required to perform the test. A gas shall also not be used for pressurising the cell. Alternatively, a cell which is normally used for triaxial compression tests (Test Method 15.2) may be used, provided that the loading piston can be locked and rigidly restrained from movements. The main features of the triaxial cell are shown diagrammatically in Figure 14.4, and shall be as follows:

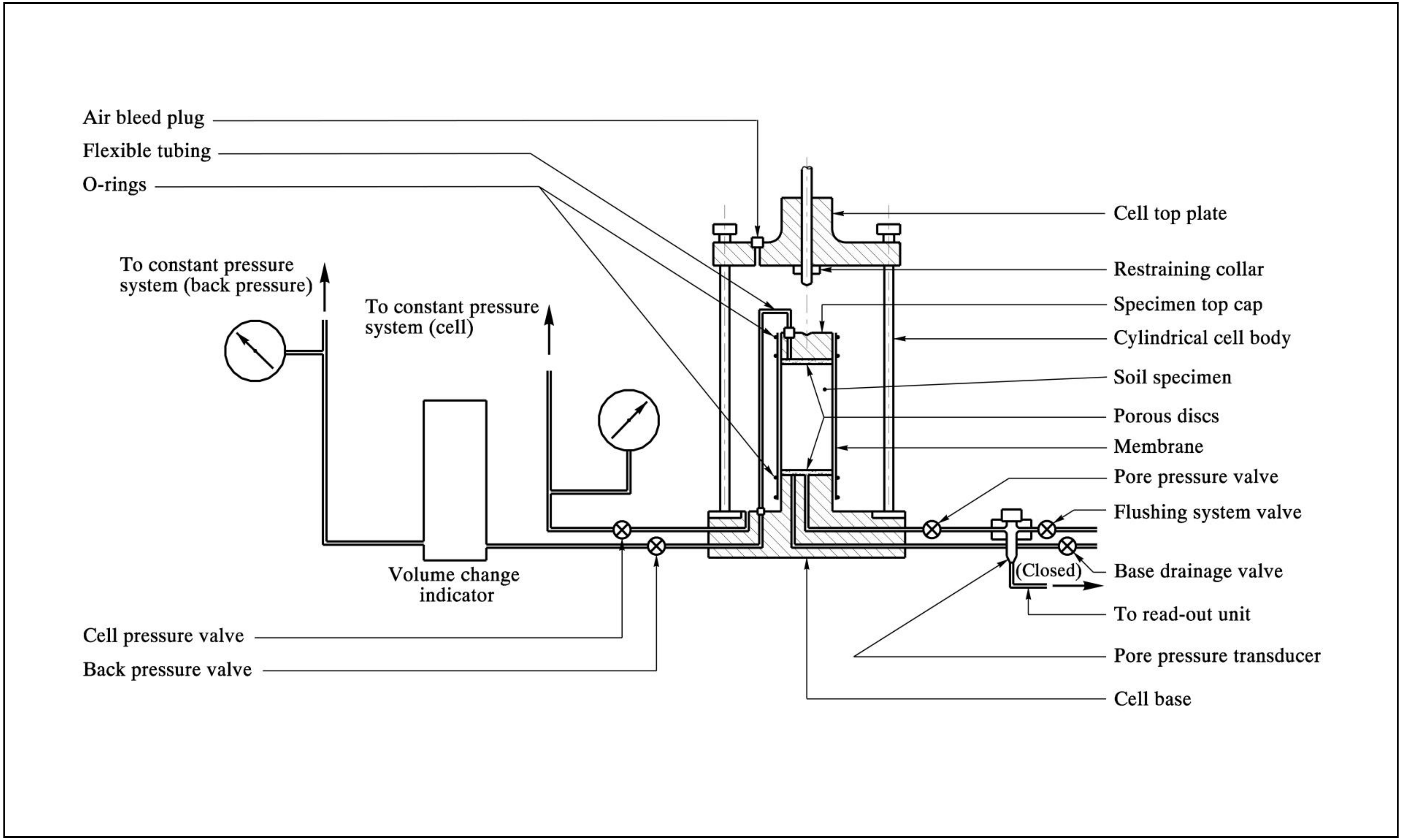


Figure 14.4 Arrangement of Cell and Equipment for Triaxial Consolidation Test

Note: De-aired tap water shall be used as the cell fluid. Distilled or de-ionised water shall not be used because of their corrosive effects on certain types of seals.

- a corrosion-resistant cell top plate fitted with an air bleed plug,

- a cylindrical cell body which shall be removable for inserting the specimen, and adequately sealed to the top plate and base plate. The cylindrical cell body shall not be used at pressures exceeding its design working pressure,

  Note: The cylinder is normally made of a transparent material, or fitted with viewing ports, so that the specimen can be observed during the test.

- a cell base which shall be of corrosion-resistant rigid material, incorporating connection ports as shown in Figure 14.4:

  (1) The base pedestal shall have a plane horizontal circular surface of a diameter equal to that of the specimen with a tolerance of ± 3 mm on radius. The cylindrical sides shall be smooth and free from scratches. Each connecting port shall be fitted with a valve, or a blanking plug if a valve is not required for the test.

  (2) The ports which shall be connected as follows:
    - from the base pedestal to the pore pressure measuring device (designated as the pore pressure valve),
    - from the top cap drainage line to the back pressure system (designated as the back pressure valve),
    - from the cell chamber to the cell pressurising system (designated as the cell pressure valve),
    - a second connection from the base pedestal (designated as the base drainage valve), and
    - from the pore pressure measuring device mounting block to the flushing system (designated as the flushing system valve).

(c) a corrosion-resistant specimen top cap which shall be of light weight, impermeable and sufficiently rigid so that its deformation under load is negligible compared with that of the specimen. A drainage hole shall be formed through the cap and connected to the back pressure inlet in the cell base by a length of flexible tubing of not more than 2.5 mm internal diameter. The tubing shall be impermeable to water and shall have an expansion coefficient of not exceeding 0.001 mL/m length when subjected to a pressure increase of 1 kPa. The cylindrical surface of the cap shall be smooth and free from scratches,

(d) pressure systems and ancillary apparatus as specified for the consolidated undrained triaxial compression test (see Test Method 15.2), and

(e) the following accessories as specified for Test Method 15.2:

- tubular membranes,
- rubber o-rings,
- membrane stretcher,
- o-ring stretcher, and
- rigid porous discs.

14.2.4 Calibration

The calibration of apparatus shall follow Clause 15.2.4 as for triaxial compression tests (Test Method 15.2).

14.2.5 Sample Preparation

The sample preparation shall follow Clause 15.2.5 as for triaxial compression tests (Test Method 15.2).

14.2.6 Test Procedures

14.2.6.1 Mount the test specimen as follows:

(i) Follow Test Method 15.2 Clause 15.2.6.1 (i), Method (A) or Method (B), as appropriate.

(ii) Follow Test Method 15.2 Clauses 15.2.6.1 (ii) to (v).

(iii) Assemble the cell body with the loading piston (if present) well clear of the top cap.

(iv) Fill the triaxial cell with de-aired tap water, ensuring that all the air is displaced through the air bleed plug (see Figure 14.4). Fill the cell as quickly as possible with no turbulence. A layer of castor oil may be introduced on top of the water to act as a lubricant for the piston and to reduce leakage around it.

(v) Keep the air bleed plug open until the cell is to be pressurised.

14.2.6.2 Saturate the specimen as described in Clause 15.2.6.2 for Test 15.2.

14.2.6.3 After completion of the saturation stage, close the back pressure valve and record the pore pressure and volume-change indicator readings.

14.2.6.4 Carry out isotropic consolidation as follows:

(i) Increase the pressure, σ_3 in the cell pressure line with the cell pressure valve closed, and maintain the pressure in the back pressure line, u_b, to give a difference equal to the required effective consolidation pressure, σ_3', such that $\sigma_3' = \sigma_3 - u_b$.

(ii) Open the cell pressure valve to admit the pressure to the cell, and observe the pore pressure until a steady value (u_i) is reached. Record and plot readings of pore pressure against time to establish when a steady value is reached.

(iii) Record the reading of the volume-change indicator. At a convenient moment (zero time), start the consolidation stage by opening the back pressure valve.

(iv) Record and plot pore pressure and volume-change indicator readings at suitable intervals of time.

Note: Suggested intervals for plotting the pore pressures (against log time) are 0, ¼, ½, 1, 2, 4, 8, 15, 30, 60 min and for plotting the volume changes (against square-root time) are 0, ¼, ½, 1, 2¼, 4, 9, 12¼, 16, 25, 36, 64 min. In both cases, additional readings at 2, 4, 8, 16, 24 h may also have to be taken. Additional 24 h interval may be needed if the consolidation is very slow or if the secondary compression is to be measured.

(v) Allow the consolidation to continue until the volume change indicator reading reaches a steady value and at least 95% of the excess pore pressure has been dissipated, i.e. U (as defined below) ≥ 95%.

$$U = \left(\frac{u_i - u}{u_i - u_b} \right) 100$$

where u is the pore pressure reading at a given time t; and
U is the degree of consolidation (in %).

(vi) Record the reading of the volume-change indicator. Calculate the volume of water expelled from the soil specimen during the consolidation stage or taken in by the soil specimen during the swelling stage. Close the back pressure valve. Record the pore pressure u_f.

(vii) Repeat Steps (i) to (vi) for each subsequent effective consolidation pressure.

14.2.6.5 If the swelling characteristics of the soil specimen are required by the Specifiers, unload the specimen as follows:

(i) Reduce the cell confining pressure in a series of decrements and record readings of volume change and pore pressure for each stage in a manner similar to the above consolidation procedure.

(ii) Swelling is considered complete if the volume change indicator reading reaches a steady value and U_s (as defined below) is equal to or greater than 95%.

$$U_s = \left(\frac{u - u_i}{u_b - u_i} \right) 100$$

14.2.6.6 When the final consolidation or swelling stage is completed, dismantle the testing assembly as follows:

(i) Close the back pressure valve and the pore pressure valve.

(ii) Reduce the cell pressure to zero and drain the cell.

(iii) Dismantle the cell, and quickly remove the top cap, rubber membrane and porous discs so that the absorption of water from the porous discs is kept to a minimum.

14.2.6.7 Process the tested specimen in accordance with Test Method 15.2 (see Clause 15.2.6.8).

14.2.7 Calculations

14.2.7.1 Calculate the initial and final moisture content of the specimen, w_0 and w_f (to 0.1%), using the equations in Clause 14.1.7.1 as for Test Method 14.1.

14.2.7.2 Calculate the initial and final bulk density, ρ_0 and ρ_f (to 0.01 Mg/m^3), of the specimen from the following equations:

$$\rho_0 = \frac{1000\ m_0}{A_0 H_0}\ ; \qquad \rho_f = \frac{1000\ m_f}{A_0 H_0 - 1000\ \Sigma\delta V}$$

where m_0 is the initial wet mass of the specimen (in g);
m_f is the final wet mass of the specimen (in g);
A_0 is the initial cross-sectional area of the specimen (in mm^2);
H_0 is the initial height of the specimen (in mm); and
$\Sigma\delta V$ is the cumulative volume of water expelled from or taken in by the soil specimen from the start of the first consolidation stage up to the end of all consolidation/swelling stages (in cm^3) (negative value for water taken in).

14.2.7.3 Calculate the moisture content of the specimen after saturation, w_{sat} (to 0.1%), from the following equation:

$$w_{sat} = w_0 + \frac{100\ \rho_w \delta V_{sat}}{m_{df}}$$

where ρ_w is the density of water = 1.0 Mg/m^3; and
δV_{sat} is the total volume of water taken in by the specimen during the saturation stage (in cm^3).

14.2.7.4 Calculate the bulk density of the specimen after saturation, ρ_{sat} (in 0.01 Mg/m^3), from the following equation:

$$\rho_{sat} = \frac{1000\ (m_0 + \rho_w \delta V_{sat})}{A_0 H_0}$$

where A_0 is the initial cross-sectional area of the specimen (in mm^2); and
H_0 is the initial height of the specimen (in mm).

14.2.7.5 Calculate the moisture content and bulk density of the specimen at the end of each consolidation/swelling stage, from the following equations:

$$w = w_{sat} - \frac{100\ \rho_w \Sigma\delta V}{m_{df}}$$

$$\rho = \frac{1000\ (m_0 + \rho_w \delta V_{sat} - \rho_w \Sigma\delta V)}{A_0 H_0 - 1000\ \Sigma\delta V}$$

where $\Sigma\delta V$ is the cumulative volume of water expelled from or taken in by the soil specimen from the start of the first consolidation stage up to the consolidation/swelling stage under consideration (in cm^3) (negative value for water taken in).

14.2.7.6 Calculate the dry density, ρ_d (to 0.01 Mg/m^3), void ratio, e (to 0.01), and degree of saturation, S_r (to 0.1%), of the specimen at each of the stages, including the initial and final stages, from the equations given in the Glossary.

14.2.7.7 For each undrained phase, evaluate the degree of saturation of the specimen by calculating the value of the pore pressure coefficient B from the following equation:

$$B = \frac{\delta u}{\delta \sigma_3}$$

where δu is the change in pore pressure; and
$\delta \sigma_3$ is the change in cell pressure.

Plot the calculated value of coefficient B against cell pressure.

14.2.7.8 Determine the consolidation characteristics of the specimen as follows:

(i) Plot the pore pressure at the end of each undrained phase and each drained phase against cell pressure.

(ii) For each drained phase, plot pore pressure dissipation, U (in %), against time to a logarithmic scale. From this plot, read off the time t_{50} (in minutes) corresponding to 50% pore pressure dissipation (see Figure 14.5).

(iii) Also for each drained phase, plot change in volume (δV) against square-root time as shown in Figure 14.6. From this plot, determine t_{100} (in min) in accordance with Clause 15.2.7.1 (v).

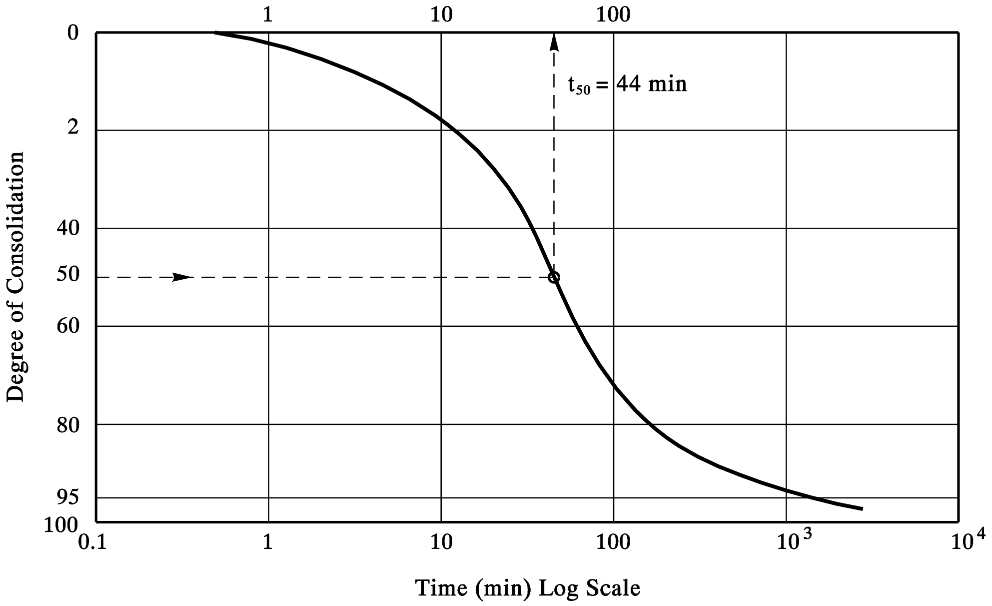


Figure 14.5 Derivation of t50 from the Plot of Pore Pressure Dissipation Against Log Time

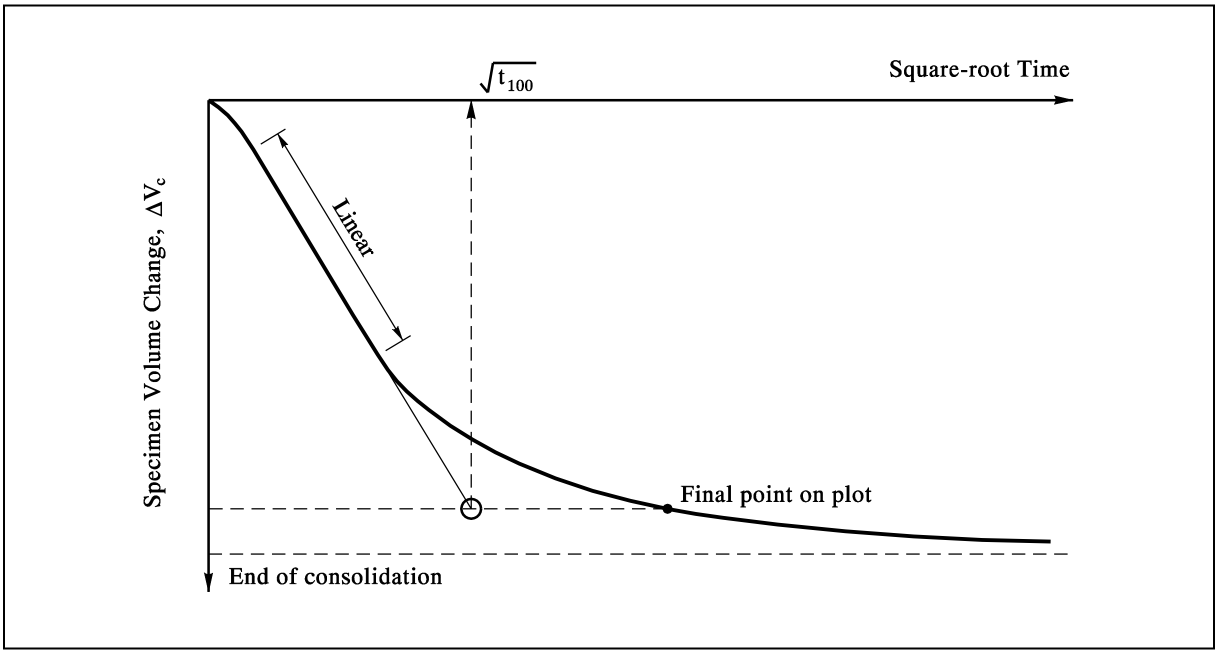


Figure 14.6 Idealised Triaxial Consolidation Curve

(iv) Calculate the height of specimen H (in mm) and area A (in mm^2) at the end of each consolidation stage from the following equations:

$$H = H_0 \left(1 - \frac{\Sigma\delta V}{V_0}\right)^{1/3}$$

$$A = A_0 \left(1 - \frac{\Sigma\delta V}{V_0}\right)^{2/3}$$

where H_0 is the initial height of the soil specimen immediately after saturation (assumed to be equal to the initial height before saturation) (in mm);

A_0 is the initial cross-sectional area of the specimen (in mm^2);

V_0 is the initial volume of the soil specimen (in cm^3); and

$\Sigma\delta V$ is the cumulative volume of water expelled from the soil specimen from the start of the first consolidation stage up to the end of the consolidation stage under consideration (in cm^3).

(v) Calculate the coefficient of volume compressibility for isotropic consolidation, m_{vi} (to 0.01 m^2/MN), for each consolidation stage from the following equation:

$$m_{vi} = \left(\frac{\Sigma\delta V_2 - \Sigma\delta V_1}{V_0 - \Sigma\delta V_1} \right) \left(\frac{1000}{p_2' - p_1'} \right)$$

where $\Sigma\delta V_1$ is the cumulative volume of water expelled from the soil specimen from the start of the first consolidation stage up to the end of the previous consolidation stage (in cm^3);

$\Sigma\delta V_2$ is the cumulative volume of water expelled from the soil specimen from the start of the first consolidation stage up to the end of the consolidation stage under consideration (in cm^3);

V_0 is the initial volume of the soil specimen (in cm^3);

p_1' is the initial effective pressure or the effective pressure applied to the soil specimen for the previous consolidation stage (in kPa); and

p_2' is the effective pressure applied to the soil specimen for the consolidation stage under consideration (in kPa).

Note: For the first consolidation stage, $\Sigma\delta V_1$ and p_1' in the above equation shall become zero.

(vi) Calculate the value of the coefficient of consolidation for isotropic consolidation, c_{vi} (in 0.1 m^2/year), for each consolidation stage from the following equation, based on the pore pressure dissipation against log time plot in (ii) above:

$$c_{vi} = \frac{0.2\,\overline{H}^2}{t_{50}} \quad \text{and} \quad \overline{H} = \frac{H_1 + H_2}{2} \text{ (in mm)};$$

where $\overline{H}$ is the average height of the soil specimen during the stage;

t_{50} is determined from the plot in (ii) above (in min);

H_1 is the height of the soil specimen at the beginning of the consolidation stage (in mm); and

H_2 is the height of the soil specimen at the end of the consolidation stage (in mm).

(vii) Calculate the value of the coefficient of consolidation for isotropic consolidation, c_{vi} (to 0.1 m^2/year), from the following equation, based on the volume change against square-root time plot in (iii) above:

$$c_{vi} = \frac{1.65\,\overline{D}^2}{\lambda t_{100}} \quad \text{and} \quad \overline{D} = \frac{D_1 + D_2}{2} \text{ (in mm)};$$

where t_{100} is determined from the plot in Clause 14.2.7.8 (iii);

$\overline{D}$ is the average diameter of the soil specimen (in mm) during the consolidation stage;

D_1 is the diameter of the soil specimen at the beginning of the consolidation stage (in mm);

D_2 is the diameter of the soil specimen at the end of the consolidation stage (in mm); and

λ is a coefficient which depends on the drainage conditions and the length to diameter ratio (r) of the soil specimen as shown in Table 14.1.

Note: D_1 and D_2 are to be calculated from the equation $D = \sqrt{(4A/\pi)}$, where A is calculated in (iv) above.

(viii) Plot the calculated values of void ratio and volumetric strain of the soil specimen against effective pressure to a logarithmic scale (i.e. plot e against log p' and $\Sigma\delta V/V_0$ against log p').

Table 14.1 Factors for Calculating c_v and Time to Failure

Drainage Conditions during Consolidation	**Values of λ**		**Values of F (for r = 2)**	
	L/D = 2	**L/D = r**	**Drained Test**	**Undrained Test**
From one end	1	$r^2/4$	8.5	0.53
From both ends	4	r^2	8.5	2.1
From radial boundary and one end	80	$3.2\ (1 + 2r)^2$	14	1.8
From radial boundary and two ends	100	$4\ (1 + 2r)^2$	16	2.3

14.2.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

Note: Refer to Note to Clause 14.1.8 as for Test Method 14.1.

(a) the general information as required in B.1.1 of Appendix B,

(b) the information as required in B.1.2 of Appendix B for Phase II tests,

(c) the initial dimensions (viz. diameter and height) of the specimen,

(d) the initial moisture content, bulk density and dry density (state the test method used for moisture content determinations; if the minimum mass requirement for carrying out the moisture content tests cannot be followed, this shall be stated),

(e) the initial void ratio and degree of saturation of the specimen,

(f) the cell pressure, back pressure and a plot of the pore pressure coefficient B against cell pressure at each stage of saturation,

(g) the volume of water taken into the soil specimen during saturation,

(h) the moisture content, bulk density, dry density, void ratio and degree of saturation of the test specimen at the end of saturation,

(i) the data for each consolidation stage comprising:

- cell pressure and back pressure,
- effective stress at the start and termination of each stage,
- pore pressure increase and B value calculated for each undrained loading phase,
- moisture content, bulk density, dry density, void ratio and degree of saturation of the specimen at the end of each consolidation phase,
- percentage pore pressure dissipated and volume change of the specimen during each consolidation phase, and
- values of the coefficient of volume compressibility, m_{vi} (in m^2/MN), and of the coefficient of consolidation, c_{vi} (in m^2/year), based on the excess pore pressure against log time plot and the volume change against square-root time plot,

(j) the excess pore pressure dissipation (in %) against log time plot, and the volume change against square-root time plot for each consolidation stage,

(k) the plot of void ratio against log effective stress at the end of each consolidation or swelling stage, and also the plot of volumetric strain against log effective stress at the end of each consolidation or swelling stage, and

(l) the final moisture content, bulk density, dry density, void ratio and degree of saturation of the specimen.

15 Determination of Shear Strength of Soils Using Triaxial Apparatus

15.1 The Unconsolidated Undrained Triaxial Compression Test without Pore Pressure Measurement

15.1.1 Scope

This test, commonly referred to as the UU test, is used for the determination of the undrained shear strength of an undisturbed soil specimen in a triaxial apparatus when subjected to a constant confining pressure and to strain-controlled axial loading with no change in moisture content.

15.1.2 General

The guidance given in Clause 3.11.1 shall be noted.

The environmental requirements as described in Clause 14.1.2 shall be observed.

15.1.3 Apparatus

The following apparatus are required:

(a) the apparatus for specimen preparation and measurement described in Clause 13.3.1 as appropriate,

(b) the triaxial cell which shall be of dimensions appropriate to the size of the test specimen, and suitable for use with de-aired tap water at the internal working pressures required to perform the test. A gas shall also not be used for pressurising the cell. The main features of the triaxial cell are shown diagrammatically in Figure 15.1, and shall consist of a top plate, a cylindrical cell body, a loading piston and a cell base. The cell base shall be of corrosion-resistant and rigid material. The base pedestal shall have a plane horizontal circular surface of a diameter equal to that of the soil specimen with a tolerance of ± 3 mm, on radius,

Note 1: De-aired tap water shall be used as the cell fluid. Distilled or de-ionised water shall not be used because of their corrosive effects on certain types of seals.

Note 2: The top plate, cell body and loading piston shall be as specified in Clause 15.2.3 (b) for Test Method 15.2.

Note 3: See note to Clause 15.2.3 (b) for Test Method 15.2.

(c) end caps, which shall be of rigid corrosion-resistant materials or plastic, and their diameters shall be at least equal to but not 2 mm more than that of the test specimen. A self-aligning seating shall be provided between the top end cap and the loading ram. The end caps shall be impermeable and shall not contain any drainage holes. The surface in contact with the specimen shall be plane and smooth,

(d) a cell pressure system with ancillary apparatus which shall be similar to that specified for the consolidated undrained triaxial compression test (see Test Method 15.2), except that one pressure system for applying and maintaining the desired pressure in the cell is adequate. The cell pressure system shall be subjected to the complete check described in Test Method 15.2,

(e) a compression machine with ancillary apparatus including an axial deformation measuring device and a force-measuring device as specified for Test Method 15.2, and

(f) the following accessories as specified for Test Method 15.2:

- tubular membranes,
- rubber o-rings,
- membrane stretcher,
- o-ring stretcher,
- apparatus for determination of moisture content,

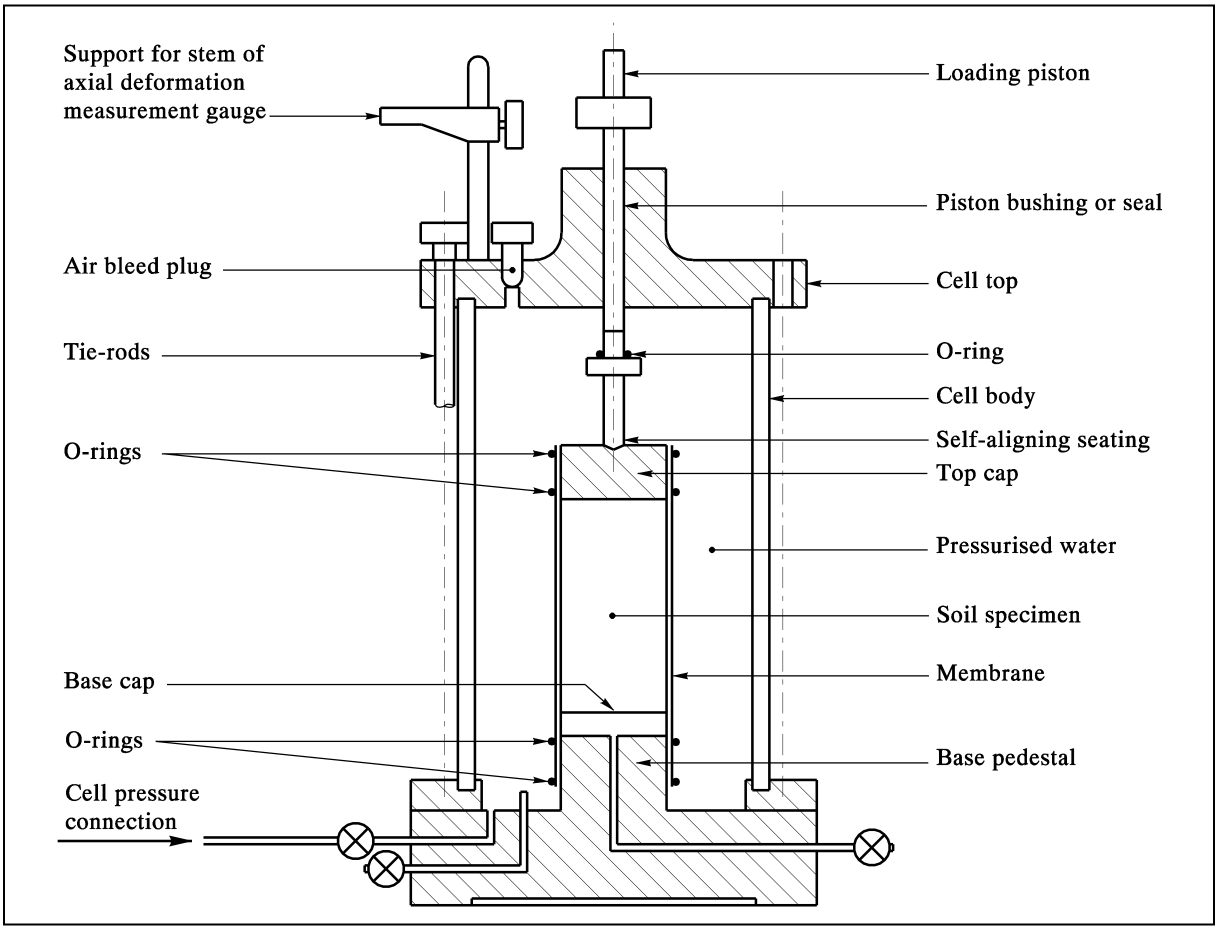


Figure 15.1 Typical Details of a Triaxial Cell for the Unconsolidated Undrained Test

- a calibrated timing device,
- a supply of de-aired tap water,
- silicone grease or petroleum jelly as lubricant, and
- a calibrated maximum and minimum temperature measuring device.

15.1.4 Calibration

The calibration of apparatus shall follow Clause 15.2.4 as for Test Method 15.2.

15.1.5 Sample Preparation

15.1.5.1 Carry out pre-test assessment on the sample received as described in Clause 13.1.

15.1.5.2 Prepare a soil specimen in the form of a right cylinder with a nominal diameter of 70 mm to 110 mm and a height to diameter ratio of 1.9 to 2.1 in accordance with Clause 13.3, taken either from a tube sample as described in Clause 13.3.3 or 13.3.4, or a block sample as stated in Clause 13.3.5, as appropriate.

15.1.5.3 Measure the height, H_0 (to 0.1 mm), diameter, D_0 (to 0.1 mm), and mass, m_0 (to 0.1 g), of the prepared specimen.

15.1.6 Test Procedures

15.1.6.1 Mount the test specimen as follows:

(i) Follow Test Method 15.2 Clause 15.2.6.1 (i) Method (A) or (B) as appropriate, except to omit the top and bottom porous discs and use impermeable end caps.

Note: The bottom end cap may be omitted if the base pedestal is impermeable and does not contain any drainage or pore pressure measurement connection.

(ii) Follow Test Method 15.2 Clauses 15.2.6.1 (ii) to (viii).

15.1.6.2 Pressurise the triaxial cell and make final adjustments as follows:

(i) Raise the water pressure in the cell to the desired value with the loading piston restrained by the load frame or force-measuring device.

(ii) Adjust the loading machine to bring the loading piston to within a few millimetres of its seating on the specimen top cap. Record the reading of the force-measuring device when steady as the initial reading.

(iii) Adjust the machine further to bring the loading piston just into contact with the seating on the top cap. Record the reading of the axial deformation gauge.

(iv) Select a rate of axial deformation such that failure can be reached within a period of 5 min to 15 min. Engage the appropriate gear on the compression machine.

15.1.6.3 Carry out compression test as follows:

(i) Start the shearing by switching on the compression machine.

(ii) Record sufficient sets of readings of the force-measuring device and the axial deformation gauge at intervals during compression so that the stress-strain curve can be clearly defined.

Note: Readings shall normally be taken at regular intervals of axial displacement. The frequency of readings to be taken shall not be less than 5 readings per 1% strain. However, after the maximum deviator stress, if attainable, is reached, the frequency can be reduced to 2 readings per 1% strain. When it is evident during compression that the peak deviator stress is approached, readings may need to be taken more frequently.

(iii) Check the cell pressure periodically to ensure that it remains constant to within 0.5% or ± 2 kPa, whichever is greater. Adjust it if necessary.

(iv) Unless otherwise specified, terminate the test at an axial strain of at least 5% more than that after the peak deviator stress is reached or at an axial strain of at least 20%, whichever occurs first.

15.1.6.4 Unload the specimen and dismantle the test assembly as described in Clause 15.2.6.7 for Test Method 15.2.

15.1.6.5 Measure and process the tested specimen as described in Clause 15.2.6.8 for Test Method 15.2.

15.1.7 Calculations

15.1.7.1 From the set of readings, calculate the axial strain of the test specimen to 0.1% from the following equation:

$$\varepsilon = \left(\frac{\delta H}{H_0}\right)100$$

where H_0 is the initial height of the specimen (in mm); and
δH is the change in height of the specimen during compression (in mm).

Note: Strains are calculated as cumulative strains, i.e. the changes in dimension related to the initial reference dimension.

15.1.7.2 From the set of readings, calculate the axial force P (to 1 N) applied to the soil specimen by multiplying the difference between that reading and the initial reading of the force-measuring device (in divisions or digits) by its calibration factor (in N/division or N/digit).

15.1.7.3 Assuming that the soil specimen deforms as a right cylinder, calculate its cross-sectional area, A (to 0.1 mm^2), from the following equation:

$$A = \left(\frac{A_0}{100 - \varepsilon}\right)100$$

where A_0 is the initial cross-sectional area of the soil specimen (which equals $\pi D_0^2/4$, in mm^2) calculated from the initial diameter D_0; and

ε is the axial strain (in %).

15.1.7.4 Calculate the measured principal stress difference, i.e. the deviator stress, $(\sigma_1 - \sigma_3)_m$ (to 0.1 kPa), for sufficient sets of readings to enable the maximum value to be derived, from the following equation:

$$(\sigma_1 - \sigma_3)_m = \left(\frac{P}{A}\right)1000$$

15.1.7.5 Apply a correction to the calculated deviator stresses to allow for the restraining effect of the membrane, if appropriate. The correction, σ_{mb}, shall be obtained directly from Figure 15.2, at the strain corresponding to failure, for soil specimens of diameter 38 mm fitted within a membrane of latex rubber 0.2 mm thick when a predominantly barrelling type of deformation occurs. For soil specimens of any diameter, D (in mm), and latex rubber membranes of any other thickness, t (in mm) (which may be made up of more than one membrane), the membrane correction, σ_{mb}, shall be determined by multiplying the correction derived from Figure 15.2 by a factor equal to:

$$\left(\frac{38}{D}\right)\left(\frac{t}{0.2}\right)$$

15.1.7.6 Subtract the membrane correction, σ_{mb}, from the measured deviator stresses $(\sigma_1 - \sigma_3)_m$, to give the corrected deviator stresses, denoted by $(\sigma_1 - \sigma_3)$.

15.1.7.7 Plot a graph of corrected deviator stress against axial strain. Obtain the maximum value of corrected deviator stress, $(\sigma_1 - \sigma_3)_{max}$.

15.1.7.8 Calculate the value of the undrained shear strength, s_u (to 0.1 kPa), of the specimen from the following equation:

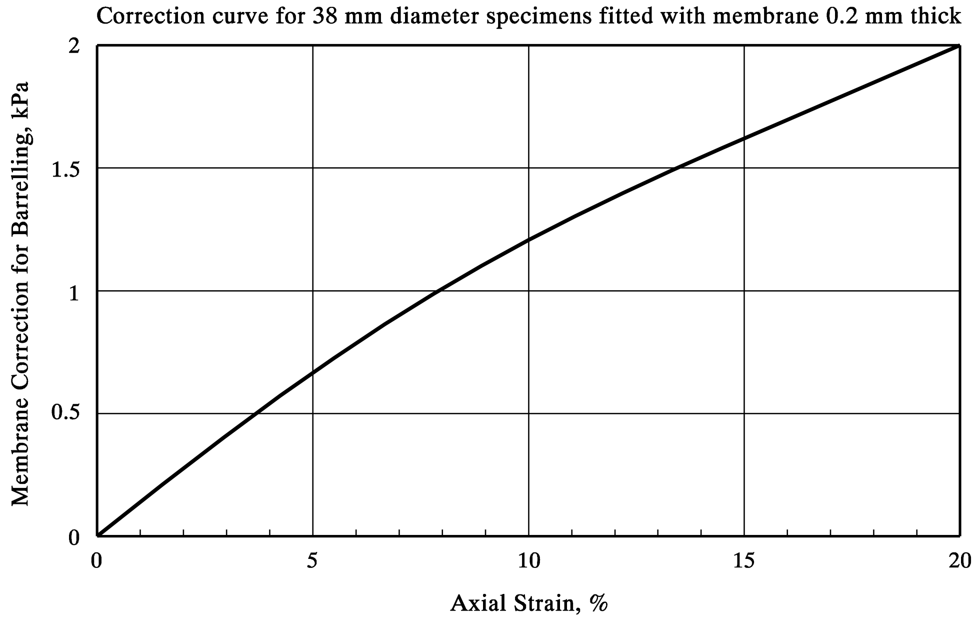
$$s_u = \frac{1}{2}\left(\sigma_1 - \sigma_3\right)_{max}$$

15.1.7.9 Calculate the bulk density, ρ (to 0.01 Mg/m^3), and moisture content, w (to 0.1%) of the specimen from the following equations:

$$\rho = \frac{1000\ m_0}{A_0 L_0}\ ; \qquad w = \frac{100\ (m_0 - m_d)}{m_d}$$

where m_0 is the initial wet mass of the specimen (in g); and
m_d is the final dry mass of the specimen (in g).

15.1.7.10 Calculate the dry density, ρ_d (to 0.01 Mg/m^3), void ratio, e (to 0.01), and degree of saturation, S_r (to 0.1%), of the specimen from the equations given in the Glossary.



Note: The correction curve can be represented approximately by the equation:
$\sigma_{mb} = 0.000088\varepsilon_1^3 - 0.00465\varepsilon_1^2 + 0.15722\varepsilon_1$

Figure 15.2 Membrane Correction Graph

15.1.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

Note: Any values which are required to be reported as indicated below shall be expressed with the same number of significant figures as the recorded values.

(a) the general information as required in B.1.1 of Appendix B,

(b) the information as required in B.1.2 of Appendix B for Phase II tests,

(c) the initial dimensions (viz. diameter and height) of the specimen,

(d) the moisture content, bulk density and dry density (state the temperature used for drying the specimen for moisture content determinations; if the minimum mass requirement for carrying out the moisture content tests cannot be followed, this shall be stated),

(e) the void ratio and degree of saturation of the specimen,

(f) the rate of strain (in %/min or mm/min) applied during the test,

(g) the thickness and type of membrane used, and correction applied,

(h) the plot of corrected deviator stress $(\sigma_1 - \sigma_3)$ against axial strain ε, and

(i) data relating to the soil specimen at failure, comprising:

- cell pressure, σ_3 (in kPa),
- corrected maximum deviator stress at failure, $(\sigma_1 - \sigma_3)_{max}$ (in kPa),
- strain at failure (in %), and
- value of $s_u = \frac{1}{2}(\sigma_1 - \sigma_3)_{max}$ (in kPa).

15.2 The Isotropically Consolidated Undrained Triaxial Compression Test with Pore Pressure Measurement

15.2.1 Scope

This test, commonly referred to as the CU test, is used for the determination of the shear strength of a soil specimen using the triaxial apparatus. The specimen, which has been saturated and subjected to an isotropic consolidation, is then sheared in compression, under a constant confining pressure, by increasing the axial strain. No drainage of pore water from the soil specimen is permitted. An option to perform the test in multi-stage is included in the test procedure.

The standard procedures described relate to strain-controlled apparatus for compression in a mechanical load frame, and a detachable triaxial cell.

15.2.2 General

The guidance given in Clause 3.11.2 shall be noted.

The environmental requirements as described in Clause 14.1.2 shall be observed.

The test is carried out in three stages: saturation, isotropic consolidation and undrained shearing by axial compression.

The objective of saturation is to ensure that all voids between the soil particles in the specimen are filled with water. This is often achieved by raising the pore pressure in the soil specimen to a level high enough for the air originally present in the voids to dissolve in the water. The pore pressure can be increased by applying water pressure (the back pressure) to the soil specimen, and at the same time increasing the cell pressure in order to maintain a small positive effective stress. The procedures are described in Clause 15.2.6.2.

The objective of consolidation is to bring the specimen to the desired state of effective stress for the compression test. Data obtained from the consolidation stage are used for estimating a suitable rate of strain to be applied during compression, for determining when consolidation is complete, and for computing the dimensions of the specimen at the start of the compression stage. The procedures are described in Clause 15.2.6.3.

During the compression stage, the cell pressure is maintained constant while the soil specimen is sheared at a constant rate of axial deformation (strain-controlled compression). No drainage is permitted and therefore the moisture content of the specimen remains constant during compression. The resulting changes in pore pressure are usually measured at the base of the specimen, and the rate of axial deformation is applied sufficiently slowly to ensure adequate equalisation of excess pore pressures within the specimen.

For multi-stage triaxial test, consolidation and shearing are repeated twice after the first stage shearing is completed, each with a preceding unloading stage.

The apparatus used for triaxial tests shall be subjected to rigorous inspection and checking before use. The checks described in Clause 15.2.4 shall be carried out on the cell pressure, back pressure and pore pressure systems at the stated frequencies. Checks on these systems can be classified into two types: complete and routine. Routine checks shall be carried out, for back and pore pressure systems only, immediately before each test. Complete checks shall be carried out for cell, back and pore pressure systems:

(a) when any item of new equipment is introduced into the system;

(b) if an integral part of the system has been removed, stripped down, overhauled or repaired; and

(c) at intervals not exceeding 3 months.

Before checking, the pressure systems and connecting lines shall be filled with de-aired tap water.

15.2.3 Apparatus

The following apparatus are required:

(a) the apparatus for specimen preparation and measurement described in Clause 13.2.1 or 13.3.1 as appropriate,

(b) the triaxial cell which shall be of dimensions appropriate to the size of the test specimen, and suitable for use with de-aired tap water at the internal working pressures required to perform the test. A gas shall also not be used for pressurising the cell. The main features of the triaxial cell are shown diagrammatically in Figure 15.3, and shall be as follows:

Note : De-aired tap water shall be used as the cell fluid. Distilled or de-ionised water shall not be used because of their corrosive effects on certain types of seals.

- a corrosion-resistant cell top plate fitted with an air bleed plug and close-fitting piston guide bushing,

- a cylindrical cell body which shall be removable for inserting the soil specimen, and adequately sealed to the top plate and base plate. It shall not be used at pressures exceeding its design working pressure,

  Note: The cylinder is normally made of a transparent material, or fitted with viewing ports, so that the specimen can be observed during the test.

- a loading piston, which shall be suitable for applying an axial compressive force to the specimen. The piston shall not bend laterally during a test. Friction between the piston or seal and its bushing shall be small enough to allow the piston to slide freely under its own weight when the cell is empty. The clearance between the piston and its bushing or seal shall have to minimise leakage from the cell,

Note: The piston should be perfectly clean and lightly oiled. Introducing a layer of castor oil into the cell to cover the cell fluid can reduce friction in the bushing, and leakage of the cell fluid passing the piston.

- a cell base, which shall be of corrosion-resistant rigid material, incorporating connection ports as shown in Figure 15.3:

  (1) The base pedestal shall have a plane horizontal circular surface of a diameter equal to that of the specimen with a tolerance of ± 3 mm on radius. The cylindrical sides shall be smooth and free from scratches. Each connecting port shall be fitted with a valve, or a blanking plug if a valve is not required for the test.

  (2) Connection ports, each shall be fitted with a valve, or a blanking plug if the valve is not required for the test, and shall be connected as follows:
    – from the base pedestal to the pore pressure measuring device (designated as the pore pressure valve),
    – from the top cap drainage line to the back pressure system (designated as the back pressure valve),
    – from the cell chamber to the cell pressurising system (designated as the cell pressure valve),
    – a second connection from the base pedestal (designated as the base drainage valve), and

    Note: A cell fitted with two base pedestal valves is preferred for effective stress triaxial tests. A cell with a single base pedestal valve can be used but this will require some amendments to the procedure. If this type of cell is used, the laboratory should have appropriate documented procedures and the fact should be reported.

    – from the pore pressure measuring device mounting block to the flushing system (designated as the flushing system valve).

- side drains, where specified, shall be of Whatman No. 54 filter paper or equivalent, and shall cover no more than 50% of the curved surface of the specimen evenly. They shall overlap the top porous disc but leave a gap of about 10 mm above the bottom porous disc. After cutting to the required size and shape, they shall be soaked in de-aired tap water before use.

(c) a corrosion-resistant specimen top cap which shall be of light weight, impermeable and sufficiently rigid so that its deformation under load is negligible compared with that of the soil specimen. A drainage hole shall be formed through the cap and connected to the back pressure inlet in the cell base by a length of flexible tubing of not more than 2.5 mm internal diameter. The tubing shall be impermeable to water and shall have an expansion coefficient due to internal pressure not exceeding 0.001 mL/m length for every 1 kPa increase in pressure. The cylindrical surface of the cap shall be smooth and free from scratches. A self-aligning seating shall be provided between the loading piston and the top cap,

Note: A central conical recess with a half-angle of 60° to accommodate a steel ball or the hemispherical end of the piston has been found to be satisfactory.

(d) pressure systems with ancillary apparatus specified as follows (a typical arrangement is shown in Figure 15.4):

- a cell pressure system and a back pressure system which shall be capable of applying and maintaining the desired pressure independently in the cell and in the specimen drainage line respectively. They shall be capable of maintaining the greatest pressure constant to the limitation of the systems to within ± 0.5% of the pressure measured using a calibrated pore water pressure measuring device as described below. If air-water systems are used, a diaphragm of, for example, butyl rubber shall be used to separate the air from the water,

  Note: Pressure systems based on air pressure regulators, dead-weight pressure cells and oil pressure regulators have been successfully used. They should be able to compensate for any cell leakage or drainage to or from the soil specimen.

- a calibrated electrical pressure transducer, or a calibrated pressure gauge of test grade to be used for independent measurements of cell pressure and back pressure. The transducer or pressure gauge shall be readable to 1 kPa and accurate to 2 kPa or 1% of the measured value, whichever is greater, over the working range. They shall be connected to the two pressure systems by means of a suitable valve or valves. Alternatively, two independent gauges may be used, each permanently connected to its own pressure system. The level of the pressure gauge relative to a datum level (usually the mid-height of the test specimen) shall be taken into account,

  Note: For measurement of pressures below 200 kPa and measurement of differential pressures less than 50 kPa, only calibrated pressure transducer should be used.

- a calibrated pore water pressure measuring device, consisting of an electric pressure transducer. The device shall be readable to 1 kPa and accurate to 2 kPa or 1% of the measured value, whichever is greater and mounted in a de-airing block fitted with an air bleed plug. One side of the block shall be fitted to the pore pressure valve on the cell base and the other side to the flushing system valve,

- a calibrated volume change indicator (burette or transducer type), which shall be connected to the back pressure line. It shall be readable to 0.1 mL and accurate to 0.3 mL or 1% of the measured value, whichever is greater,

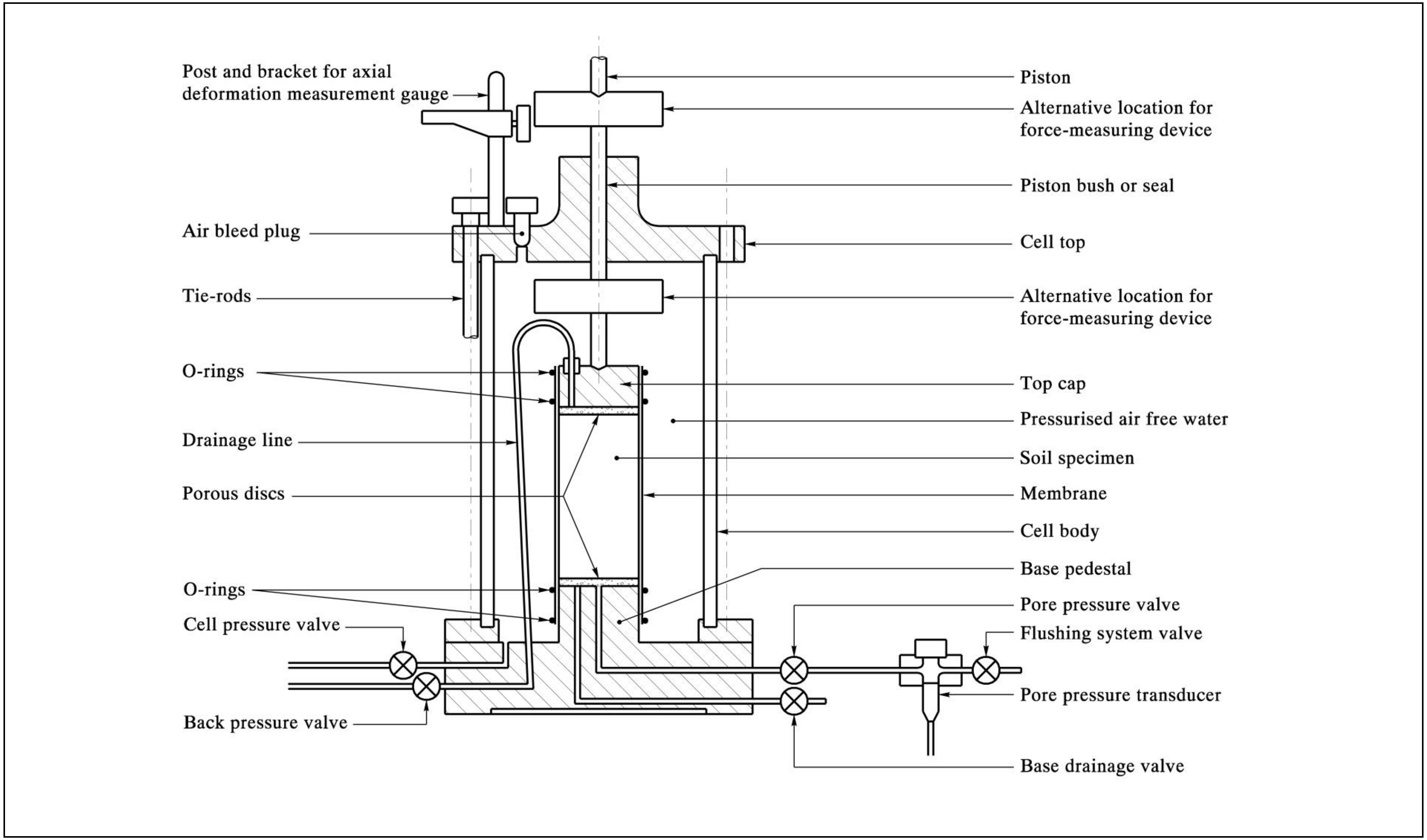


Figure 15.3 Essential Features of a Typical Triaxial Cell for the Consolidated Drained/Undrained Test

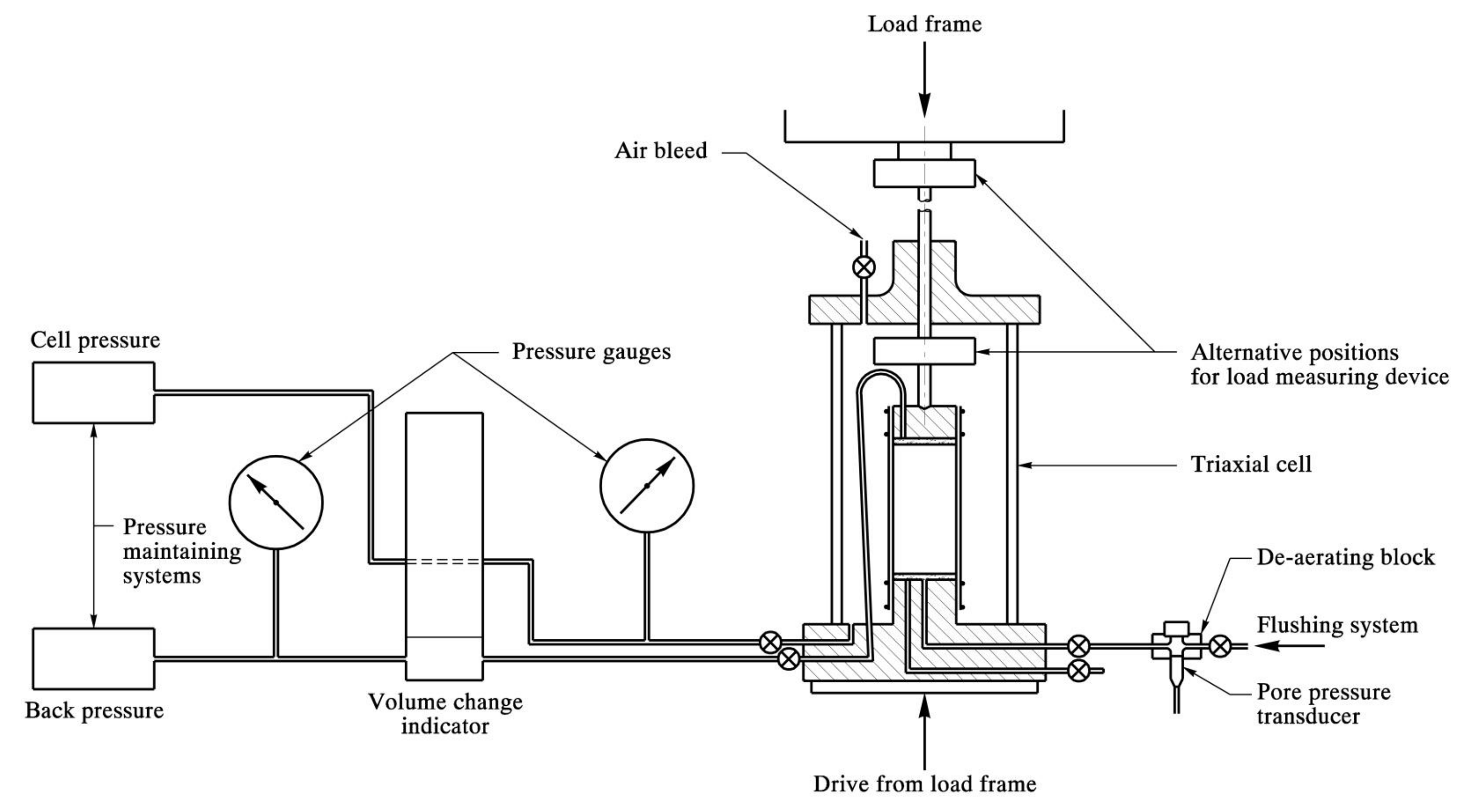


Figure 15.4 Typical General Arrangement of a Triaxial Test Apparatus for the Consolidated Drained/Undrained Test

- suitable tubing, as specified in (c) above, to be used for connecting the components of each pressure system to the cell, and

- on-off valves which shall be capable of withstanding the maximum working pressure without leakage. They shall produce negligible pressure change and volume displacement during operation.

(e) a compression machine with ancillary apparatus specified as follows:

- a calibrated machine which shall be capable of applying an axial deformation to the soil specimen at a range of speeds suitable for the tests, and providing smoothly an axial deformation upto about one-third the height of the soil specimen,

- a calibrated axial deformation measuring device which shall be readable to 0.01 mm and accurate to 0.02 mm and with a range of not less than about one-third of the length of the soil specimen. It may consist of a calibrated dial gauge or displacement transducer, and

- a calibrated force-measuring device which shall be of suitable capacity, readable to 0.005 kN and accurate to 0.01 kN or 2% of the measured value, whichever is greater. An externally-mounted device shall be supported by the cross-head of the compression machine so as to prevent its own weight being transferred to the test specimen. If the force-measuring device is mounted inside the triaxial cell, allowance shall be made for its compressibility when determining the axial deformation of the soil specimen.

  Note: The force measuring device can be a proving ring (coupled with a dial gauge, a LVDT or a digimatic gauge), a load transducer, or a submersible load transducer mounted inside the triaxial cell. A range of calibrated force measuring devices should be available so that the one most appropriate for the test is selected.

(f) the following accessories as specified:

- tubular membranes of high-density latex or similar impermeable material, to be used for enclosing the soil specimen and for providing protection against leakage from the cell fluid. The unstretched internal diameter of the membranes shall not be less than 90% of the diameter of the soil specimen nor greater than the diameter of the soil specimen. The length shall be about 50 mm greater than the length of the specimen. The thickness of the membrane (or the total thickness of the membranes, if more than one membrane are used) shall not exceed 1% of the diameter of the soil specimen. Before use, the membrane shall be soaked in de-aired tap water overnight and checked visually for imperfections. Faulty membranes shall be discarded,

  Note: Membranes of natural latex rubber are generally used. Two or more membranes should be fitted where there is a danger of puncturing by angular particles, or for tests of long duration. Excess surface water should be removed from the membrane after soaking to avoid having parts of it stuck together when being fit over a soil specimen.

- two rubber O-rings, to be used for sealing each end of the membrane onto the top cap and base pedestal. The unstretched diameter of the O-rings shall be between 80% and 90% of the diameter of the soil specimen. They shall be free from flaws and necking when stretched,
- a membrane stretcher, which shall fit the size of the soil specimen,
- an O-ring stretcher shall be in the form of an openable cylindrical ring to allow for the presence of the top drainage lead when placing the O-rings onto the base pedestal and top cap,
- rigid porous discs, to be placed between the specimen ends and the top cap and base. The diameter of the discs shall be at least equal to but not 2 mm more than that of the soil specimen, and their surfaces shall be plane and smooth. Their permeability shall be at least one order of magnitude greater than the estimated permeability of the soil specimen, and they shall withstand the maximum vertical pressure (cell pressure plus applied axial load) likely to be imposed. The discs shall be checked before each use to ensure that they are not clogged by soil particles. They shall be boiled for at least 10 min in distilled water before use and kept immersed in de-aired tap water until required,

  Note: For an estimated permeability of a soil specimen, Table 8 of Geoguide 1 (GEO, 1993), which gives typical ranges of geotechnical parameters including permeability for selected Hong Kong soils other than marine clay, may be referred to. For marine clay, the typical range of permeability is 10^{-10}-10^{-11} m/s.

- the apparatus for determination of moisture content, in accordance with Clause 5,
- a calibrated timing device readable to 1 s and accurate to 1 s in 5 min,
- a supply of de-aired tap water,
- silicone grease or petroleum jelly shall be used as lubricant, and
- a calibrated maximum and minimum temperature measuring device readable to 0.5°C and accurate to 1°C.

15.2.4 Calibration

15.2.4.1 Complete check on the cell pressure system shall be carried out as follows:

(i) Carry out a pressure test of the cell pressure system and the triaxial cell to ensure that the maximum cell pressure required for the tests can be maintained for at least 1 hour within the limits of ± 0.5% of the reading indicated at all times during the check.

Note: Longer period of check is necessary if periodic checking of the cell pressure during compression will not be performed (see Note 2 to Clause 15.2.6.5 (v)).

(ii) If the check is passed, affix a label onto the cell indicating the date of the check and the maximum test pressure. The cell shall not be subjected to pressure greater than the maximum test pressure in any subsequent tests unless another complete check is carried out for the higher pressure.

15.2.4.2 Complete check on the back pressure system shall be carried out as follows:

(i) Flush de-aired tap water through the back pressure connecting line from the volume-change indicator and through the internal drainage line. In this operation, work the indicator at least twice to its limits of travel, allowing water to pass out of the top cap and replacing it with de-aired tap water from the pressure system.

(ii) Seal the end of the back pressure internal drainage line at the top cap with a watertight plug.

(iii) Pressurise the back pressure system to a pressure exceeding the maximum back pressure which the system will be subjected to in subsequent tests (normally about 700 to 800 kPa, depending on the limitation of the system), with the back pressure drainage line valve open. Record the volume change indicator reading when steady. If steady readings cannot be obtained which may indicate possible defects in the system, investigate and rectify the defects and repeat Steps (i) to (iii).

(iv) Leave the system pressurised for at least 12 h and record the volume change indicator reading again.

(v) If the difference between the two readings, after deducting the volume change due to expansion of the tubing, does not exceed 0.2 mL, the system can be considered to be leak-free and ready for a test. Otherwise, investigate and rectify the leaks and repeat the check until the requirement is achieved.

15.2.4.3 Routine check on the back pressure system shall be carried out as follows:

(i) Flush the back pressure line and drainage connections as in the above Clause 15.2.4.2 for complete check.

(ii) Close the back pressure drainage line valve.

(iii) Increase the pressure in the back pressure system to a pressure exceeding the maximum back pressure (about 700 to 800 kPa depending on the limitation of the system), and record the volume change indicator reading when steady. If steady readings cannot be obtained which may indicate possible defects in the system, investigate and rectify the defects and repeat Steps (i) to (iii).

(iv) Proceed to Clauses 15.2.4.2 (iv) and (v), except that the system is pressurised for at least 10 min only and the check is considered passed if the volume change does not exceed 0.2 mL during that period.

15.2.4.4 Complete check on the pore pressure system shall be carried out as follows:

(i) Connect a volume change indicator to the flushing system valve.

(ii) Flush de-aired tap water from the volume change indicator and through the pore water pressure measuring system and cell base and out through the base pedestal port. In this operation, work the indicator twice to its limits of travel to ensure that the entire system is filled with de-aired tap water.

(iii) Close the flushing system valve and the pore pressure valve. Remove the air bleed plug in the transducer mounting block.

(iv) Open the flushing system valve so that water flows out of the air bleed plug hole from the de-aired supply until no bubbles are seen to come out.

(v) Screw the air bleed plug back into the transducer mounting block while water continues to emerge.

(vi) Seal the pore pressure measurement port on the base pedestal with a water tight plug, without entrapping air.

(vii) Open the pore pressure valve and pressurise the pore pressure measuring system to a pressure exceeding the maximum pore pressure which the device will be subjected to in subsequent tests (normally about 700 to 800 kPa, depending on the limitation of the system). Record the volume change indicator reading when steady. If steady readings cannot be obtained which may indicate possible defects in the system, investigate and rectify the defects and remove the seal to the pore pressure measurement port and repeat Steps (ii) to (vii).

(viii) Leave the system pressurised for at least 12 h and record the volume change indicator reading again.

(ix) If the difference between the two readings, after deducting the volume change due to expansion of the tubing, does not exceed 0.2 mL, the system can be considered to be leak-free and ready for a test. Otherwise, investigate and rectify the leaks and repeat the check until the requirement is achieved.

15.2.4.5 Routine check on the pore pressure system shall be carried out as follows:

(i) Connect a volume change indicator to the flushing system valve.

(ii) Flush the pore pressure measuring system as in Clause 15.2.4.4 (ii) for complete check.

(iii) Proceed to Clauses 15.2.4.4 (vi) to (ix), except that the system is pressurised for at least 10 min only and the check is considered pass if the volume change does not exceed 0.2 mL during that period.

(iv) Keep the base pedestal covered with de-aired tap water by fitting a cut-down membrane, secured with O-rings, until the test specimen is ready for setting up.

15.2.4.6 Porous discs shall be checked before each test as follows:

(i) Inspect the porous discs to ensure that water drains freely through them and there is no signs of damage and cracks. Discs that are clogged by soil particles shall be rejected.

Note: Removal of soil particles from the pores of the disc can be aided by immersion in an ultrasonic water bath.

(ii) Before use, boil the discs for at least 10 min in distilled water. Then keep them under de-aired tap water in a beaker until required. Remove excess surface water immediately before placing, but ensure that the pores of the disc remain saturated.

15.2.5 Sample Preparation

15.2.5.1 Prepare a soil specimen in the form of a right cylinder with a nominal diameter of 70 mm to 110 mm and a height to diameter ratio of 1.9 to 2.1 in accordance with Clause 13, as appropriate. Follow either Clause 13.2 for remoulded samples, or Clause 13.3 for undisturbed specimen taken either from a tube sample as described in Clause 13.3.3 or 13.3.4, or a block sample as stated in Clause 13.3.5.

15.2.5.2 Measure the height, H_0 (to 0.1 mm), diameter, D_0 (to 0.1 mm) and mass, m_0 (to 0.1 g) of the prepared specimen.

15.2.5.3 Take portions of soil from the sample which are similar to that in the specimen for the determination of particle density, if required, and initial moisture content, w_i, in accordance with the test method specified.

15.2.6 Test Procedures

15.2.6.1 Mount the test specimen as follows:

(i) Follow either Method (A) or Method (B) below:

Method (A) - Standard Procedure

(1) Place the saturated porous disc by sliding it on to a layer of water on the triaxial base pedestal without entrapping air. Remove any surplus water.

Note: A filter paper disc of Whatman No. 54 filter paper or equivalent saturated in the same manner as the filter paper side drains described in Clause 15.2.3 (f) can be placed at both the top and bottom of the soil specimen, between the porous disc and the specimen to prevent fine soil particles from clogging the pores of the porous disc.

(2) Place the soil specimen on the disc centrally without delay and without entrapping air.

(3) Place a second saturated porous disc, with excess water removed, centrally on top of the soil specimen.

(4) If side drains are specified, allow surplus water to drain from the saturated filter paper and fit it to the curved surface of the soil specimen. Remove any pockets of air by light stroking. Ensure that the drains overlap the top porous disc but leave a gap of about 10 mm above the bottom porous disc.

(5) Using a membrane stretcher, place the soaked rubber membrane, after removing surplus surface water, around the soil specimen. Remove air pockets from between the membrane and the specimen by light stroking upwards. No excess water shall be sandwiched between the specimen and membrane.

Method (B) - Alternative Procedure (for Soft to Very Soft or Loose to Very Loose Soil Specimens)

(1) Place the soil specimen on top of a plastic disc of about the same diameter as the soil specimen.

(2) Place the saturated porous disc centrally on top of the soil specimen without entrapping air.

Note: See Note to the Step (1) of Method (A) above.

(3) Hold the soil specimen together with the porous disc and turn it upside down and place it on top of the triaxial base pedestal without delay and without entrapping air.

(4) Remove the plastic disc and place a second saturated disc, with excess water removed, centrally on top of the soil specimen.

(5) Proceed to Steps (4) and (5) of Method (A) above.

Note: This may be carried out before Step (3) of Method (B) if the specimen is too soft or too loose to handle.

(ii) Seal the rubber membrane to the base pedestal using two rubber O-rings.

Note: A smear of rubber grease on the curved surfaces of the pedestal and top cap improves the seal. Avoid allowing the grease to come into contact with the porous discs or filter paper drains.

(iii) Place two O-rings around the drainage lead connected to the top cap.

(iv) Open the back pressure valve momentarily to moisten the top cap, and fit the cap onto the top porous disc without entrapping air. Seal the membrane onto the top cap with the two O-rings, using the split-ring stretcher.

(v) Ensure that the axis of the soil specimen is in vertical alignment, and that the drainage line from the top cap does not interfere with the setting up of the cell body.

(vi) Assemble the cell body with the loading piston well clear of the top cap. Check alignment by allowing the piston to slide slowly until it just makes contact with the bearing surface on the top cap, then retract the piston. If necessary, remove the cell body and correct any eccentricity.

(vii) Fill the triaxial cell with de-aired tap water, ensuring that all the air is displaced through the bleed plug. Fill the cell as quickly as possible but without allowing turbulence, which could aerate the water. A layer of castor oil may be introduced on top of the water to act as lubricant for the piston and to reduce leakage round it.

(viii) Keep the air bleed plug open until the cell is ready to be pressurised, in order to maintain the pressure at atmospheric.

(ix) Apply the first cell pressure increment as soon as possible, as required by the saturation procedure.

15.2.6.2 Saturation of the specimen shall be achieved by alternate increments of cell pressure and back pressure. The cell pressure increment stages are carried out without allowing drainage into or out of the soil specimen, which enables values of the pore pressure coefficient B to be determined at each cell pressure increment stage. The procedures shall be as follows:

(i) Ensure that the back pressure valve and the flushing system valve are closed. Record the initial pore pressure when steady.

(ii) Apply an increment of cell pressure of not exceeding 25 kPa (or 50 kPa if the pore pressure coefficient B, calculated by Step (iv) below, exceeds 0.9) or any of the consolidation pressures which the soil specimen will be subjected to subsequently, whichever is the less.

(iii) Observe the pore pressure until it reaches a steady value and record it.

Note: When observing changes in pore pressure it may be convenient to plot readings against time to ascertain when a steady state has been achieved.

(iv) Calculate the value of the pore pressure coefficient B from the following equation:

$$B = \frac{\delta u}{\delta \sigma_3}$$

where δu is the change in pore pressure; and
$\delta \sigma_3$ is the change in cell pressure.

Note: This step may be omitted in the first increment of cell pressure as the pore pressure response of the specimen may not be meaningful after initial set-up.

(v) Keeping the back pressure valve and the flushing system valve closed, increase the pressure in the back pressure line to a value equal to the cell pressure less the selected differential pressure. Record the reading of the back pressure line volume-change indicator when it reaches a steady value.

Note: The difference between cell pressure and back pressure (the ‘differential pressure’) during the pressure increments shall neither be less than 5 kPa nor greater than 10 kPa, unless otherwise specified.

(vi) Open the back pressure valve to admit the back pressure into the soil specimen.

Note: The water applied to the soil specimen from the back pressure system shall be de-aired tap water, unless specified otherwise.

(vii) Observe the pore pressure and the volume-change indicator readings. When they reach steady values, record them and close the back pressure valve.

(viii) Calculate the volume of water taken in by (or draining out from) the soil specimen from the difference between the volume-change indicator readings recorded in Steps (v) and (vii) above.

(ix) Repeat the above Steps (ii) to (viii) until the pore pressure coefficient B is greater than or equal to 0.95 and the back pressure is greater than or equal to 200 kPa. Then repeat the above Steps (v) to (viii) again, except to leave the back pressure valve open for at least 12 h in Step (vii) and close the back pressure valve afterwards.

(x) Calculate the total volume of water taken up by (or draining out from) the soil specimen into the air voids by totalling the differences obtained in the above Step (viii).

15.2.6.3 Isotropic consolidation of the specimen shall be carried out immediately after the saturation stage using the same apparatus. The effective stress in the soil specimen is increased to the desired value by raising the cell pressure and dissipating the resulting excess pore pressure to an appropriate back pressure. The procedures are as follows:

(i) After completion of the saturation stage, keep the back pressure valve closed and record the pore pressure and volume-change indicator readings.

Note: The back pressure shall not be reduced below the pore pressure reached in the final step of the saturation stage, or 200 kPa, whichever is greater.

(ii) Increase the cell pressure (σ_3) and back pressure (u_b), if necessary, to give a difference equal to the desired effective consolidation pressure (σ_3') such that:

$$\sigma_3' = \sigma_3 - u_b .$$

(iii) Record the pore pressure until a steady value (u_i) (in kPa) is reached. Record and plot readings of pore pressure against time to establish when a steady value is reached. The excess pore pressure to be dissipated is equal to ($u_i - u_b$).

(iv) Record readings of the volume-change indicator. At a convenient moment (zero time) start the consolidation stage by opening the back pressure valve.

(v) Record and plot readings of the volume-change indicator and the pore pressure transducer, at suitable intervals of time.

Note: Suggested intervals for plotting the pore pressures (against log time) are 0, ¼, ½, 1, 2, 4, 8, 15, 30, 60 min and for plotting the volume changes (against square-root time) are 0, ¼, ½, 1, 2¼, 4, 9, 12¼, 16, 25, 36, 64 min. In both cases, additional readings at 2, 4, 8, 16, 24 h may also have to be taken. More frequent readings at the initial stage may need to be taken for soils which compress very rapidly. Readings may be taken at other time intervals so long as they enable the curves to be plotted with sufficient accuracy.

(vi) Allow consolidation to continue until the volume change indicator reading reaches a steady value and at least 95% of the excess pore pressure has been dissipated, i.e. U (as defined below) ≥ 95%.

$$U = \left(\frac{u_i - u}{u_i - u_b} \right) 100$$

where U is the degree of consolidation (in %); and
u is the pore pressure reading at a given time t.

(vii) Record the reading of the volume-change indicator and calculate the total change in volume (δV_c) during the consolidation stage. Record the pore pressure u_c (in kPa).

(viii) The consolidated specimen is then ready for the compression test. The back pressure valve shall remain open until immediately before shearing.

15.2.6.4 From the data obtained from consolidation, calculate the rate of axial displacement to be applied to the specimen in shearing in accordance with Clause 15.2.7.1.

15.2.6.5 Carry out compression of the specimen as follows:

(i) Set up and adjust the triaxial test assembly as follows:

(1) Set up the triaxial cell on the compression machine if it has been placed elsewhere during the saturation and consolidation stages.

(2) Adjust the machine platen, either by hand or by motor drive, until the cell loading piston is brought to within a short distance of the specimen top cap.

Note: This procedure allows for the combined effects of cell pressure acting on the piston and frictional resistance in the piston bush or seal. If the design of force-measuring device permits, the scale of the device should be adjusted so that the initial reading is zero.

(3) Adjust the compression machine to give a rate of displacement as close as possible to, but not exceeding, that calculated in Clause 15.2.7.1.

(4) Make further adjustments to bring the loading piston just into contact with the seating on the top cap of the soil specimen. Check that the piston is properly seated and in correct alignment, ensuring that the axial load applied to the specimen is as small as possible.

(5) Secure the axial deformation gauge so that it can measure a vertical deformation up to at least 25% of the length of the soil

specimen.

(ii) Close the back pressure valve, and ensure that the cell pressure valve and the pore pressure valve are open.

(iii) Record the date and time to start the compression stage and the initial readings for the following:

- deformation gauge reading,
- force-measuring device reading,
- pore pressure, and
- cell pressure.

(iv) Apply compression to the soil specimen and simultaneously start the timer.

(v) Record sufficient sets of readings of the deformation gauge, force-measuring device and pore pressure measuring device at intervals during the compression so that the stress-strain curve can be clearly defined.

Note 1: Readings shall normally be taken at regular intervals of axial displacement. The frequency of readings to be taken shall not be less than 5 readings per 1% strain. However, after the maximum deviator stress, if attainable, is reached, the frequency can be reduced to 2 readings per 1% strain. When it is evident during compression that the peak deviator stress or maximum pore pressure is approached, readings may need to be taken more frequently.

Note 2: The cell pressure should be checked periodically during compression to ensure that it remains constant to within 0.5% or ± 2 kPa, whichever is greater. It should be adjusted where necessary. However, periodic checking of the cell pressure overnight or over weekend or holidays is not necessary provided that:

(1) the cell pressure is found to remain constant to within 0.5% or ± 2 kPa, whichever is greater, during the first half hour of compression, and

(2) the cell pressure system has passed the complete check carried out in accordance with Clause 15.2.4.1, except with the maximum cell pressure maintained for a period longer than the aforementioned overnight or the weekend or holiday periods.

Note 3: The axial deformation over a certain period of time should be calculated periodically to provide a check on the actual rate of strain applied.

(vi) Calculate values of deviator stress ($\sigma_1 - \sigma_3$) (in kPa) and effective principal stress ratio (σ_1'/σ_3'), as described in Clause 15.2.7, while the test is still in progress.

Note: While the test is in progress, the deviator stress, the effective principal stress ratio and the pore pressure may be plotted against axial strain, and the stress paths of t against s' and q against p', showing the corresponding total stress paths may also be plotted.

(vii) For a multi-stage test, skip the two steps below and proceed to

Clause 15.2.6.6.

(viii) Unless otherwise specified, terminate the test at an axial strain of at least 5% more than that after the peak deviator stress is reached or at an axial strain of at least 20%, whichever occurs first.

(ix) Stop the shearing. Close the pore pressure valve and open the flushing system valve to protect the transducer.

15.2.6.6 When multi-stage test is specified, carry out the procedures as follows:

(i) Terminate the compression at maximum effective principal stress ratio (σ_1'/σ_3') or the maximum deviator stress ($\sigma_1 - \sigma_3$) whichever occurs first. Record readings of the deformation gauge, force measuring device and pore pressure measuring device.

(ii) Reduce the deviator stress ($\sigma_1 - \sigma_3$) to zero by reversing the motor.

(iii) Increase the cell pressure (σ_3) but keep the back pressure (u_b) at the same value as that at the consolidation phase of the first stage to give a difference equal to the desired effective consolidation pressure (σ_3') for the next stage. Then repeat consolidation following Clauses 15.2.6.3 (iii) to (viii).

(iv) Calculate the coefficient of consolidation (c_{vi}) and coefficient of volume compressibility (m_{vi}) for isotropic consolidation for the consolidation phase in accordance with Clause 15.2.7.1.

(v) Repeat the compression stage following Clauses 15.2.6.5 (i) to (vi).

(vi) Terminate the compression as in Clauses 15.2.6.6 (i) and (ii).

(vii) Repeat the steps in Clauses 15.2.6.6 (iii) to (v) above for the third stage of the triaxial test but at the target effective consolidation pressure for that stage. Terminate the test as in Clauses 15.2.6.5 (viii) and (ix).

15.2.6.7 Unload the specimen and dismantle the test assembly as follows:

(i) Ensure that the back pressure valve and the pore pressure valve are closed.

(ii) Remove the axial force from the soil specimen.

(iii) Reduce the cell pressure to zero and drain the water from the cell.

(iv) Dismantle the cell.

(v) Remove the rubber membrane, filter paper side drains (if used), top cap, porous discs and the soil specimen from the base pedestal.

(vi) Sketch the mode of failure of the soil specimen.

15.2.6.8 Measure and process the tested specimen as follows:

(i) Immediately weigh the whole soil specimen to determine its final wet mass (m_t) to 0.1 g.

(ii) Take photographs of the tested specimen (at a scale of about 1:2) both before and after it is split vertically into two halves, alongside a suitable scale and a colour chart. Describe the soil including its fabric in accordance with Geoguide 3 (GCO, 1988).

Note: The above two steps should be completed without delay to avoid loss of moisture from the specimen.

(iii) Dry the specimen to constant mass at the same temperature as that used for the determination of moisture content and determine the dry mass (m_{df}) to 0.1 g.

Note: The final dry mass of the soil specimen so determined shall be used together with the initial wet mass of the specimen for calculating the initial moisture content.

(iv) For undisturbed soil specimen, soak it in water until it is sufficiently softened for breaking up into individual particles. Break it up for inspection. If there are particles of size larger than one-fifth of the diameter of the soil specimen, determine their percentage by mass and take photograph of them alongside a suitable scale and a colour chart.

15.2.7 Calculations

15.2.7.1 Using the data obtained from the consolidation stage, carry out the following calculations:

(i) Calculate the dimensions (volume, V_c, in cm^3, cross sectional area, A_c, in mm^2 and height, H_c, in mm) of the soil specimen after consolidation from the following equations:

$$V_c = V_0 - \delta V_c$$

$$A_c = A_0\left(1 - \frac{\delta V_c}{V_0}\right)^{2/3}$$

$$H_c = H_0\left(1 - \frac{\delta V_c}{V_0}\right)^{1/3}$$

where V_0 is the original volume of the specimen prior to the saturation stage (in cm^3);

δV_c is the change in volume during consolidation as determined from the volume of water draining out of the specimen (in cm^3);

A_0 is the original cross sectional area of the specimen (in mm^2); and

H_0 is the original height of the specimen (in mm).

Note 1: Where net volume of water has drained out from the soil specimen during the saturation stage, V_0 shall be taken to be the original volume of the specimen prior to the saturation stage less that net volume of water.

Note 2: If the change in volume during saturation is significant, it should be estimated and included with δV_c.

(ii) Plot a graph of the degree of consolidation (U) against logarithm of time and also plot the measured volume change (δV_c) against square-root time.

(iii) From the plot of degree of consolidation (U) against logarithm of time, read off the time t_{50} (in minutes) corresponding to 50% consolidation (see Figure 14.5).

(iv) Calculate the value of the coefficient of consolidation for isotropic consolidation, c_{vi} (to 0.01 m^2/year), from the equation:

$$c_{vi} = \frac{0.2\ H^2}{t_{50}} \quad \text{for} \quad H = \frac{H_0 + H_c}{2}$$

where H is the average height of the specimen during the consolidation stage (in mm); and

t_{50} is the value determined from the Figure 14.5 (in min).

Note: The above formula for the calculation of c_{vi} assumes drainage is vertical towards one end of the soil specimen and no side drains are used. If these assumptions are not met, the calculation for c_{vi} should be omitted.

(v) On the plot of volume change against square-root time, draw the straight line which best fits the early portion of the plot of volume change against square-root time (this portion normally lies within the first 50% of the volume change readings). Draw a horizontal line through the final point on the plot (see Figure 14.6). At the point where these lines intersect, read off the value of square-root time, denoted by $\sqrt{t_{100}}$ and calculate the time intercept of this point, t_{100} (in min).

(vi) Calculate the value of the coefficient of consolidation for isotropic consolidation, c_{vi} (to 0.01 m^2/year), from the following equation:

$$c_{vi} = \frac{1.65\,D^2}{\lambda t_{100}} \quad \text{for} \quad D = \frac{D_0 + D_c}{2}$$

where D is the average diameter of the soil specimen during the consolidation stage (in mm);

D_c is the diameter of the consolidated specimen (in mm) derived from the value A_c obtained in Step (i) above; and

λ is a coefficient which depends on the drainage conditions and the length to diameter ratio (r) of the soil specimen as shown in Table 14.1.

Note: Where side drains have been used, the value of C_{vi} derived in this way should not be applied to engineering settlement calculations because it has been shown to be grossly in error.

(vii) Calculate the value of the coefficient of volume compressibility for isotropic consolidation, m_{vi} (to 0.01 m^2/MN), from the following equation:

$$m_{vi} = \left(\frac{\frac{\delta V_c}{V_0}}{u_i - u_c} \right) 1000$$

where δV_c is the change in volume of the specimen due to consolidation (in cm^3);

V_0 is the original specimen volume (in cm^3);

u_i is the pore pressure at the start of the consolidation (in kPa); and

u_c is the pore pressure at the end of the consolidation (in kPa).

(viii) Calculate the significant testing time t_f (to 0.01 minute) for the compression test, from the following equation:

$$t_f = Ft_{100}$$

where F is a coefficient which depends on the drainage conditions, and the type of compression test, i.e. undrained or drained (obtained in Table 14.1); and

t_{100} is the time for 100% consolidation obtained from the square-root time plot.

Note: The factor F is based on 95% dissipation of excess pore pressure induced by shear, which is acceptable for most practicable purposes.

(ix) Estimate the strain at which failure will occur, ε_f, to 0.1%.

(x) Calculate the rate of axial displacement, d_r (in mm/min), to be applied to the soil specimen from the following equation:

$$d_r = \frac{\varepsilon_f L_c}{100\ t_f}$$

where L_c is the length of the consolidated specimen (in mm);
ε_f is the strain at which failure will occur as estimated in Step (ix) above (in %); and
t_f is the significant testing time (in min).

This gives the maximum nominal machine speed for the test.

Note 1: Soils of relatively high permeability may give calculated times to failure that are unrealistically short. The maximum rate of axial displacement in these cases should be limited to 2% per hour.

Note 2: The 'machine displacement speed' is the speed quoted by the manufacturer for each gear ratio when the machine is running under zero load. The actual speed under load may be less than this. The 'closing gap speed' is less than the machine speed due to deformation of the load-measuring device and of the load frame. The actual rate of axial displacement of the specimen is the 'closing gap speed', and allowance should be made for the difference between this and the nominal machine displacement speed if greater accuracy is necessary.

15.2.7.2 After the completion of the test, carry out the following calculations:

(i) Calculate the axial strain, ε_1 (to 0.1%) from the following equation:

$$\varepsilon_1 = \left(\frac{\delta H}{H_c}\right) 100$$

where δH is the change in height (from the initial height) during compression, as determined from the deformation gauge (in mm); and
H_c is the height of the soil specimen after consolidation (in mm) calculated in Clause 15.2.7.1 (i).

Note: In this procedure, strains are calculated as cumulative strain, i.e. the change in dimension relative to the initial reference dimension.

(ii) Calculate the cross-sectional area, A_s (to 0.1 mm^2) of the soil specimen normal to its axis, assuming that it deforms as a right cylinder from the following equation:

$$A_s = \frac{100\ A_c}{100 - \varepsilon_1}$$

where A_c is the initial area of soil specimen normal to its axis after consolidation (in mm^2) calculated in Clause 15.2.7.1 (i).

Note: This equation is based on the assumption that the volumetric strain is zero in an undrained test on a fully saturated soil specimen.

(iii) Calculate the axial force, P (to 1 N), applied to the soil specimen additional to that due to the cell pressure from the following equation:

$$P = (R - R_0)\ C_r$$

where R is the reading of the force-measuring device (in division or digit);

R_0 is the initial reading of the force-measuring device corresponding to zero applied load (in division or digit); and

C_r is the calibration factor of the force-measuring device (in N/division or digit).

(iv) Calculate the applied axial stress, i.e. the measured principal stress difference, or deviator stress $(\sigma_1 - \sigma_3)_m$ (to 0.1 kPa) from the following equation:

$$(\sigma_1 - \sigma_3)_m = \left(\frac{P}{A_s}\right) 1000$$

(v) Read out the membrane correction, σ_{mb}, which shall be applied to allow for the restraining effect of the membrane, from the curve in Figure 15.2, for specimen of 38 mm diameter enclosed in a membrane of 0.2 mm thick. For other conditions the value of σ_{mb} obtained from Figure 15.2 shall be multiplied by:

$$\left(\frac{38}{D_0}\right)\left(\frac{t_m}{0.2}\right)$$

where D_0 is the initial diameter of the soil specimen (in mm); and

t_m is the total thickness of membrane (which may consist of more than one layer) enclosing the soil specimen (in mm).

(vi) Read out the side drain correction factor, σ_{dr}, if vertical side drains have been used, from Table 15.1 below.

Table 15.1 Corrections for Vertical Side Drains

Specimen Diameter (mm)	**Drain Correction, σ_{dr} (kPa)**	
	Strain (ε%) ≤ 2%	**Strain (ε%) Exceeding 2%**
70	$\frac{5\varepsilon}{2}$	5
100	$\frac{5\varepsilon}{2}$	3.5
150	$\frac{2.5\varepsilon}{2}$	2.5

Note: Corrections for specimens of intermediate diameters may be obtained by interpolation. For calculating the drain corrections for the 2nd and 3rd stages of a multi-stage test, the strain ε% in the above table shall be the cumulative strain measured from the start of the 1st stage of the multi-stage test.

(vii) Calculate the corrected deviator stress, $(\sigma_1 - \sigma_3)$ (to 0.1 kPa) from the following equation:

$$(\sigma_1 - \sigma_3) = (\sigma_1 - \sigma_3)_m - \sigma_{mb} - \sigma_{dr}$$

(viii) Calculate the major principal stress, σ_1 (to 0.1 kPa) from the following equation:

$$\sigma_1 = (\sigma_1 - \sigma_3) + \sigma_3$$

where σ_3 is the cell pressure.

(ix) Calculate the effective major and minor principal stresses, (σ_1' and σ_3' respectively) (to 0.1 kPa) from the following equations:

$$\sigma_1' = \sigma_1 - u$$

$$\sigma_3' = \sigma_3 - u$$

where u is the pore pressure.

(x) Calculate the effective principal stress ratio, σ_1'/σ_3' to 0.01.

(xi) Calculate the pore pressure coefficient, A_f (to 0.01), at failure from the following equation:

$$A_f = \frac{u - u_0}{(\sigma_1 - \sigma_3)}$$

where u_0 is the pore pressure in the soil specimen at the start of compression; and

u is the pore pressure at failure.

(xii) Calculate the stress path parameters, s' and t (to 0.1 kPa), in terms of effective stress from the following equations:

$$s' = \frac{(\sigma_1' + \sigma_3')}{2}$$

$$t = \frac{(\sigma_1 - \sigma_3)}{2}$$

(xiii) Calculate the stress path parameters, p' and q (to 0.1 kPa), in term of effective stress from the following equations:

$$p' = \frac{(\sigma_1' + 2\,\sigma_3')}{3}$$

$$q = (\sigma_1 - \sigma_3)$$

(xiv) Calculate the initial moisture content, w_0 (to 0.1%), and bulk density, ρ_0 (to 0.01 Mg/m^3), of the specimen from the following equations:

$$w_0 = \frac{100\,(m_0 - m_d)}{m_d}\;; \qquad \rho_0 = \frac{1000\,m_0}{A_0 H_0}$$

where m_0 is the initial wet mass of the specimen (in g);
m_d is the final dry mass of the specimen (in g);
A_0 is the initial cross-sectional area of the specimen (in mm^2); and
H_0 is the initial height of the specimen (in mm).

(xv) Calculate the moisture content, w_{sat} (to 0.1%), and bulk density, ρ_{sat} (to 0.01 Mg/m^3), of the specimen after saturation from the following equations:

$$w_{sat} = w_0 + \frac{100\,\rho_w \delta V_{sat}}{m_d}\;; \qquad \rho_{sat} = \frac{1000\,(m_0 + \rho_w \delta V_{sat})}{A_0 H_0}$$

where ρ_w is the density of water = 1.0 Mg/m^3; and
δV_{sat} is the total volume of water taken in by the specimen during saturation stage (in cm^3).

(xvi) Calculate the moisture content, w_{con} (to 0.1%), and bulk density, ρ_{con} (to 0.01 Mg/m^3), of the specimen after consolidation from the following equations:

$$w_{con} = w_{sat} - \frac{100\ \rho_w \delta V_{con}}{m_d}\ ;\quad \rho_{con} = \frac{1000\ (m_0 + \rho_w \delta V_{sat} - \rho_w \delta V_{con})}{A_0 H_0 - 1000\ \delta V_{con}}$$

where δV_{con} is the total volume of water expelled during the consolidation stage (in cm^3, negative for volume of water taken in during a swelling stage).

(xvii) Calculate the final moisture content, w_f (to 0.1%), and bulk density, ρ_f (to 0.01 Mg/m^3), of the specimen from the following equations:

$$w_f = \frac{100\ (m_f - m_d)}{m_d}\ ;\qquad \rho_f = \frac{1000\ m_f}{A_0 H_0 - 1000\ \delta V_{con}}$$

Note 1: The final moisture content and bulk density of the specimen calculated in this step are served as a check on the values obtained in Step (xvi) above. Both values shall be reported noting that the former values are deduced from the final wet mass of the specimen, while the latter are deduced from the initial wet mass of the specimen and the measured volume changes.

(xviii) Calculate the dry density, ρ_d (to 0.01 Mg/m^3), void ratio, e (to 0.01), and degree of saturation, S_r (to 0.1%), of the specimen at the initial stage, end of the saturation and consolidation stages and the final stage using the equations given in the Glossary.

15.2.7.3 Plot the following graphs:

(i) deviator stress, plotted as ordinate, against the axial strain (usually expressed as percentage) as abscissa,

(ii) effective principal stress ratio σ_1'/σ_3', plotted as ordinate, against the axial strain as abscissa,

(iii) stress path for effective stresses, with values of s' as abscissa and t as ordinate, on a plot in which the vertical and horizontal scales are the same,

(iv) stress path for effective stresses, with values of p' as abscissa and q as ordinate, on a plot in which the vertical and horizontal scales are the same, and

(v) pore pressure change curve, using the same abscissa as in (i), and pore pressure as ordinate. Mark clearly the initial pore pressure during the compression stage on the graph.

15.2.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

Note: Any values which are required to be reported as indicated below shall be expressed with the same number of significant figures as the recorded values.

(a) the general information as required in B.1.1 of Appendix B,

(b) the information as required in B.1.2 of Appendix B for Phase II tests,

(c) the initial dimensions (viz. diameter and height) of the specimen,

(d) the initial moisture content, bulk density and dry density (state the test method for moisture content determinations; if the minimum mass requirement for carrying out the moisture content tests cannot be followed, this shall be stated),

(e) the initial void ratio and degree of saturation of the specimen,

(f) whether filter paper side drains were fitted,

(g) sequence of cell pressure and back pressure applied during saturation,

(h) pore pressure, cell pressure and value of pore pressure coefficient B at the end of saturation,

(i) cell pressure, back pressure and effective pressure used for consolidation,

(j) graphical plots of volume change or volumetric strain against square-root time and degree of consolidation against log time for the consolidation stage(s),

(k) the coefficients of consolidation calculated at each consolidation phase,

(l) the coefficients of volume compressibility determined from the consolidation stages,

(m) pore pressure and effective stress at the end of consolidation and start of the compression stage, also moisture content, bulk density, dry density, void ratio and degree of saturation at these stages,

(n) rate of axial displacement applied to the soil specimen (in millimetres per minute or percent strain per hour),

(o) the termination criterion adopted (or the termination criteria adopted for the three compression stages of a multi-stage test),

(p) the corrections applied to the measured deviator stress,

(q) the final moisture content, bulk density, dry density, void ratio and degree of saturation,

(r) the pore pressure coefficient A_f, at failure, and

(s) graphical plots, as described in Clause 15.2.7.3 and tabulated raw data for these plots.

15.3 The Isotropically Consolidated Drained Triaxial Compression Test with Measurement of Volume Change

15.3.1 Scope

This test, commonly referred to as the CD test, is used for the determination of the shear strength of a soil specimen using the triaxial apparatus. The specimen, which has been saturated and subjected to an isotropic consolidation, is then sheared in compression, under a constant confining pressure, by increasing the axial strain. Free drainage of pore water from the soil specimen is permitted.

The standard procedures described relate to strain-controlled apparatus for compression in a mechanical load frame, and a detachable triaxial cell.

15.3.2 General

The guidance given in Clause 3.11.2 shall be noted.

The environmental requirements as described in Clause 14.1.2 shall be observed.

This test is carried out in three stages: saturation, isotropic consolidation and drained shearing by axial compression.

The objectives and procedures for the saturation and consolidation stages are the same as those for the consolidated undrained test (Test Method 15.2) and are described in Clause 15.2.

The procedures for the compression stage of this test are described in Clause 15.3.6. During the compression stage, the cell pressure is maintained constant while the soil specimen is sheared at a constant rate of axial deformation (strain-controlled compression). Free drainage of pore water from the soil specimen is permitted. The test is run slowly enough to ensure that pore pressure changes due to shearing are negligible. The volume of pore fluid draining out of or into the volume change indicator in the back pressure line is taken to be equal to the change in volume of the soil specimen during shear. Pore pressure is monitored at the base of the soil specimen as a check on the efficiency of drainage.

15.3.3 Apparatus

All the apparatus listed in Clause 15.2.3 for Test Method 15.2 are required for this test.

15.3.4 Calibration

The preparation and checking of apparatus shall follow Clause 15.2.4 as for Test Method 15.2.

15.3.5 Sample Preparation

The sample preparation shall follow Clause 15.2.5 as for Test Method 15.2.

15.3.6 Test Procedures

15.3.6.1 Mount the test specimen as described in Clause 15.2.6.1 for Test Method 15.2.

15.3.6.2 Saturate the specimen as described in Clause 15.2.6.2 for Test Method 15.2.

15.3.6.3 Consolidate the specimen as described in Clause 15.2.6.3 for Test Method 15.2.

15.3.6.4 Calculate the appropriate rate of axial displacement as described in Clause 15.2.6.4 for Test Method 15.2.

15.3.6.5 Carry out compression of the specimen as follows:

(i) Set up and adjust the triaxial test assembly as described in Clause 15.2.6.5 (i) for Test 15.2.

(ii) Ensure that the cell pressure valve, back pressure valve and pore pressure valves are open.

(iii) Record the date and time to start the compression stage and the initial readings for the following:

- deformation gauge reading,
- force-measuring device reading,
- pore pressure,
- cell pressure, and
- volume-change gauge reading.

(iv) Apply compression to the soil specimen and simultaneously start the timer.

(v) Record sufficient sets of readings of the deformation gauge, force-measuring device and volume-change gauge at intervals during the compression so that the stress-strain curve can be clearly defined.

Note 1: Readings shall normally be taken at regular intervals of axial displacement. The frequency of readings to be taken shall not be less than 5 readings per 1% strain. However, after the maximum deviator stress, if attainable, is reached, the frequency can be reduced to 2 readings per 1% strain. When it is evident during compression that the peak deviator stress or maximum volume change is approached, readings may need to be taken more frequently.

Note 2: The cell pressure and back pressure should be checked periodically during compression to ensure that they remain constant to within 0.5% or ± 2 kPa, whichever is greater. They should be adjusted where necessary. However, periodic checking of the cell pressure and back pressure overnight or over weekend or holidays is not necessary provided that:

(1) the cell pressure and back pressure are found to remain constant to within 0.5% or ± 2 kPa, whichever is greater, during the first half hour of compression, and

(2) the cell pressure and back pressure systems have passed the complete check carried out in accordance with Clauses 15.2.4.1 and 15.2.4.2, during which the maximum cell pressure was maintained for a period longer than the aforementioned overnight or the weekend or holiday periods.

Note 3: The axial deformation over a certain period of time should be calculated periodically to provide a check on the actual rate of strain applied.

(vi) Calculate values of deviator stress ($\sigma_1 - \sigma_3$) (in kPa) as described in Clause 15.3.7, while the test is in progress.

Note: While the test is in progress, the deviator stress, the effective principal stress ratio and the volumetric strain or specimen volume change may be plotted against axial strain.

(vii) Observe the pore pressure periodically, and if it varies from the value of the back pressure by more than 4% of the effective confining pressure or 2 kPa whichever is larger, decrease the rate of strain accordingly until the pore pressure meets the above requirements.

(viii) Unless otherwise specified, terminate the test at an axial strain of at least 5% more than that after the peak deviator stress is reached or at an axial strain of at least 20%, whichever occurs first.

(ix) Stop the compression stage, close the pore pressure valve and the back pressure valve. Open the flushing system valve to protect the transducer.

15.3.6.6 Unload the specimen and dismantle the test assembly as described in Clause 15.2.6.7 for Test Method 15.2.

15.3.6.7 Measure and process the tested specimen as described in Clause 15.2.6.8 for Test Method 15.2.

15.3.7 Calculations

15.3.7.1 Using the data obtained from the consolidation stage, carry out the calculations as described in Clause 15.2.7.1 for Test Method 15.2.

15.3.7.2 After the completion of the compression test, carry out the following calculations:

(i) Calculate the axial strain, ε_1 (to 0.1%), from the equation in Clause 15.2.7.2 (i) as for Test Method 15.2.

(ii) Calculate the volumetric strain due to compression, ε_v (to 0.01%), from the following equation:

$$\varepsilon_v = \left(\frac{\delta V}{V_c}\right) 100$$

where δV is the change in volume of the soil specimen from the start of compression (in cm^3); and

V_c is the volume of the consolidated soil specimen at the start of compression (in cm^3) calculated in Clause 15.2.7.1 (i).

Note: The sign convention used for δV is that compressive strains are positive, and therefore a decrease in volume (compression or consolidation) is positive and an increase in volume (dilation or swelling) is negative.

(iii) Calculate the cross-sectional area, A_s (in mm^2) of the soil specimen normal to its axis, assuming that it deforms as a right cylinder, from the following equation:

$$A_s = \left(\frac{100 - \varepsilon_v}{100 - \varepsilon_1}\right) A_c$$

where A_c is the initial area of soil specimen normal to its axis after consolidation (in mm^2) calculated in Clause 15.2.7.1 (i).

(iv) Calculate the applied axial force, P (to 1 N), and the measured principal stress difference, or deviator stress $(\sigma_1 - \sigma_3)_m$ (to 0.1 kPa) from the equations in Clauses 15.2.7.2 (iii) and (iv).

(v) Evaluate the membrane correction, σ_{mb} , and the side drain correction, σ_{dr}, as in Clauses 15.2.7.2 (v) and (vi).

(vi) Calculate the corrected deviator stress, $(\sigma_1 - \sigma_3)$, and major principal stress, σ_1, and the effective major and minor principal stresses, (σ_1' and σ_3') as described in Clauses 15.2.7.2 (vii) to (ix) respectively (to 0.1 kPa).

(vii) Determine the stress path parameters (s' and t) and (p' and q) as described in Clauses 15.2.7.2 (xii) and (xiii) respectively (to 0.1 kPa).

(viii) Determine the moisture content (w_0, w_{sat}, w_{con}) (to 0.1%), and bulk density (ρ_0, ρ_{sat}, ρ_{con}) (to 0.01 Mg/m^3) at the initial stage, end of the saturation, and at the end of the consolidation stage as described in Clauses 15.2.7.2 (xiv) to (xvi) respectively.

(ix) Determine the moisture content, w_{sh} (to 0.1%), and bulk density, ρ_{sh} (to 0.01 Mg/m^3), of the specimen after compression or shearing from the following equations:

$$w_{sh} = w_{con} + \frac{100\ \rho_w \delta V_{sh}}{m_d}\ ;$$

$$\rho_{sh} = \frac{1000\ (m_0 + \rho_w \delta V_{sat} - \rho_w \delta V_{con} - \rho_w \delta V_{sh})}{A_0 H_0 - 1000\ \delta V_{con} - 1000\ \delta V_{sh}}$$

where δV_{sh} is the total volume of water expelled during the compression or shearing stage (in cm^3, negative for volume of water taken in during the compression or shearing stage).

(x) Determine the final moisture content, w_f (to 0.1%), and bulk density, ρ_f (to 0.01 Mg/m^3), of the specimen from the following equations:

$$w_f = \frac{100\ (m_f - m_d)}{m_d}\ ; \qquad \rho_f = \frac{1000\ m_f}{A_0 H_0 - 1000\ \delta V_{con} - 1000\ \delta V_{sh}}$$

Note: The final moisture content and bulk density of the specimen calculated in this step may be served as a check on the values obtained in (ix) above. Both values shall be reported noting that the former values are deduced from the final wet mass of the specimen, while the latter are deduced from the initial wet mass of the specimen and the measured volume changes.

(xi) Calculate the dry density, ρ_d (to 0.01 Mg/m^3), void ratio, e (to 0.01), and degree of saturation, S_r (to 0.1%), of the specimen at the initial stage, end of the saturation and consolidation stages and the final stage, calculated using the equations given in the Glossary.

15.3.7.3 Plot the following graphs:

(i) The graphs as described in Clauses 15.2.7.3 (i) to (iv).

(ii) Volume change (volumetric strain), plotted as ordinate, against the axial strain as abscissa.

15.3.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

Note: Any values which are required to be reported as indicated below shall be expressed with the same number of significant figures as the recorded values.

(a) all information listed in Clauses 15.2.8 (a) to (q) as for Test Method 15.2, and

(b) the graphical plots, as described in Clause 15.3.7.3 and the tabulated raw data for these plots.

16 Determination of Shear Strength of Soils Using Shear Box Apparatus

16.1 The Direct Shear Test (Small Shear Box Apparatus)

16.1.1 Scope

This test is used for the determination of the effective shear strength of a soil at a specified normal stress.

16.1.2 General

The guidance given in Clause 3.12 shall be noted.

The environmental requirements as described in Clause 14.1.2 shall be observed.

Two test methods, Method A and Method B, are specified. In Method A, a square or circular shear box of a nominal size of 60 mm to 100 mm is used, with a specimen thickness of about 20 mm. This Method is suitable for soils containing particles up to 4 mm in size. In Method B, a square or circular shear box of a nominal size of 100 mm with the top and bottom porous plates replaced with filter papers is used and the bottom grooved base plate is omitted. This permits a specimen thickness of about 44 mm to be tested. This Method is suitable for soils containing particles up to about 10 mm in size. However, it is not recommended for cohesive soils of low permeability as the drainage conditions in Method B are not as effective as those in Method A.

16.1.3 Apparatus

The following apparatus are required:

(a) the apparatus for specimen preparation and measurement described in Clause 13.2.1 or 13.3.1, as appropriate,

(b) the apparatus for moisture content determination as specified in Clause 5,

(c) a small shear box apparatus shall enable a soil specimen of a nominal size of 60 mm to 100 mm square or circular by about 20 mm thick in the case of Test Method A and 100 mm square or circular by about 44 mm thick in the case of Test Method B to be sheared horizontally along its mid-height plane while subjected to a vertical stress. The minimum ratio of the width or diameter of the soil specimen to its thickness shall be 2:1. The whole apparatus shall be mounted on a rigid bed and shall comprise the following essential components:

- a shear box (typical details are shown in Figure 16.1) shall be a square or circular container for the soil specimen and can be divided horizontally into two halves. For Method A, the lower half shall be fitted with a removable retaining grooved baseplate, but this shall be omitted for

Method B. The shear box shall be rigid enough to resist distortion under the maximum load. Arrangements shall be provided for locking the two halves of the shear box securely together while the soil specimen is being placed, and for lifting the upper half of the box off the lower half by a small and controlled vertical displacement without tilt after a vertical load has been applied to the specimen. When released, the lower half shall be able to move freely relative to the upper half. The shear box shall be placed in an outer container, in which the lower half of the box can be secured rigidly in place. The upper half shall be fitted with a central attachment which ensures that the applied horizontal shearing force is in the same plane as the plane of shear induced in the specimen,

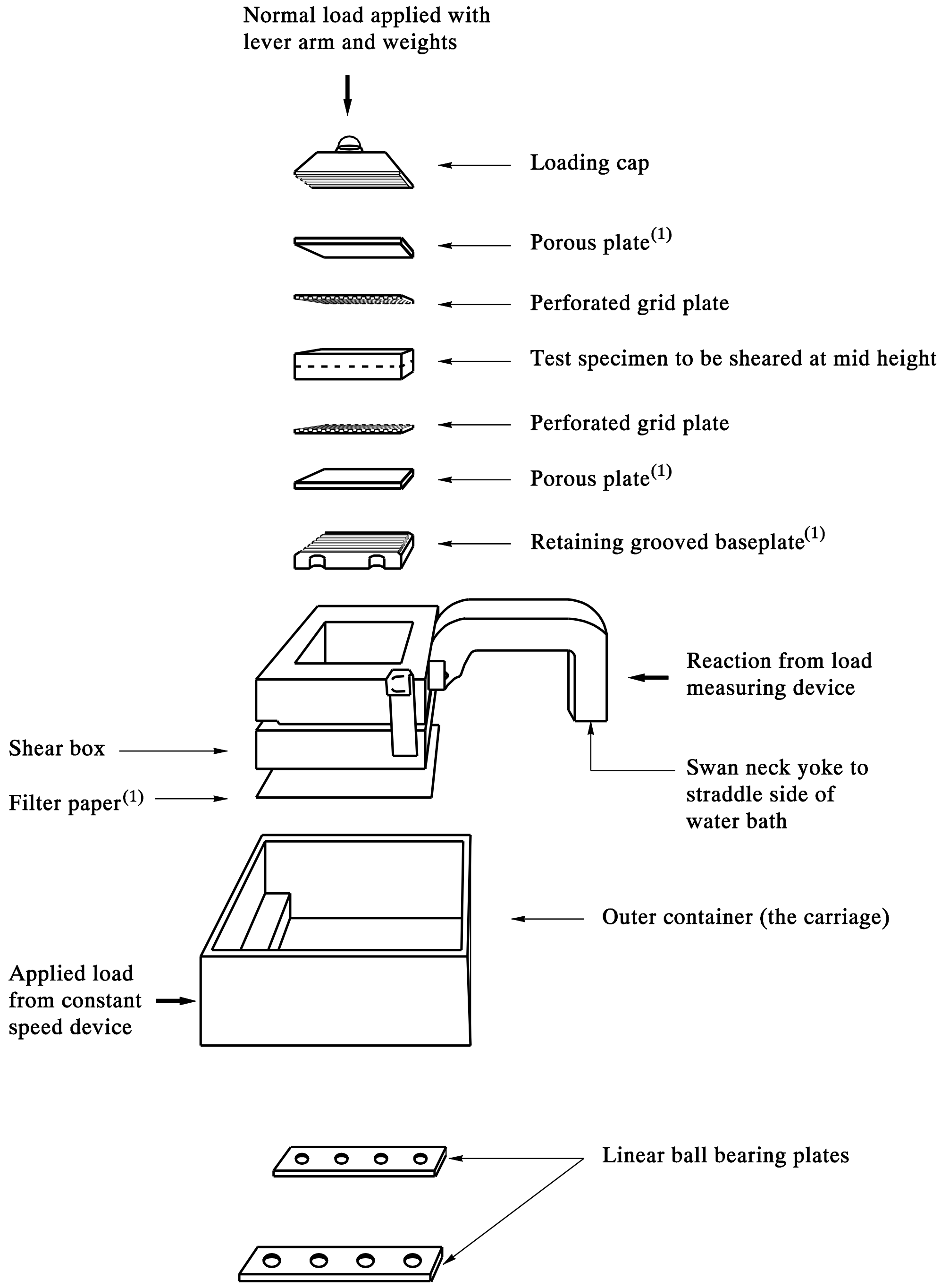
- the carriage, which is an outer container such that the shear box can be placed to enable the test specimen to be submerged under water during the test (typical assemblies for Methods A and B are shown in Figure 16.2 and Figure 16.3 respectively). The carriage shall be supported on the bed of the machine by a low-friction bearing which allows movement in the longitudinal direction only. The materials comprising the shear box, the carriage and all components which fit into them shall be resistant to corrosion by electro-chemical reaction with each other,

- two corrosion-resistant porous plates, to be used for Method A only. The porous plate shall be of 0.4 mm - 0.6 mm smaller than the internal plan dimensions of the shear box, in order to permit free compression of the soil specimen. The requirements for the material, thickness, surface conditions, porosity and permeability of the porous plate shall be as described in Clause 14.1.3 (d) for the porous plate used for the oedometer test,

- filter papers (Whatman No. 54 or equivalent), to replace the two porous plates for Method B. The dimensions of the upper filter paper shall be slightly smaller than the internal plan area of the shear box, and the lower filter paper shall be about the same size as the outer dimensions of the shear box to enable better penetration of water into the soil specimen. Unused filter papers shall be used for every test. The papers shall be soaked in water overnight before use,

- two perforated grid plates of about the same size in plan as the porous plates,

- a loading cap covering the top porous plate or the grid plate. The cap shall be fitted with a central ball seating through which the vertical load is applied to the specimen. It shall be 0.4 mm - 0.6 mm smaller in plan than the internal dimensions of the shear box, and shall be rigid enough to transmit the vertical load uniformly to the specimen without deformation,



Note: (1) In method B, the porous plates are omitted and replaced by the filter papers. Also the retaining grooved baseplate is omitted, and a filter paper is placed directly beneath the shear box insider the outer container.

Figure 16.1 Exploded Diagram of a Small Shear Box

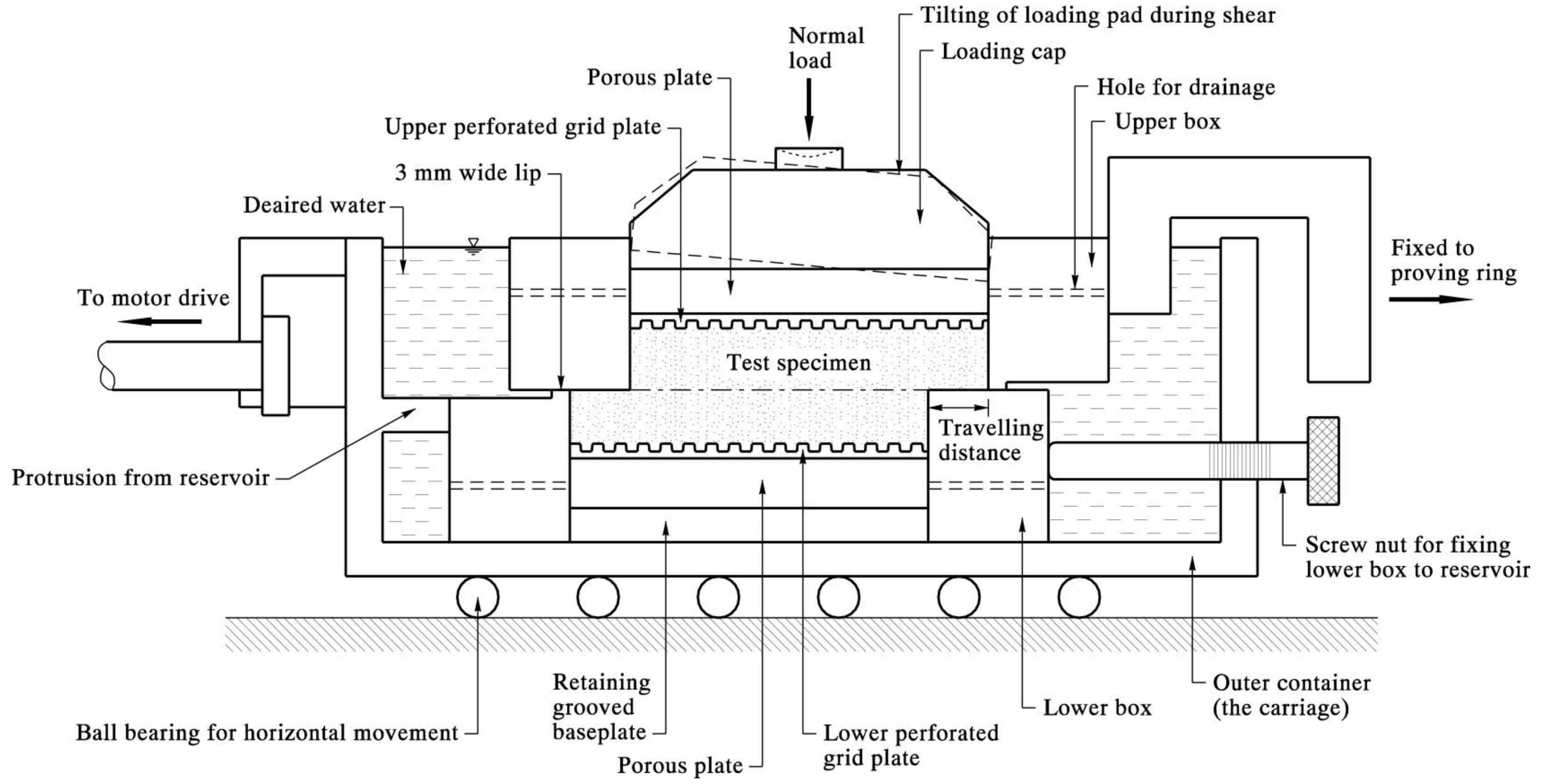


Figure 16.2 Cross-section of Small Shear Box with a 20 mm Thick Test Specimen (Method A)

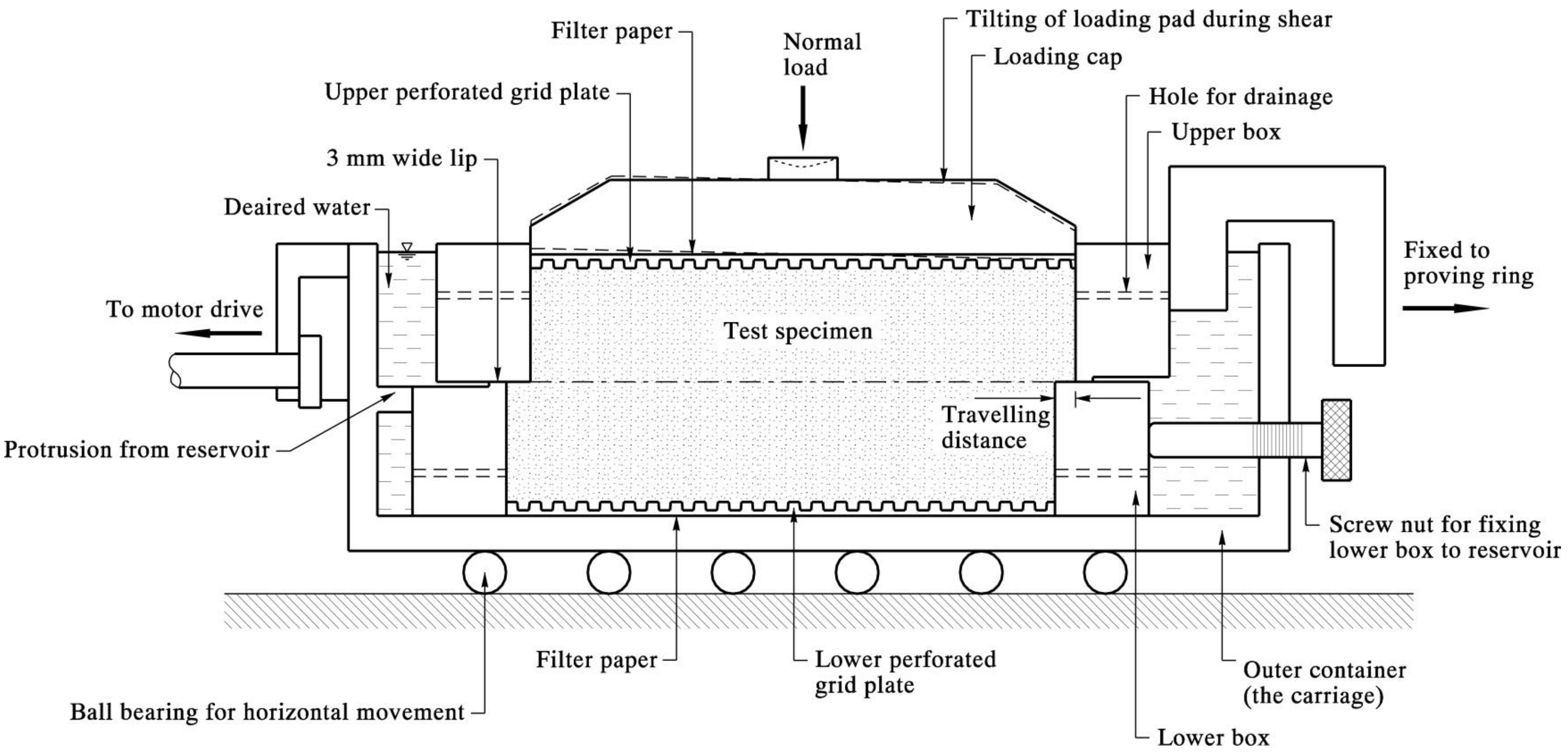


Figure 16.3 Cross-section of Small Shear Box with a 44 mm Thick Test Specimen (Method B)

- a means of applying a vertical force to the loading cap such as a loading yoke, which shall preferably be counterbalanced and carry calibrated masses. For applying large forces, a mechanical lever system, preferably counterbalanced, may be used. The vertical force applied to the test specimen shall produce a pressure to the nearest 2 kPa and accurate to 4 kPa or 2% of the applied stress, whichever is greater. The loading device shall enable the vertical stress to be applied to the specimen without significant impact. This can be done with a screwjack support,

- a calibrated shear displacement device which shall be a motorised loading device capable of applying a horizontal shear to the vertically loaded specimen at the specified constant rates of displacement. The actual rate of displacement shall not vary by more than 10% of the target value. The device shall be capable of applying a horizontal displacement of at least 10 mm to the specimen,

- a calibrated force-measuring device which shall be readable to 0.005 kN and accurate to 0.01 kN or 2% of the measured value whichever is greater, of appropriate range suitable for the test specimen. It shall be suitably mounted,

- a horizontal displacement gauge which shall be a calibrated dial gauge or displacement transducer suitably mounted to measure the relative horizontal displacement of the two halves of the shear box. It shall be readable to 0.01 mm and accurate to 0.02 mm, and

- a vertical deformation gauge which shall be a calibrated dial gauge or displacement transducer capable of measuring the vertical deformation of the specimen during the test, readable to 0.002 mm and accurate to 0.01 mm.

(d) a tool, such as a wooden dolly, for removing the specimen from the cutter,

(e) a metal tamping rod with a square end of about 10 mm across flats,

(f) a levelling template for trimming the surface of a soil specimen in the shear box to a known level,

(g) a calibrated vernier depth-gauge or a micrometer gauge on a suitable comparator support, readable to 0.01 mm and accurate to 0.02 mm, for measuring the depth to the top of the soil specimen in the shear box and the projection of the top cap, and

(h) the other miscellaneous apparatus and materials as in Clause 14.1.3 (j) for the oedometer test.

16.1.4 Calibration

The calibration of apparatus shall be in accordance with Appendix A.

16.1.5 Sample Preparation

16.1.5.1 Ensure that the specimen cutter is clean and dry and the cutting edge is in good condition.

16.1.5.2 Determine and record the mass of the cutter to 0.01 g.

16.1.5.3 Determine the mass of the watch glass or perspex plate to 0.01 g.

16.1.5.4 Measure and record the mean internal dimensions of the cutter to 0.05 mm.

16.1.5.5 Provide a description of the sample in accordance with Geoguide 3 (GCO, 1988) and carry out pre-test assessment on the sample as described in Clause 13.1.

16.1.5.6 Prepare the disc specimen of the appropriate size specified for cutter used in accordance with Clause 13, as appropriate. Follow either Clause 13.2 for remoulded samples, or Clause 13.3 for undisturbed specimen taken either from a tube sample as described in Clause 13.3.6, or a block sample as stated in Clause 13.3.7.

16.1.5.7 Measure the height of the cutter to 0.01 mm, which shall be taken to be equal to the height of the specimen, H_0.

16.1.5.8 Weigh the specimen in its cutter together with the watch glass or perspex plate and determine the initial mass of the specimen, m_0, immediately and to 0.01 g.

16.1.5.9 Take separate specimen from the same sample for the determination of particle density, if required, and initial moisture content, w_i, in accordance with the test method specified for reference purpose.

16.1.6 Test Procedures

16.1.6.1 Prepare and assemble the shear box as follows:

(i) Ensure that the shear box components are clean and dry. Apply a thin coating of silicone grease or petroleum jelly to the inside faces of the shear box and to the surfaces of contact between the two halves of the shear box.

(ii) Assemble the shear box with two halves securely clamped together using the clamping screws. Fit the retaining grooved baseplate (for Method A) or filter paper (for Method B) and place them securely in position in the carriage.

(iii) For Method A, place a porous plate at the base inside the shear box followed by a perforated grid plate. The shear box assembly shall then be placed on top of a dry flat surface during specimen preparation. For Method B, place a perforated grid plate at the base inside the shear box followed by a filter paper beneath the shear box, which shall be extended to the outer edges of the shear box. The shear box assembly shall then be placed inside the carriage during specimen preparation. The perforated grid plates shall be placed in a such a way that their grids are at right angle to the direction of shear.

16.1.6.2 Mount the specimen in the shear box as follows:

(i) Rest the cutter on the top surface of the assembled shear box with its inside faces in exact alignment with the inside faces of the box.

(ii) Push the specimen out of the cutter into the shear box by means of a wooden dolly and keeping its upper face horizontal, until it is bedded onto the lower perforated grid plate. Avoid consolidating the specimen.

(iii) Place the upper perforated grid plate firmly on the specimen followed by the upper porous plate (in Method A) or filter paper (in Method B). Ensure that there is an equal clearance all around the edges of the plates. The grids of the perforated grid plate shall be at right angle to the direction of shear.

(iv) Place the loading cap on top of the porous plate or the filter paper with a uniform all-round clearance.

16.1.6.3 Carry out initial adjustment of the test assembly as follows:

(i) Position the carriage on its bearings on the machine bed, and adjust the drive unit to the correct starting point of the shear test. Secure the horizontal displacement gauge in position.

(ii) Assemble the vertical loading system so that the cross-beam of the loading yoke is in contact with the self-aligned seating on the loading cap with the weight of the loading yoke supported from below.

(iii) Apply a small seating load to the specimen so that the resulting pressure on the specimen after taking into account of the weight of the loading cap, porous plate and perforated grid plate shall not be greater than 5 kPa. Record the actual seating pressure applied to the specimen.

(iv) Secure the vertical deformation gauge in position so that it can measure the vertical displacement at the centre of the top of the loading cap, ensuring that it allows enough vertical displacement in either direction.

Record the initial zero reading.

16.1.6.4 Fill the outer container with water to a level above the top of the specimen. Soak the specimen for a minimum period of 12 hours prior to consolidation. Record the amount of swelling or compression at the end of this period.

Note: If necessary, trials may be carried out to determine the minimum soaking period.

16.1.6.5 Carry out consolidation as follows:

(i) Apply a normal force to the specimen to give the desired vertical (normal) stress, σ_n (in kPa), smoothly and as rapidly as possible without jolting. Start the clock at the same instant.

(ii) Record readings of the vertical deformation gauge and the elapsed time at suitable time intervals to allow a graph to be drawn of the vertical deformation as the ordinate, against the square-root of elapsed time as the abscissa. A plot of the vertical deformation against time to a logarithmic scale should also be made. Continue the recording until the plotted readings indicate that the primary consolidation is complete. The end of primary consolidation is determined from either the square-root of time plot or the logarithmic of time plot, whichever gives a longer consolidation period.

Note 1: In some cases, the end of primary consolidation can be identified on only the square-root time plot or the log time plot. In such cases, that shall be taken as the end of primary consolidation.

Note 2: This method does not permit the derivation of a reliable value of coefficient of consolidation, c_v.

(iii) On the square-root time plot, extend the approximately linear portion of the graph (which normally lies between just after zero time to about 50% of primary consolidation) downwards. Identify the point at which this line intersects the horizontal line through the final point on the curve of primary consolidation, and read off the value $\sqrt{t_{100}}$ on the square-root time axis.

(iv) Calculate the minimum time to shear the soil specimen to failure, t_f (min), from the equation:

$$t_f = 12.7\ t_{100} \text{ or } 30 \text{ min, whichever is longer}.$$

(v) Estimate the likely horizontal shear displacement of the soil specimen at failure (in mm). Divide it by t_f to obtain the maximum rate of shear displacement (in mm/min) to be applied during the shear test.

16.1.6.6 Set the rate of shear displacement to a value not greater than that calculated in Clause 16.1.6.5 (v) and that failure shall not be induced in less than 30 min.

16.1.6.7 Carry out final adjustments and checks for the assembly as follows:

(i) Ensure that all associated components from the constant rate of shear displacement device through to the load measuring device and its point of restraint are properly in contact under zero horizontal load.

(ii) Remove the clamping screws which lock the two halves of the shear box together.

(iii) Raise the upper half of the box, keeping it level, by turning the lifting screws. The amount of clearance between the two halves of the box should be enough to prevent them coming together during the test, but shall not permit extrusion of the soil between them. Retract the lifting screws.

Note: Lifting by about a half-turn of the screws is usually sufficient.

(iv) Record the initial readings of the horizontal displacement gauge, the vertical deformation gauge and the force measuring device.

16.1.6.8 Carry out shearing as follows:

(i) Check that the rate of shear displacement has been set in accordance with Clause 16.1.6.6.

(ii) Start the test and at the same instant start the timer. Record sufficient sets of readings of the force measuring device, the horizontal displacement gauge, the vertical deformation gauge and elapsed time at intervals during shearing so that the stress-strain curve can be clearly defined.

Note: Readings shall normally be taken at regular intervals of horizontal displacement. The frequency of readings to be taken shall not be less than 5 readings per 1% strain. However, after the maximum deviator stress, if attainable, is reached, the frequency can be reduced to 2 readings per 1% strain. Additional readings may be taken as the maximum horizontal force is approached so that if the ‘peak’ occurs it can be defined clearly.

(iii) During the test, monitor the rate of relative displacement of the two halves of the shear box regularly. If this rate exceeds the maximum rate in Clause 16.1.6.6, reduce the speed of travel of the shearing device accordingly.

(iv) Continue shearing until the maximum shear force can be clearly defined or until the full travel of the apparatus has been reached, then stop the test.

16.1.6.9 Unload the specimen and dismantle the test assembly as follows:

(i) Reverse the direction of travel of the carriage and return the two halves of the shear box to their original position.

(ii) If the soil specimen has been sheared under water, siphon off the water from around the specimen and allow it to stand for at least 10 min to enable free water to drain from the apparatus.

(iii) Remove the vertical force and loading yoke from the soil specimen.

16.1.6.10 Process the tested specimen as follows:

(i) Where feasible, separate the two halves of the specimen by pushing them in the same manner as that during the shear test, and take photographs of the shear surfaces (at a scale of about 1:2) alongside a scale and a colour chart. Describe the soil including its fabric in accordance with Geoguide 3 (GCO, 1988). For undisturbed specimens, examine the shear surface, if any, for the presence of particles larger than that acceptable.

Note: The above operation should be completed without delay to avoid loss of moisture from the specimen.

(ii) Transfer the soil specimen from the shear box to a small tray, taking care not to lose any soil. Remove any free water with a tissue.

(iii) Weigh the soil specimen on the tray to determine its final wet mass (m_f) to 0.01 g.

(iv) Dry the specimen to constant mass at the same temperature as that used for the determination of moisture content and determine the dry mass (m_d) to 0.01 g. Determine the final moisture content of the soil specimen to 0.1%.

(v) For undisturbed soil specimen, soak it in water until it is sufficiently soften for breaking up into individual particles. Break it up for inspection. Determine the percentage by mass of the particles larger than that acceptable, if present, and take photograph of them alongside a scale and a colour chart.

16.1.7 Calculations

16.1.7.1 Calculate the initial and final moisture content of the specimen, w_0 and w_f (to 0.1%), from the following equations:

$$w_0 = \frac{100\,(m_0 - m_d)}{m_d}\;; \qquad w_f = \frac{100\,(m_f - m_d)}{m_d}$$

where m_0 is the initial wet mass of the specimen (in g);
m_f is the final wet mass of the specimen (in g); and
m_d is the final dry mass of the specimen (in g).

16.1.7.2 Calculate the initial bulk density, ρ_0 (to 0.01 Mg/m^3), from the following equation:

$$\rho_0 = \frac{1000\ m_0}{AH_0}$$

where A is the plan area of the specimen (in mm^2); and
H_0 is the initial thickness of the specimen (in mm).

16.1.7.3 Calculate the initial dry density, ρ_{do} (to 0.01 Mg/m^3), from the following equation:

$$\rho_{do} = \frac{1000\ m_d}{AH_0}$$

16.1.7.4 Calculate the initial void ratio, e_0 (to 0.01), from the following equation:

$$e_0 = \frac{\rho_s}{\rho_{do}} - 1$$

where ρ_s is the particle density (to 0.01 Mg/m^3) (which may be measured, or assumed; if assumed, a default value of 2.65 is to be used, unless otherwise specified).

16.1.7.5 Calculate the initial degree of saturation, S_0 (to 0.1%), from the following equation:

$$S_0 = \frac{w_0 \rho_s}{e_0 \rho_w}$$

where ρ_w is the density of water = 1.0 Mg/m^3.

16.1.7.6 Calculate the void ratio, e (to 0.01), after soaking, at the end of the consolidation stage, and at the end of shearing from the equation:

$$e = e_0 - \frac{\delta H}{H_0}(1 + e_0)$$

where δH is the change in thickness (vertical deformation) of the soil specimen (in mm) from its initial thickness.

16.1.7.7 Calculate the dry density, ρ_d (to 0.01 Mg/m^3), after soaking, at the end of the consolidation stage and at the end of shearing from the following equation:

$$\rho_d = \frac{\rho_s}{1 + e}$$

16.1.7.8 Calculate the final bulk density, ρ_f (to 0.01 Mg/m^3), from the following equation:

$$\rho_f = \frac{1000\ m_f}{A\ (H_0 - \delta H)}$$

where m_f is the final wet mass of the specimen (in g).

16.1.7.9 Calculate the final degree of saturation, S_f (to 0.1%), from the following equation:

$$S_f = \frac{w_f \rho_s}{e_f \rho_w}$$

where e_f is the void ratio at the end of shearing as determined in Clause 16.1.7.6.

16.1.7.10 Carry out the calculations on stress and displacement as follows:

(i) From the data obtained during the shear test, calculate the horizontal shear force, P (to 1 N), applied to the soil specimen.

(ii) Calculate the shear stress on the surface of shear, τ (to 0.1 kPa), applied to the soil specimen from each set of readings from the following equation:

$$\tau = \left(\frac{P}{A}\right) 1000$$

where A is the initial plan area of the soil specimen (in mm^2).

Note: The continual change in the area of contact (the shear surface) is not taken into account.

(iii) Calculate the normal stress, σ_n (to 0.1 kPa), applied to the soil specimen from the following equation:

$$\sigma_n = \frac{9810\ m}{A}$$

where m is the total mass of the hanger and hanger weights (or equivalent mass if a lever-arm loading system is used), including the loading cap, porous plate and perforated grid plate, applied to the specimen (in kg).

16.1.7.11 Plot the following graphs:

(i) the graph of shear stress, τ (in kPa) against horizontal displacement (in mm); and

(ii) the graph of cumulative vertical deformation of the soil specimen (in mm) against horizontal displacement (in mm).

16.1.8 Reports

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the general information as required in B.1.1 of Appendix B,

(b) the information as required in B.1.2 of Appendix B for Phase II tests,

(c) the initial moisture content, bulk density and dry density of the specimen and also its dry density after soaking, at the end of consolidation and at the end of shearing, as well as its final moisture content, bulk density and dry density (state the test method used for moisture content determination; if minimum mass requirement for carrying out the moisture content tests cannot be followed, this shall be stated),

(d) the initial and final void ratio and degree of saturation, and also the void ratio after soaking, at the end of consolidation and at the end of shearing,

(e) the rate of horizontal displacement,

(f) the actual seating pressure applied to the specimen,

(g) plots of vertical deformation during consolidation of the specimen against both log time and square-root time,

(h) the shear strength of the specimen (i.e. the maximum shear stress reached in the test), the corresponding horizontal and vertical displacement and normal stress and plots in accordance with Clause 16.1.7.11,

(i) the period of soaking,

(j) the amount of swelling or compression upon soaking, and

(k) where feasible, photographs of the upper and lower shear surfaces of the tested specimen (at a scale of about 1:2) taken alongside a suitable scale and a colour chart.

16.2 The Direct Shear Test (Large Shear Box Apparatus)

16.2.1 Scope

This test is used for the determination of the effective shear strength of a remoulded soil specimen at a specified normal stress. In this test, a large shear box is used.

16.2.2 General

The test is suitable for soils containing particles up to 25 mm in size. The general information given in Clause 3.12 shall be noted.

The environmental requirement as described in Clause 14.1.2 shall be observed.

16.2.3 Apparatus

The following apparatus are required:

(a) the apparatus for moisture content determination as specified in Clause 5,

(b) a large shear box apparatus shall enable a soil specimen of a normal size of 300 mm square by about 150 mm thick to be sheared horizontally along its mid-height plane at a constant rate of horizontal displacement while subjected to a vertical stress. The whole apparatus shall be mounted on a rigid bed and comprise the following essential components:

- a large shear box shall fulfil similar requirements as specified in Clause 16.1.3 (c) for Method A of the small shear box, except with a larger size (typical details of a large shear box are shown in Figure 16.4),

- an extension former which shall be about 40 mm thick, with suitable tolerances to fit to the top of the shear box to facilitate compaction of the fill material in the shear box,

- a carriage which shall be similar to that described in Clause 16.1.3 (c), except with a large size to accommodate the large shear box,

- two grid plates which shall be about 2 mm smaller than the internal plan dimensions of the shear box. They shall permit drainage of water from the specimen,

- a loading cap fitted with a central ball seating through which the vertical load is applied to the specimen. The cap shall be about 2 mm smaller in plan than the internal dimensions of the shear box, and shall be rigid enough to transmit the vertical load uniformly to the specimen. If integral with the top grid plate, it shall permit drainage of water from the specimen,

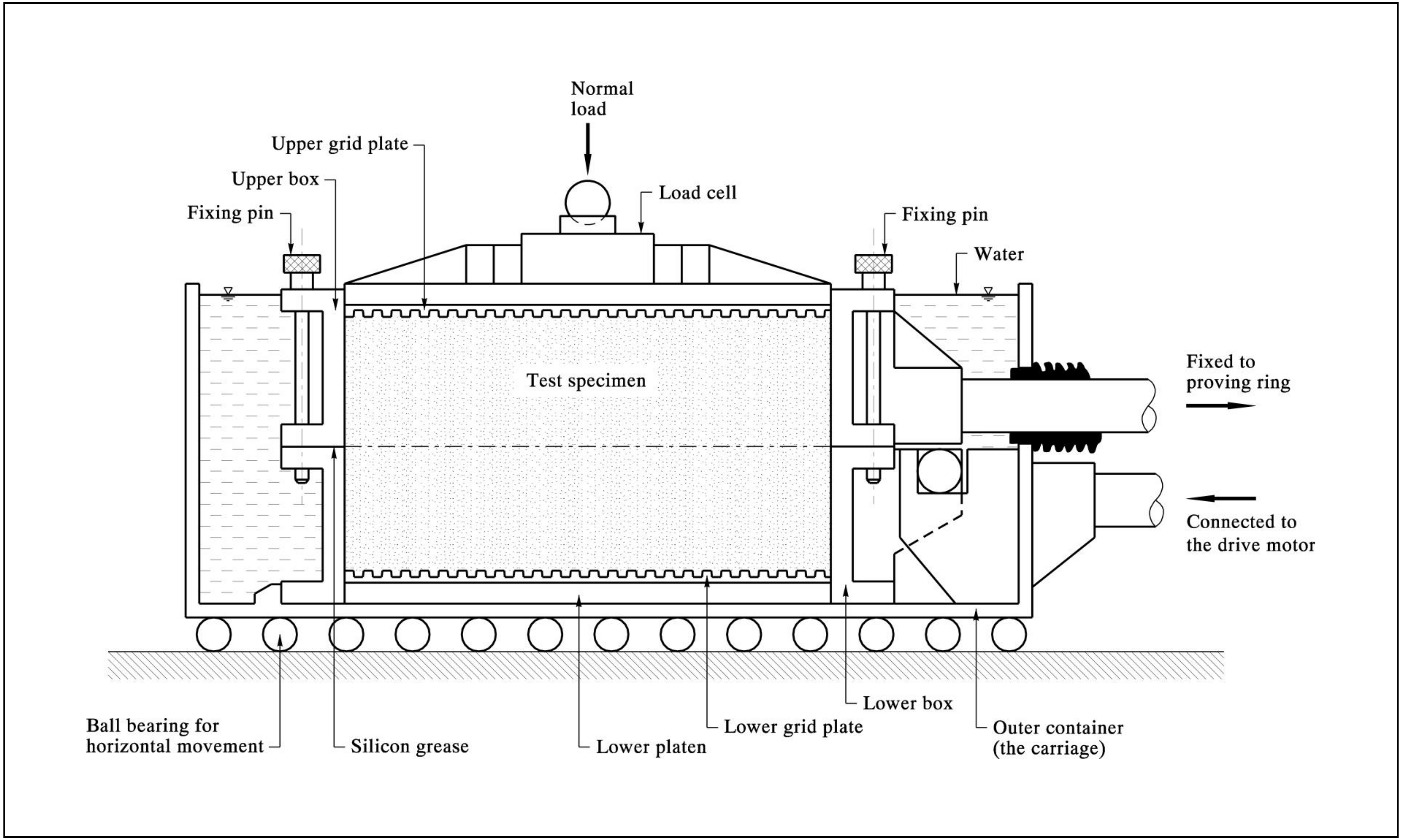


Figure 16.4 Cross-section of a Large (300 mm Square) Shear Box

- a means of applying a vertical force to the loading cap, which shall be either a hydraulic system or a mechanical lever loading system using calibrated hanger weights. It shall be able to apply forces to the specimen to produce a pressure to 2 kPa and accurate to 4 kPa or 2% of the applied stress, whichever is greater. It shall enable the vertical stress be applied to the specimen without significant impact. The pressure if applied hydraulically shall be indicated by a pressure gauge of test grade or a transducerised force-measuring device readable to 1 kPa and accurate to 2 kPa,

  Note: A calibrated load cell of the required readability placed between the loading cap and the loading yoke may be used to measure the pressure.

- a calibrated shear displacement device which shall be similar to that described in Clause 16.1.3 (c), except that it shall be capable of applying a larger horizontal displacement of at least 50 mm to the specimen, and

- a calibrated force-measuring device, and horizontal and vertical displacement gauges which shall be similar to those described in Clause 16.1.3 (c), with a range suitable for the test.

(c) a vibrating hammer, if the test specimen is to be prepared by vibratory compaction,

(d) a steel tamper attached to the vibrating hammer which shall have a square foot and of mass not exceeding 3 kg. A suitable size would be 100 mm square,

(e) a square steel plate, about 16 mm thick, with a removable lifting handle which shall have suitable tolerances to form a flush fit inside the shear box, if the test specimen is to be prepared by static compaction,

(f) a suitable compression machine (e.g. Universal Testing Machine), if the test specimen is to be prepared by static compaction,

(g) a steel tamping rod with a square end of about 25 mm across flats,

(h) a levelling template, for trimming the surface of the soil in the shear box to a known level,

(i) calibrated external/internal vernier calipers, readable to 0.05 mm and accurate to 0.1 mm,

(j) a calibrated balance, of 25 kg capacity and readable to 5 g and accurate to 25 g,

(k) a calibrated platform scale, of 100 kg capacity, readable to 50 g and accurate to 0.1 kg,

(l) a calibrated maximum and minimum temperature measuring device, readable to 0.5°C and accurate to 1°C,

(m) a supply of distilled water at room temperature,

(n) a straightedge scraper,

(o) a steel rule, at least 450 mm long and graduated in millimetres,

(p) a sharp-bladed trimming knife,

(q) a wire saw,

(r) two or more spatulas,

(s) a metal scoop,

(t) a garden trowel,

(u) a small pointing trowel,

(v) a polyethylene sheet,

(w) several containers such as buckets,

(x) a few kilograms of dry medium sand, and

(y) a riffle box of suitable size for the soil to be tested.

16.2.4 Calibration

The calibration of apparatus shall be in accordance with Appendix A.

16.2.5 Sample Preparation

16.2.5.1 Prepare the soil sample in accordance with Clauses 13.2.2.1 to 13.2.2.9 for remoulded samples.

Note: The sample shall be large enough for the series of tests to be carried out without having to re-use any part of it.

16.2.5.2 Determine the percentage by weight of soil passing the 63 μm BS sieve after drying of the sample.

16.2.5.3 Compact the soil at the specified moisture content into the large shear box to achieve the specified dry density as described below:

(i) Weigh out a mass of prepared soil which will give the required density when it just fills the shear box to the required level. Subdivide the soil into five equal portions, and place each portion in an air tight container until it is required for use.

(ii) Before compacting the soil specimen into the shear box, fit the grooved baseplate inside the shear box and the extension former on top of the shear box where necessary.

(iii) Mark the levels clearly on the internal surfaces of the shear box up to which each of the three portions of the soil specimen must be compacted in order to achieve the specified target density. The top level of the finally compacted specimen shall be approximately 20 mm below the top of the shear box. None of the compacted layers shall finish at the same level as the top of the lower shear box.

(iv) Carry out compaction by either Method A or Method B as follows:

Method A - Vibratory Compaction

(1) Pour a portion of the soil material into the shear box, spread it evenly, and compact uniformly using the vibrating hammer so that after compaction the top level of the soil specimen matches the target level marked on the internal faces of the shear box. During compaction, the shear box shall be seated on a solid base, e.g. a structural floor or concrete plinth.

(2) Repeat (1) above until all three portions of the soil material are compacted into the shear box.

Method B - Static Compaction

(1) Pour a portion of the soil material into the shear box and spread it evenly. Lightly tamp the soil material by means of a steel tamping rod and prepare the top surface so that it is approximately level.

(2) Place a square steel plate on top of the soil material in the shear box, and place the whole box into the compression machine. Apply a compression load to the plate through an arrangement of steel distributing blocks and with steel spacers of suitable size placed on the top of the extension former, so that after compaction the top level of the soil specimen matches the target level marked on the internal faces of shear box. Then relieve the compression load and re-apply the load if necessary until the rebound on releasing the load is negligible.

(3) Repeat (1) and (2) above until all three portions of the soil material are compacted into the shear box.

16.2.6 Test Procedures

16.2.6.1 Prepare and assemble the large shear box as follows:

(i) Ensure that the shear box components are clean and dry. Clamp the two halves of the box securely together.

(ii) Weigh the top grid plate to 50 g.

(iii) Determine the internal plan dimensions (L_1 x L_2) of the shear box to 0.05 mm, and calculate its plan area A (to 0.1 mm^2).

16.2.6.2 Carry out initial adjustment of the test assembly as in Clause 16.1.6.3 for the small shear box tests.

16.2.6.3 Soak the test specimen for a minimum period of 12 hours where the soil is found to contain not more than 10% by mass of material passing the 63 µm BS sieve. Otherwise, soak the specimen for at least 72 hours. During soaking, maintain the seating pressure of not exceeding 5 kPa as in Clause 16.1.6.3. Determine the amount of swelling or compression during soaking from the measurements of displacements taken at the centre of the top of the loading hanger.

Note: If necessary, trials should be carried out to determine the minimum soaking period.

16.2.6.4 Carry out consolidation in accordance with Clauses 16.1.6.5 (i) and (ii) as for the small shear box test.

16.2.6.5 Adjust the rate of shearing as specified. Where the rate is not specified, the following guidelines may be adopted:

(i) For soil containing not more than 10% by mass of material passing the 63 µm BS sieve, the rate of shearing shall not be greater than 1.0 mm/min.

(ii) For soil containing more than 10% by mass of material passing the 63 µm BS sieve, the rate of shearing shall not be greater than 0.1 mm/min.

16.2.6.6 Carry out final adjustments and checks for the assembly as in Clause 16.1.6.7 for the small shear box test.

16.2.6.7 Carry out shearing as in Clause 16.1.6.8 for the small shear box test, except that the maximum rate of shear displacement shall be as determined in Clause 12.2.6.5 above.

16.2.6.8 Unload the specimen and dismantle the test assembly as in Clause 16.1.6.9 for the small shear box test.

16.2.6.9 Take three representative soil samples near the sheared surface and at about the top and bottom third points of the soil specimen. Dry them to constant mass at the same temperature as specified for the determination of moisture content, and determine their average moisture content (w_f) to 0.1%.

16.2.6.10 Take another representative soil sample and determine its particle size distribution in accordance with the test method specified.

16.2.7 Calculations

16.2.7.1 Calculate the initial bulk density, ρ_0 (to 0.01 Mg/m^3), from the following equation:

$$\rho_0 = \left(1 + \frac{w_0}{100}\right) \rho_{do}$$

where w_0 is the initial moisture content of the specimen (in %); and
ρ_{do} is the initial dry density of the specimen (in Mg/m^3).

16.2.7.2 Calculate the initial void ratio (e_0), initial and final degree of saturation (S_0 and S_f), void ratio (e) and dry density (ρ_d) after soaking, at the end of the consolidation stage and at the end of shearing, from the equations given in Clause 16.1.7 for small shear box test.

16.2.7.3 Carry out the calculations on stress and displacement as in Clause 16.1.7.10, except that the normal stress, σ_n (to 0.1 kPa), applied to the soil specimen shall be determined from the following equation:

$$\sigma_n = \left(\frac{F}{A}\right) 10^6$$

where F is the force applied to the soil specimen including the weight of the loading cap and the grid plate (in kN).

16.2.7.4 Plot the graphs as in Clause 16.1.7.11 for the small shear box test.

16.2.8 Report

The test report shall affirm that the test was carried out in accordance with this test method and shall contain the following information:

(a) the information as required in Clause 16.1.8 as for small shear box test, and

(b) the particle size distribution of the test specimen after shearing (state the test method used).

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Appendices

Appendix A

Calibration Requirements for Reference Standards, Test Equipment and Materials

A.1 Calibration Requirements for Reference Standards

Where calibration of measuring instruments is carried out in-house, the laboratory shall hold reference standards or instruments that are used solely for calibration purposes. Reference standards or instruments shall be retained securely in a suitable environment when not in use. The detailed requirements, including the maximum calibration intervals, on in-house and external calibrations given in HOKLAS 003 (HKAS, 2000) and HOKLAS Supplementary Criteria No. 2 (HKAS, 1998) shall be followed.

A.2 Calibration and Checking Requirements for Test Equipment And Materials

The detailed calibration requirements, including the maximum calibration intervals, for test equipment and materials given in HOKLAS 003 (HKAS, 2000) and HOKLAS Supplementary Criteria No. 2 (HKAS, 1998) shall be followed.

The detailed calibration procedures and acceptance criteria for force-measuring device, pressure measuring device, volume change measuring device and linear displacement measurement device (LVDT) are given in Clause A.3.

A.3 Methods of Calibration for Some Equipment

A.3.1 Force-measuring Device (Compressive Forces)

A.3.1.1 General

Each force-measuring device shall be calibrated against a reference proving device having a range and sensitivity appropriate to that of the measuring device. Where it is not practicable to calibrate each force-measuring device in the load frame in which it is to be used, it shall be calibrated in a load frame of an equivalent stiffness. The load frame used shall be identified in the calibration records. Where a device is fitted with a dial gauge or displacement transducer (such as LVDT or digimatic gauges) this shall be considered to be an integral part of the device and shall be marked as such. It shall not be replaced without recalibration of the device. The device shall be used only over the range for which it has been calibrated. The calibration uncertainty shall be determined and the assessment of the uncertainty shall be in accordance with the ISO Guide to the Expression of Uncertainty in Measurement (GUM) (ISO, 1995).

A.3.1.2 Procedures

A.3.1.2.1 For calibration using a calibrated proving device as reference standard, mount the force-measuring device and the proving device in the calibration apparatus so that forces are applied to the devices along the loading axis of the frame. The reference proving device shall be in accordance with BS EN ISO 376 : 2011 (BSI, 2011b). [Amd GS3/01/2017]

A.3.1.2.2 For calibration using a calibrated dead-weight tester as the reference standard, mount the force-measuring device in the load frame attached to the dead-weight tester.

A.3.1.2.3 Record the temperature of the equipment when stabilised.

A.3.1.2.4 Exercise the device as set up in either Clause A.3.1.2.1 or A.3.1.2.2 above at least three times up to the nominal capacity and down to zero load.

A.3.1.2.5 Reset to zero the dial indicator or digital display of the displacement transducer on the force-measuring device being calibrated and, if necessary, reset the indicator or display of the proving device or the dead-weight tester.

A.3.1.2.6 Operate the calibration apparatus to apply a series of at least ten more or less equally spaced known forces (as determined by the proving device in Clause A.3.1.2.1 or the dead-weight tester in Clause A.3.1.2.2) upwards from 10% of the nominal capacity of the force-measuring device. Record each reading of the dial indicator or digital display on the force-measuring device.

A.3.1.2.7 Repeat the steps in Clause A.3.1.2.6 to give three series of readings at the same forces. After each series remove the force completely and record the zero reading of the force-measuring device.

A.3.1.2.8 Average the three sets of force-measuring device dial indicator or digital display readings (divisions or digits) at each applied force.

A.3.1.2.9 Calculate the repeatability of each set of three readings. (The repeatability shall be taken to be equal to the greatest difference among the three readings of the force-measuring device at the same force applied by the reference device).

A.3.1.2.10 Divide the applied force by the average reading to obtain the calibration factor (force/division or force/digit) for each calibration force. Plot each calibration factor as ordinate against the average reading (divisions or digits) as abscissa. Join any two consecutive points with a straight line to form the calibration curve.

A.3.1.2.11 Draw a horizontal line representing the calibration factor for the mid-scale force (or closest for which readings have been obtained).

A.3.1.2.12 Calculate values of calibration factors that are 2% higher and 2% lower than the mid-scale factor.

A.3.1.2.13 The mid-range calibration factor may be used in a test to calculate the force in a test where the calibration curve lies within the ± 2% limits established in

Clause A.3.1.2.12. Where any parts of the calibration curve lies outside these limits the calibration factor shall be obtained directly from the calibration curve established in Clause A.3.1.2.10 or from a table, in which all the calibration factors are tabulated against the average reading and intermediate values are obtained by interpolation.

A.3.1.2.14 In addition, the calibration data obtained in Clause A.3.1.2.10 are acceptable over the range within which the repeatability obtained in Clause A.3.1.2.9 does not exceed 2% of the average value of the three readings.

A.3.2 Pressure Measuring Device

A.3.2.1 General

Pressure measuring device, whether of Bourdon tube types or transducer types, shall be calibrated against a reference dead-weight tester or a reference gauge. The gauge shall be used only over the range for which it has been calibrated. The calibration uncertainty shall be determined and the assessment of the uncertainty associated with the calibration shall be in accordance with the ISO GUM (ISO, 1995).

A.3.2.2 Procedures

A.3.2.2.1 Put together the pressure measuring device which is fully filled up with deareated water and the reference standard for an appropriate period until equalisation of temperature and environmental conditions.

A.3.2.2.2 Record the temperature of the equipment when stabilised.

A.3.2.2.3 Exercise the device at least three times up to the nominal capacity and down to zero pressure.

A.3.2.2.4 Reset to zero the analogue indicator or digital display of the device being calibrated and, if necessary, reset the display of the reference standard.

A.3.2.2.5 Operate the calibration apparatus to apply a series of at least ten more or less equally spaced pressures upwards from 10% of the nominal capacity of the pressure range.

A.3.2.2.6 Apply the series of pressures in ascending order. Record each reading of the display on the gauge.

A.3.2.2.7 Repeat the steps in Clauses A.3.2.2.5 and A.3.2.2.6 to give three series of readings at the same pressures. After each series remove the pressure completely and record the zero reading of the pressure-measuring device.

A.3.2.2.8 Average the three sets of pressure-measuring device analogue indicator or digital display readings at each applied pressure.

A.3.2.2.9 Divide the reference applied pressure by the average reading to obtain the calibration factor (in unit of pressure/division, pressure/digit or pressure/pressure) for each calibration pressure. Plot each calibration factor as ordinate against the average reading (division, digit or pressure) as abscissa. Join any two consecutive adjacent points with a straight line to form the calibration curve.

A.3.2.2.10 Draw a horizontal line representing the calibration factor for the mid-scale pressure.

A.3.2.2.11 Calculate values of calibration factors that are 0.5% higher and 0.5% lower than the mid-scale factor. Also calculate values of calibration factors that are 1% higher and 1% lower than the mid-scale factor.

A.3.2.2.12 The mid-range calibration factor may be used in a test to calculate the pressure in a test where the calibration curve lies wholly within the ± 0.5% limits established in Clause A.3.2.2.11. Where any parts of the calibration curve lies outside these limits the calibration factor shall be obtained directly from the calibration curve established in Clause A.3.2.2.9 or from a table, in which all the calibration factors are tabulated against the average reading and intermediate values are obtained by interpolation.

A.3.2.2.13 The pressure measuring device shall not be used for any parts of the calibration curve lies outside the 1% higher and 1% lower limits.

A.3.3 Volume Change Measuring Device

A.3.3.1 General

Volume change measuring devices, whether of burette type or transducer type, shall be calibrated by weighing the amount of deaired water that the volume change measuring devices displace at a measured temperature, applying any temperature corrections necessary in accordance with BS EN ISO 4787: 2011 (BSI, 2011a). Where a device is fitted with a displacement transducer such as a LVDT or a digimatic gauge, the transducer together with its readout unit shall be considered to be an integral part of the device and shall be marked as such. It shall be recalibrated if the transducer or its readout unit is replaced. The device shall be used only over the range for which it has been calibrated. The calibration uncertainty shall be determined and the assessment of the uncertainty associated with the calibration shall be in accordance with the ISO GUM (ISO, 1995). [Amd GS3/01/2017]

A.3.3.2 Procedures

A.3.3.2.1 Put together the volume change measuring device fully filled up with deaired water and a reference balance with a glass beaker or cylinder placed on it for an appropriate period until equalisation of temperature and environmental conditions.

Note: The discharge end of the device shall be at atmospheric pressure while the pressure source end shall be subjected to a pressure less than 5 m of water head.

A.3.3.2.2 Record the temperature of the equipment when stabilised.

A.3.3.2.3 Exercise the device at least three times up to the nominal capacity and down to the near zero displaced volume position.

A.3.3.2.4 Reset to zero the display of the device being calibrated.

A.3.3.2.5 Operate the volume change measuring device to arrive at series of at least ten more or less equally spaced displaced volumes (as determined from the mass of water displaced using the reference balance in Clause A.3.3.2.1) upwards from the initial near zero position to the nominal capacity of the volume change measuring device. Record each reading of the display on the device.

A.3.3.2.6 Repeat the step in Clause A.3.3.2.5 to give at least three series of readings. After each series, return the volume change measuring device back to its original near zero displaced volume position.

A.3.3.2.7 Calculate three least square best fit lines from the three series of readings from the equation:

$$Y = c + dX$$

where Y is the displaced volume in mL as determined using the reference balance;
X is the digit or division from the readout of the volume change measuring device;
c is the intercept of the best fit line in mL; and
d is the slope of the best fit line in mL/digit or mL/division.

A.3.3.2.8 Determine the mean slope, d_m, by averaging the three d values.

A.3.3.2.9 For the first series of readings obtained from Clause A.3.3.2.5, plot a straight with a slope equal to d_m, but keep the intercept as a variable. Draw two boundary lines (upper and lower) parallel to the straight line that are 0.3 mL higher and 0.3 mL lower than that line.

A.3.3.2.10 Where any one of the data points lies outside the upper and lower boundary lines, the calibration procedure should be repeated or the volume change measuring device should not be used.

A.3.3.2.11 Where all the data points lie inside the upper and lower boundary lines, repeat the procedure of Clauses A.3.3.2.9 to A.3.3.2.10 for another two series of readings, as obtained from Clause A.3.3.2.6.

A.3.3.2.12 Where all three series of readings lie inside the upper and lower boundary line, the mean slope factor, d_m, is used as the calibration factor for the volume change measuring device.

Note: Clauses A.3.3.2.7 to A.3.3.2.11 may be more conveniently done in a tabulated form.

A.3.3.2.13 If the device permits volume change measurements also in the reversed direction, the above procedure shall be repeated to obtain the calibration factor for volume change measurements in that direction.

A.3.4 Linear Displacement Measurement Device

A.3.4.1 General

Linear displacement measuring devices (LVDT), whether of mechanical dial gauge types or transducer types, shall be calibrated by using reference gauge blocks or reference micrometer type calibrators. The device shall be used only over the range for which it has been calibrated. The calibration uncertainty shall be determined and the assessment of the uncertainty associated with the calibration shall be in accordance with the ISO GUM (ISO, 1995).

The method of calibrating a dial gauge shall be in accordance with BS EN ISO 463 : 2006 (BSI, 2008), AS 2103 (Standard Association of Australia, 1978) or any other relevant standards. [Amd GS3/01/2017]

The method of calibrating a transducer type linear displacement measuring device is described in Clause A.3.4.2 below.

A.3.4.2 Procedures

A.3.4.2.1 Put together the measuring device and the reference standard for an appropriate period until equalisation of temperature and environmental conditions.

A.3.4.2.2 Record the temperature of the equipment when stabilised.

A.3.4.2.3 Exercise the device at least three times up to the nominal capacity and down to the zero displacement position.

A.3.4.2.4 Reset to zero the display of the device being calibrated.

A.3.4.2.5 Operate the reference and displacement measuring devices to apply a series of at least ten more or less equally spaced displacement upwards from the initial zero position to the nominal capacity of the displacement measuring device. Record each reading of the display on the device.

A.3.4.2.6 Repeat the step in Clause A.3.4.2.5 to give at least three series of reading at the same displacements. After each series, return the displacement measuring device back to its original zero displacement position.

A.3.4.2.7 Calculate the absolute values of the correction at each displacement position from the equation $|C| = |\text{Reference value} - \text{Measured Displacement value}|$.

A.3.4.2.8 Calculate the overall accuracy of the displacement device over the entire range by the following:

$$|C_{max}| + U$$

where $|C_{max}|$ is the maximum value of $|C|$ obtained from Clause A.3.4.2.7; and

U is the estimated expanded uncertainty of the device over the same range using the method in ISO GUM (ISO, 1995) mentioned above.

A.3.4.2.9 If the accuracy of the device calculated from Clause A.3.4.2.8 is better and more accurate than that in the testing requirement, the device can be used without any correction. Otherwise, the device should not be used.

A.4 References

[Amd GS3/01/2017]

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Appendix B

General Information to be Included in Test Reports

B.1 Laboratory Tests

B.1.1 General

Reports giving laboratory test data and results as specified for each test procedure shall include the following general information:

Note: Any values which are required to be reported shall be expressed with the same number of significant figures as the recorded values.

(a) date of test,

(b) method of test used, in accordance with this Geospec,

(c) sample identification reference or number, and location where appropriate,

(d) type of sample (Mazier, block, disturbed, etc.),

(e) Sample origin (sapolitic, residual, colluvial, marine etc.),

> Note: The geological origin of the soil should be indicated where this is provided by the Specifiers. Where particle size distribution and Atterberg limits test results are available for the same soil taken from the same sample, the laboratory soil description should be based on such test results in accordance with Table 20 of Geoguide 3 (GCO, 1988). Otherwise, the description should be based on visual identification in accordance with Table 11 of Geoguide 3 (GCO, 1988). Where the laboratory soil description differs from the sample description provided by the Specifiers, both descriptions should be indicated.

(f) visual description of soil including soil fabric and any unusual features, in accordance with Geoguide 3 (GCO, 1988),

(g) method of preparation of test specimen,

(h) the mass of sample used, particularly if undisturbed samples (e.g. Mazier or piston) are used and the required minimum sample mass is not achieved,

(i) the particle density indicating whether it was measured or assumed, and if assumed, the value adopted,

(j) unavoidable variations from specified procedure, with reasons, and

(k) all additional information provided by the Specifiers.

B.1.2 Phase II Tests

Reports on Phase II tests shall contain the following information:

(a) the initial dimensions of the specimen,

(b) for undisturbed samples, the location and orientation (if other than vertical) of test specimens within the original sample, and whether the specimen was selected by the Specifiers or the laboratory, in particular, the name, designation and affiliation of the persons who selected the specimen,

(c) for remoulded test specimens, the method and temperature for drying and the method of remoulding,

(d) where appropriate, comments on observed or inferred sample disturbance, including possible loss of moisture,

(e) the daily maximum and minimum temperatures recorded in the vicinity of the test apparatus over the whole period of the test,

(f) the percentage by mass of particles of sizes larger than that acceptable if found within the test specimen and a photograph of them taken alongside a suitable scale and a colour chart, and

(g) for cylindrical specimen used in the triaxial apparatus, photographs of the tested specimen (at a scale of about 1:2) taken both before and after it is split vertically into two halves alongside a suitable scale and a colour chart.

B.2 In-situ Tests

Reports giving in-situ test data and results as specified for each test procedure shall include the following general information:

(a) the date of test,

(b) method of test used, in accordance with this Geospec,

(c) test location, test number and borehole or pit number where appropriate,

(d) test level with respect to ground level and the reduced level of the test, where known,

(e) name and affiliation of the persons who located the test positions and who carried out the tests,

(f) description (in accordance with Geoguide 3 (GCO, 1988)) of the soil tested if accessible, including reference to the factors relevant to the test method (see Note to B.1.1 (e) above),

(g) where possible, information on the groundwater level,

(h) weather and environment conditions at time of test, e.g. if wet, sunny, frosty; and

(i) all additional information provided by the Specifiers.

Glossary of Terms

Angle of shear resistance in terms of effective stress (ϕ'). The slope of the Mohr-Coulomb effective stress envelope.

Area ratio. The area ratio of a sampling tube or cutting shoe is defined as:

$$\text{Area ratio (\%)} = \left(\frac{D_w^{\,2} - D_c^{\,2}}{D_c^{\,2}} \right) 100$$

where D_w is the outside diameter of the sampling tube or cutting shoe; and
D_c is the inside diameter of the sampling tube or cutting shoe.

Back pressure (u_b). Pressure applied directly to the pore fluid in the specimen voids.

Bulk density (ρ). The mass of material (including solid particles and any contained water) per unit volume including voids.

Cell pressure. The pressure of the cell fluid which applies isotropic stress to the specimen. In axial compression tests, it is the total minor principal stress, denoted by σ_3.

Clay fraction. The fraction of a soil composed of particles of size smaller than 0.002 mm.

Cobble fraction. Solid particles of sizes between 200 mm and 60 mm.

Coefficient of consolidation (c_v). The parameter which relates the change in excess pore pressure with respect to time, to the amount of water draining out of the voids of a soil prism during that time, due to consolidation:

$$c_v = \frac{k}{m_v \rho_w g}$$

where k is the permeability of the soil;
m_v is the coefficient of volume compressibility;
ρ_w is the mass per unit volume of water; and
g is the acceleration due to gravity.

Coefficient of secondary compression (C_{sec}). The ratio of the change in height ,δH_{sec}, to the initial height, H_i, of a test specimen at the start of the primary consolidation under a particular vertical stress increment over one log cycle of time during the secondary compression phase.

$$C_{sec} = \frac{\delta H_{sec}}{H_i} \text{ over one } \log_{10} \text{ cycle of time}$$

Coefficient of volume compressibility (m_v). The change in volume per unit volume, per unit pressure change, as a result of consolidation due to pressure change:

$$m_v = \left(\frac{1}{1+e}\right)\left(\frac{\delta_e}{\delta_p}\right)$$

where δ_e is a change in void ratio produced by a change in pressure;
δ_p is the change in pressure; and
e is the void ratio.

Cohesion intercept in terms of effective stress (c'). The intercept of the Mohr-Coulomb effective stress envelope.

Note: The symbols ϕ' and c' are collectively referred to as the effective shear strength parameters.

Compaction. The process of packing soil particles more closely together by rolling or other mechanical means, thus increasing the dry density of the soil.

Consolidation. The process whereby soil particles are packed more closely together over a period of time by application of continued pressure. It is accompanied by drainage of water from the voids between solid particles.

Degree of consolidation (U). A measure of consolidation at a given time, expressed as a percentage defined by the equation:

$$U = \left(\frac{u_i - u_w}{u_i - u_0}\right)100$$

where u_w is the pore pressure at the time considered;
u_i is the initial pore pressure; and
u_0 is the final equilibrium pore pressure when consolidation is complete.

Degree of saturation (S_r). The volume of water contained in the void spaces between soil particles, expressed as a percentage of the total voids:

$$S_r = \frac{w\rho_s}{e\rho_w}$$

Deviator stress (σ_1-σ_3). The difference between the major and minor principal stresses, i.e. the principal stress difference in a triaxial test.

Dry density (ρ_d). The mass of dry soil per unit volume of undried material:

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

Dry soil. Soil that has been dried to constant mass at a specified temperature.

Effective confining pressure. The difference between the cell pressure and the pore water pressure.

Effective consolidation pressure. The difference between the cell pressure and the back pressure against which the pore fluid drains during the consolidation stage, i.e. $\sigma_3 - u_b$.

Effective shear strength parameters. The slope and intercept of the Mohr-Coulomb effective stress envelope.

Effective stress (σ'). The difference between the total stress, σ, and the pore water pressure, u_w:

$$\sigma' = \sigma - u_w$$

Excess pore pressure. The increase in pore water pressure due to the application of an external pressure or stress.

Fines fraction. The fraction of a soil composed of particles of size smaller than 0.06 mm (i.e. both the silt fraction and clay fraction materials).

Gravel fraction. The fraction of a soil composed of particles between the sizes of 60 mm and 2 mm. The gravel fraction is subdivided as follows:

Coarse gravel	60 mm to 20 mm
Medium gravel	20 mm to 6 mm
Fine gravel	6 mm to 2 mm

Maximum compacted dry density. The dry density obtained using specified amount of compaction at the optimum moisture content.

Moisture content (w). The mass of water which can be removed from the soil, usually by heating at 45°C ± 5°C or 105°C ± 5°C, expressed as a percentage of the dry mass. The term water content is also widely used.

Normally consolidated soil. A soil which has never been subjected to an effective pressure greater than the present effective overburden pressure.

Optimum moisture content. The moisture content at which a specified amount of compaction will produce the maximum dry density.

Overconsolidated soil. A soil which has been consolidated under effective pressures greater than that due to the present effective pressure.

Particle density (ρ_s). The average mass per unit volume of the solid particles in a sample of soil, where the volume includes any sealed voids contained within the solid particles.

Pore pressure coefficient at failure (A_f). The value of the pore pressure coefficient A at failure.

Pore pressure coefficients A and B. Coefficients relating the change in the pore pressure to the changes in total stresses applied to a specimen when no drainage is permitted from the specimen. The changes are in accordance with the following equation:

$$\delta u = B\,[\delta\sigma_3 + A\,(\delta\sigma_1 - \delta\sigma_3)]$$

where	δu	is the change in pore pressure;
	$\delta\sigma_3$	is the change in total minor principal stress;
	$(\delta\sigma_1 - \delta\sigma_3)$	is the change in deviator stress; and
	A and B	are the pore pressure coefficients.

Pore water pressure (u or u_w). The pressure of water in the voids between solid particles.

Quartering. The reduction in quantity of a large sample of material by dividing a circular heap, by diameters at right angles, into four more or less equal parts, removing two diagonally opposite quarters, and thoroughly mixing the two remaining quarters together so as to obtain a truly representative half of the original mass. The process is repeated until a sample of the required size is obtained.

Relative compaction. The percentage ratio of the dry density of the soil to the maximum compacted dry density of a soil when a specified amount of compaction is used.

Riffling. The reduction in quantity of a large sample of material by dividing the mass into two approximately equal portions by passing the sample through an appropriately sized sample divider. The process is repeated until a sample of the required size is obtained.

Sample. A portion of soil (taken as being representative of a particular material, deposit or stratum) submitted to the laboratory for testing.

Sampling. The selection of a representative portion of a material.

Sand fraction. The fraction of a soil composed of particles between the sizes of 2.0 mm and 0.06 mm. The sand fraction is subdivided as follows:

Coarse sand	2.0 mm to 0.6 mm
Medium sand	0.6 mm to 0.2 mm
Fine sand	0.2 mm to 0.06 mm

Saturation. The condition under which all the voids in a soil are completely filled with water.

Shear resistance. The resistance offered to deformation by a soil when it is subjected to stress.

Shear strength. The maximum shear resistance which a soil can offer under defined conditions of effective stress and drainage.

Silt fraction. The fraction of a soil composed of particles between the sizes of 0.06 mm and 0.002 mm. The silt fraction is subdivided as follows:

Coarse silt	0.06 mm to 0.02 mm
Medium silt	0.02 mm to 0.006 mm
Fine silt	0.006 mm to 0.002 mm

Specimen. A portion of a sample on which a test is carried out.

Strain (ε) (cumulative strain). The change in dimension, expressed as a ratio or a percentage, of the initial reference dimension.

Stress path parameters (p', q). The stress path parameters (in term of effective stress) can be established from the following equations:

$$p' = \frac{1}{3}(\sigma_1' + 2\sigma_3')$$

$$q = (\sigma_1' - \sigma_3') = (\sigma_1 - \sigma_3)$$

Stress path parameters (s', t). The stress path parameters (in terms of effective stress) can be established from the following equations:

$$s' = \frac{1}{2}(\sigma_1' + \sigma_3')$$

$$t = \frac{1}{2}(\sigma_1' - \sigma_3') = \frac{1}{2}(\sigma_1 - \sigma_3)$$

Swelling. The process opposite to consolidation, i.e. expansion of a soil on reduction of pressure due to water being drawn into the voids between particles.

Swelling pressure. The pressure required to maintain constant volume, i.e. to prevent swelling, when a soil has access to water.

Test sieve. A sieve complying with BS 410 : 2000 (BSI, 2000).

Time factor (T_v). The dimensionless parameter which is related to time, t, the coefficient of consolidation, c_v, and the length of drainage path, H, used for defining the theoretical rate of consolidation curve:

$$T_v = \frac{c_v t}{H^2}$$

Total stress (σ). The actual stress in a soil mass through the application of a pressure or force.

Voids. The space between solid particles of soil.

Void ratio (e). The ratio between the volume of voids (air and water) and the volume of a mass of soil:

$$e = \frac{\rho_s}{\rho_d} - 1$$

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