

Interim Guidelines on Testing of Unconfined Compressive Strength of Cement Stabilised Soil Cores in Hong Kong

**The Hong Kong Institution of Engineers
Geotechnical Division
Task Force on Testing Unconfined Compressive Strength
of Cement Stabilised Soil in Hong Kong**

OCTOBER 2017

Disclaimer

This Report has been prepared by the Task Force on Testing Unconfined Compressive Strength of Cement Stabilised Soil in Hong Kong established under the auspices of the Geotechnical Division of The Hong Kong Institution of Engineers. It recommends a test method for determining unconfined compressive strength of cement-soil cores based on the best knowledge of the Task Force. Information deliberated by the Task Force for developing the recommendations and views formed by the Task Force are documented in this Report. The recommendations can serve as an interim guideline. When sufficient test data and experience accrue, the Task Force will undertake a review for enhancing the guidelines.

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Abstract

Deep cement mixing has become widely used in reclamation works especially for mega projects in Hong Kong. Compliance tests like unconfined compressive strength (UCS) test on cement stabilised soil will be carried out to verify the quality of the works during construction. A commonly accepted test method for determining UCS of cement stabilised soil cores has not been established in Hong Kong. After reviewing several international/national and local testing standards for testing of the compressive strength of soil, concrete cores and rock cores, the latest publications and available UCS test results on local cement stabilised soil cores, a test method is recommended. Explanatory notes on salient items of the recommended test method are documented.

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1 Introduction

In Hong Kong, deep cement mixing has become widely used in reclamation works especially for mega projects. Cement or cement slurry is blended with soft soil deposit to form a composite material with improved engineering properties such as increased strength, lower permeability and reduced compressibility. Compliance tests like unconfined compressive strength (UCS) test on cored composite material are required to verify the quality of the deep cement mixing works during construction. International and local testing standards for testing of the unconfined compressive strength of soil, rock cores and concrete cores are available but a similar standard for testing cement stabilised soil cores has not been established in Hong Kong. There is a pressing need in the local geotechnical community to develop guidelines on the UCS test of cement stabilised soil cores in the control of the quality of the materials and standardising the pertinent laboratory practice.

The Geotechnical Division of Hong Kong Institution of Engineers therefore established the Task Force on Testing UCS of Cement Stabilised Soil in Hong Kong with an aim at developing guidelines on testing of UCS of cement stabilised soil cores. Terms of reference and membership for the Task Force are presented in Appendix A. The Task Force reviewed several international/national and local testing standards, the latest publications and UCS test results on local cement stabilised soil cores, and on this basis recommended a test method suitable for local practice.

Deep cement mixing can be classified based on the method of additive injection, i.e. dry mixing or wet mixing method. In dry mixing method, cement in powder form is injected into soil and reacts with water present in soil; while wet mixing method involves injection of cement based slurries to form the soil-cement mixture. The slurries can be either injected into the ground by rotary method at low pressure, by jet at a high pressure (e.g. known as jet grouting) or by a chainsaw type of vertical rotation.

The recommendations in this Report are applicable to cement stabilised soil cores, formed in field or in laboratories, with UCS values below 10 MPa. Should the designer consider necessary and applicable, the recommendations in this Report can be applied on cement stabilised soil that is formed by other construction methods. The procedure for preparing cement stabilised soil core in the laboratory is outside the scope of this Report.

2 Review of Relevant Testing Standards and Preliminary Testing Results

2.1 Review of Relevant Testing Standards

In the course of developing the guidelines, the Task Force has reviewed several international/national and local testing standards for determination of unconfined compressive strength of cylindrical specimen of cohesive soil, laboratory mixed cement stabilised material, concrete and rock (Table 1). Of the loading rates specified for determining unconfined compressive strength of selected construction materials as shown in Table 2, strain rate and stress rate are commonly used to control the rate of loading for testing relatively weak materials (e.g. soil and cement stabilised soil) and strong materials (e.g. rock and concrete) respectively.

Table 1 Several International/National and Local Testing Standards for Determination of Unconfined Compressive Strength of Various Materials

Testing Standards	Test Methods
BS 1377-7:1990 (Section 7)	Methods of Test for Soils for Civil Engineering Purposes – Part 7: Shear Strength Tests (Total Stress)
ASTM D2166/D2166M-16	Standard Test Method for Unconfined Compressive Strength of Cohesive Soil
BS 1924-2:1990 (Section 4.1)	Stabilised Materials for Civil Engineering Purposes – Part 2: Methods of Test for Cement-stabilized and Lime-stabilized Materials
BS EN 12390-3:2009	Testing Hardened Concrete – Part 3: Compressive Strength of Test Specimens
ASTM C39/C39M-17a	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimen
CS1:2010 (Section 15)	Construction Standard CS1:2010 Testing Concrete
ASTM D2938-95	Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimen
ASTM D7012-14	Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Table 2 Loading Rates for Determination of Unconfined Compressive Strength of Selected Construction Materials as specified in Several International/National and Local Testing Standards

Testing Standards	Materials	Loading Rate	Remarks
BS 1377-7:1990	Cohesive soil	$\leq 2 \text{ %/min}$	Strain rate control
ASTM D2166M-16	Cohesive soil	$0.5 - 2 \text{ %/min}^{(1)}$	Strain rate control
BS 1924-2:1990	Cement stabilised soil	$1 \text{ mm/min}^{(2)}$	Strain rate control
BS EN 12390-3:2009	Concrete core	$0.6 \pm 0.2 \text{ MPa/s}$	Stress rate control
ASTM C39/C39M-17a	Concrete core	$0.25 \pm 0.05 \text{ MPa/s}$	Stress rate control
CS1:2010	Concrete core	$0.2 - 1.0 \text{ MPa/s}^{(3)}$	Stress rate control
ASTM D2938-95	Rock core	Rate that can produce failure in a test time between 2 and 15 min ⁽⁴⁾	Stress rate or strain rate control
ASTM D7012-14			

Note:

- (1) Time to failure should not exceed about 15 minutes.
- (2) For specimen height of 100 to 200 mm, strain rate is around 0.5-1%/min.
- (3) For concrete cube and concrete cylinders, CS1:2010 specifies a stress rate of $0.6 \pm 0.2 \text{ MPa/s}$ in compressive strength test.
- (4) Strain rate control is usually used in Hong Kong and a typical value is around 0.18 mm/min.

Several testing standards for preparation of specimen for the determination of UCS of selected construction materials (viz. soil, laboratory mixed cement stabilised material, concrete and rock) are also reviewed (Table 3). Except for soil, there are specific requirements on flatness and perpendicularity of the specimen surface of laboratory mixed cement stabilised material, concrete and rock. It should be noted that in general, more relaxed tolerances are allowed for flatness and perpendicularity of the specimen surface of laboratory mixed cement stabilised material and concrete when compared to that of rock.

Table 3 Requirements on Preparation of Specimen for Determination of Unconfined Compressive Strength of Selected Construction Materials in Several International/National and Local Testing Standards

Testing Standards	Materials	Requirements		
		Flatness tolerance for the prepared end surface	Perpendicularity tolerance for prepared end surface with respect to the axis	Parallelism tolerance for the prepared end surface
BS 1377-7:1990	Cohesive soil	Nil	Nil	Nil
ASTM D2166M-16	Cohesive soil	Nil	Nil	Nil
BS 1924-2:1990	Laboratory mixed cement stabilised material ⁽¹⁾	< 0.03 mm	< 1 mm in 200 mm	Nil
BS EN 12390-1:2012	Concrete	< 0.06% of specimen diameter	< 0.7% of specimen diameter	Nil
ASTM C39/C39M-17a	Concrete	< 0.05 mm	< 1 mm in 100 mm	Nil
CS1:2010	Concrete	< 0.06% of specimen diameter	< ± 1.0 mm	< ± 2.0 mm
ASTM D4543-85 ⁽²⁾	Rock	< 0.025 mm	< 0.43% of specimen diameter	Nil

Note:

(1) Requirements on specimen from drilled cores are not specified.

(2) Both ASTM D2938-95 and ASTM D7012-14 refer to ASTM D4543-85 for preparation of rock specimen.

2.2 Preliminary Test Results

An attempt was made to review preliminary UCS test results on cement stabilised soil cores collected from local projects. The tests were mainly conducted based on the test method for determination of the UCS of cylindrical specimen of cohesive soil in BS 1377-7:1990 or ASTM D2166M-16. Cores were mainly of about 74 mm and 100 mm in diameter. Cement content, water cement ratio and age of the cores at test vary amongst the cores. UCS values of cement stabilised soil cores which ranged between 0.5 MPa and 9 MPa are compared with those of typical cohesive soil cores, concrete cores (Grade 30 to 85) and typical local rock cores (Grade II or better) in Figure 1. In general, UCS values of cement stabilised soil cores are higher than those of cohesive soil cores, but far lower than those of concrete cores and rock cores. Preliminary test results on cement stabilised soil cores suggest that cement stabilised soil is stronger than cohesive

soil, but weaker than concrete and rock in terms of UCS. However, in terms of appearance, cement stabilised soil cores can retain a stable shape as concrete cores (Figure 2).

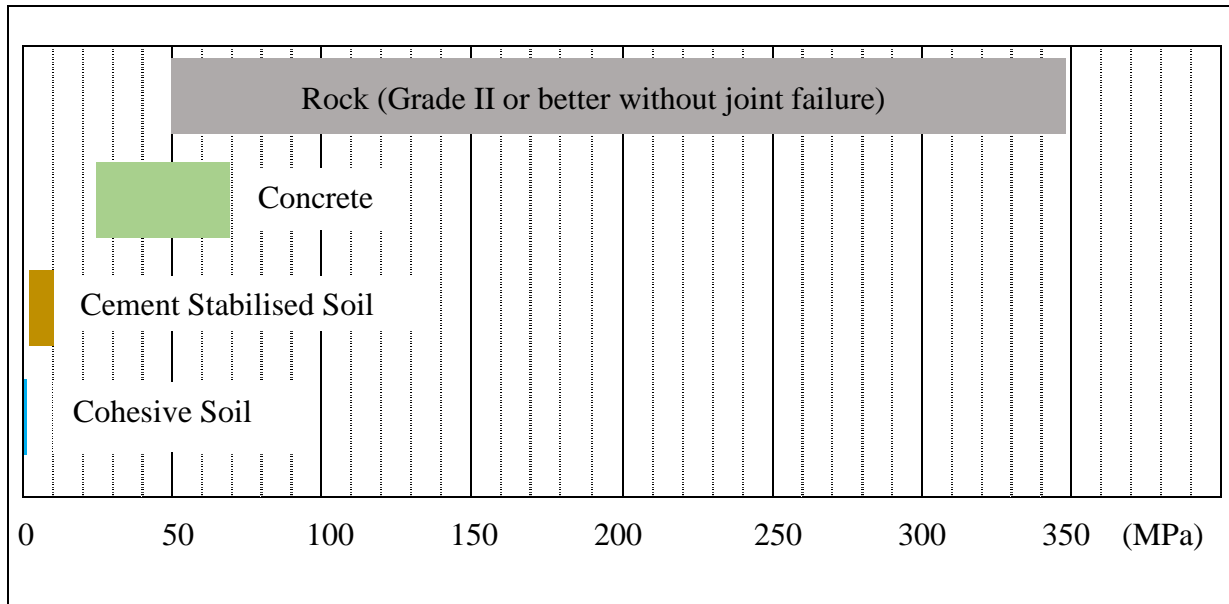


Figure 1 Approximate Values of UCS of Selected Construction Materials

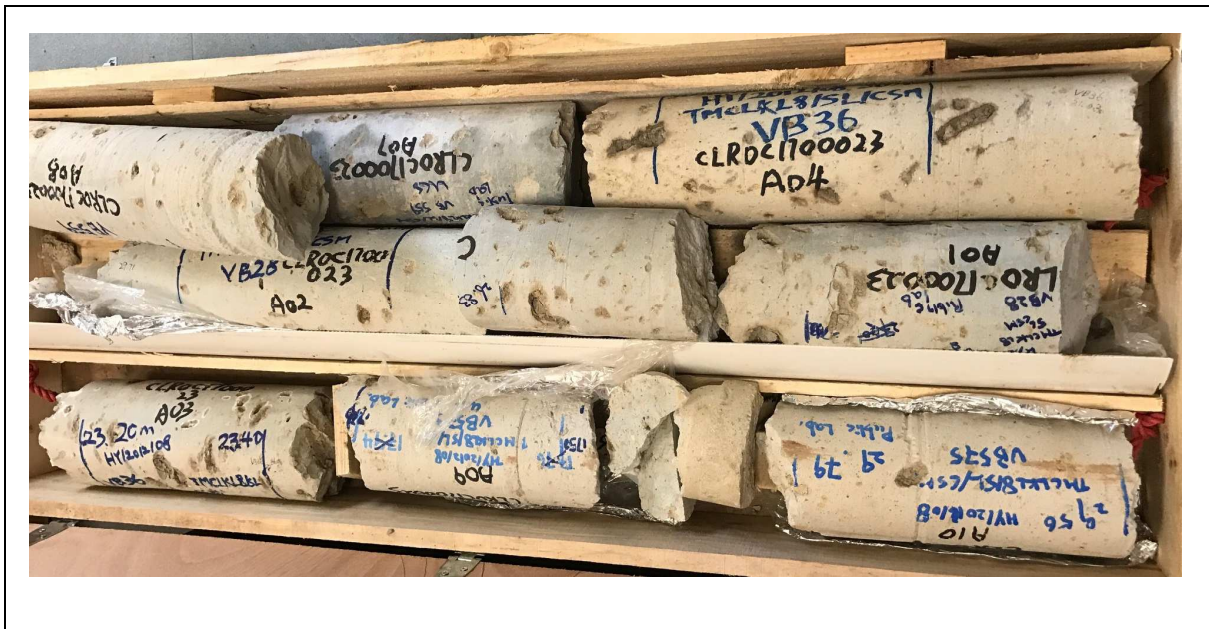


Figure 2 General Appearance of Cement Stabilised Soil Cores (Photo Credit: Public Works Central Laboratory, CEDD)

Taking cognizance of the UCS values and the appearance of cement stabilised soil cores, it is recommended that the testing procedure for determining UCS of cement stabilised soil should make reference to the existing testing standards for soil, e.g. BS 1377-7:1990 or ASTM D2166M-16, and

laboratory mixed cement stabilised material, e.g. BS 1924-2:1990, rather than those for concrete or rock. For preparation of cored cement stabilised soil specimens, reference made to standards pertinent to preparation of concrete specimens is suggested. Modifications, where appropriate, as discussed in the following sections are recommended to suit local practice.

3 Recommended Test Method

Appendix B presents the laboratory test method recommended for determining UCS of cement stabilised soil cores. Having considered the available UCS test results on local cement stabilised soil cores, the Task Force considers that the recommendations in Appendix B can be regarded as an interim guideline. Further review on the guideline will be conducted when feedback and more test data, especially from local sources, are collected from practitioners/researchers. Explanatory notes on salient items of the recommended test method are given in Sections 3.1 to 3.9 below. Further discussion of the review is presented in Section 4.

3.1 Scope

The recommended test method is applicable to cement stabilised soil formed in field or in laboratories. The diameter of the drilled/prepared cores is preferably between 63 mm and 100 mm, with UCS values below 10 MPa. Should the designer consider necessary and applicable, the recommendations in this Report can be applied on cores with diameter outside the preferable range. However, the apparatus should be checked to ensure that the measured force is within the calibrated range.

3.2 Apparatus

Testing machine of sufficient capacity to apply compressive load at a steady and suitable rate of axial deformation should be used. Built-in or external force and displacement measuring devices should be calibrated and coaxiality of the set up should be checked. The measured force should be within the calibrated range. The accuracy and readability of the measuring devices should be of a range appropriate to the strength properties of the material being tested.

It is considered that mechanical load frames (Figures 3 and 4), conventional triaxial test set-up (Figure 5) without the addition of pressurising fluid and Universal Testing Machine (UTM) (Figure 6) are applicable to the test. Regarding the accuracy and the readability of the measuring device and the requirements on calibration, it is recommended that the mechanical load frame and conventional triaxial test set-up should follow the requirements in BS 1377-7:1990; while UTM, which is commonly used for steel and concrete testing in Hong Kong, should follow the requirements in CS2:2012.

The specimen may crush when it is close to its peak strength or the limit of the loading device. Broken pieces from the failed specimen may project into surrounding area. Safety measures such as protective screens around the testing machine should be provided.



Figure 3 Example of Load Frame (Photo Credit: Quality Control Consultants Ltd.)

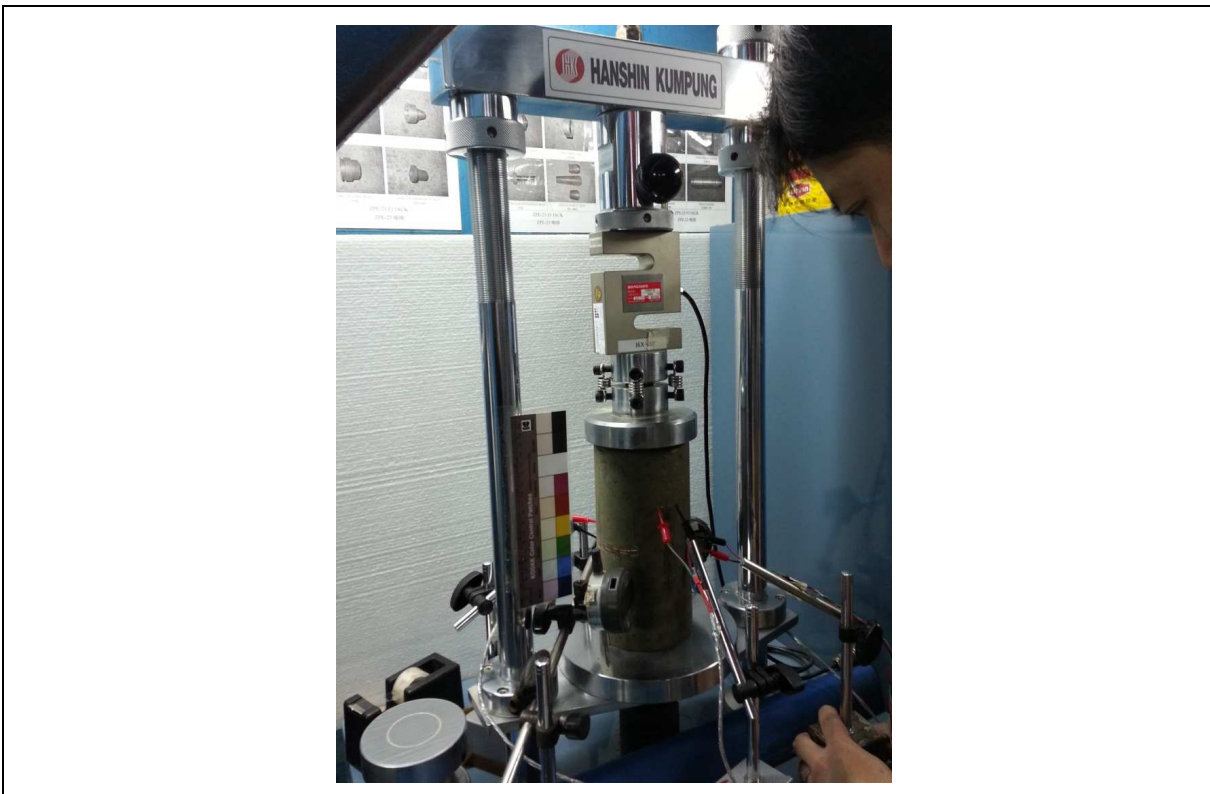


Figure 4 Example of Load Frame and Load Cell (Photo Credit: FT Laboratories Ltd.)

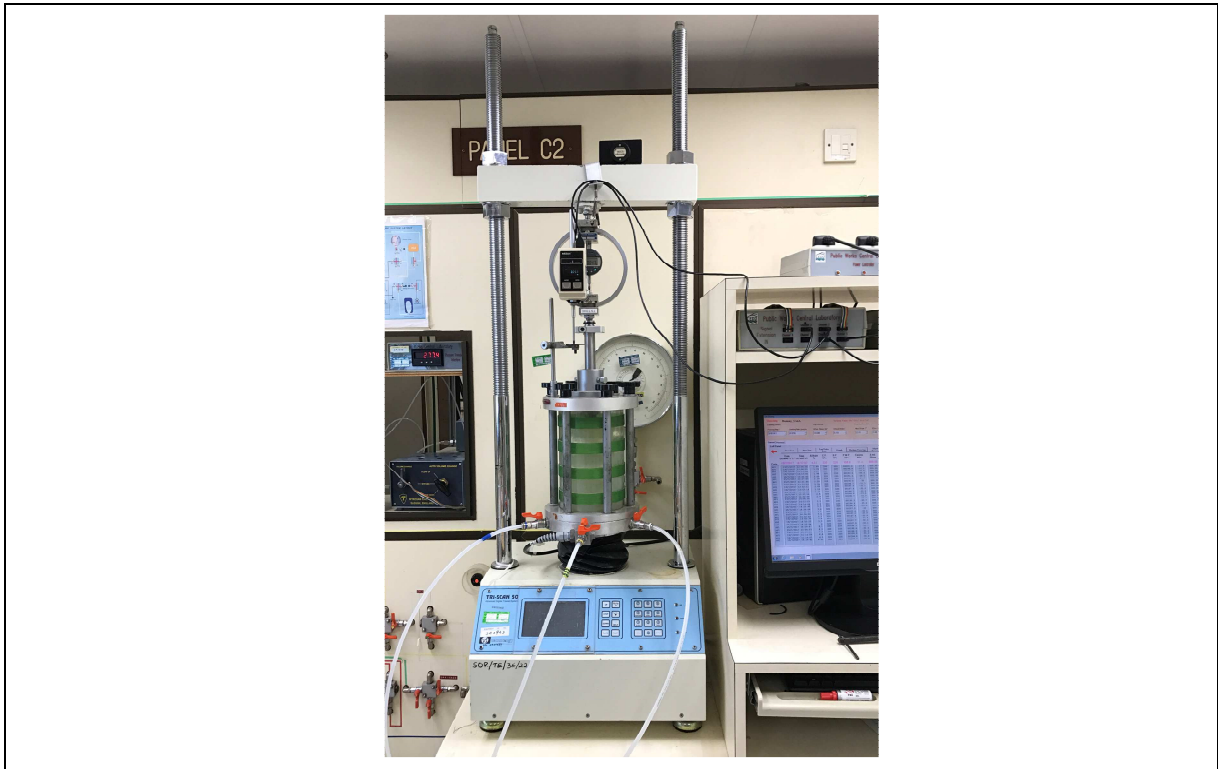


Figure 5 General View of Conventional Triaxial Test Set-up (Photo Credit: Public Works Central Laboratory, CEDD)



Figure 6 General View of UTM Machine (Photo Credit: Public Works Central Laboratory, CEDD)

3.3 On Receipt of Core and Curing of Sample

In deep cement mixing works, it is assumed that water within soil and slurry is sufficient to fill the voids in soil and a saturated composite material is formed. The mechanism of stabilisations by cement consists of four steps: the hydration of binder, ion exchange reaction, formation of cement hydration products, and formation of pozzolanic reaction products (Kitazume and Terashi, 2013). Since the development of compressive strength depends, inter alia, on the moisture content of the core/specimen and the curing environment, procedures should be taken to prevent moisture loss after sampling, during transportation to laboratories and before testing. For example, the cores should be kept in a sealed container or sealed in a plastic wrap after sampling.

In the laboratory, with reference to FHWA (2013), the sealed core/specimen should be stored in a mist chamber under controlled conditions at 95 to 100 percent relative humidity and at room temperature (i.e. about 20 to 25°C) until test is carried out. If a mist chamber is not available, the core/specimen should be stored under water provided that they are sealed in a water-tight plastic bag. Cement stabilised soil core/specimen should not be submerged in water without sealing in a water-tight, zip-sealed plastic bag.

3.4 Cutting of Specimen

To facilitate the compliance with the requirements on flatness, perpendicularity and parallelism of the specimen, rock saw is found satisfactory for preparing the specimen. The rock saw cut facility must be properly set up with necessary safety measures. The rate of cutting should be controlled to avoid chipping of the specimen. The general set-up of rock saw and end of specimen prepared by rock saw cutting are shown in Figures 7 and 8, respectively.



Figure 7 General Set-up of Rock Saw (Photo Credit: Public Works Central Laboratory, CEDD)



Figure 8 Surface of Specimens Cutting by Rock Saw (Photo Credit: Public Works Central Laboratory, CEDD)

3.5 Length to Diameter Ratio of Specimen

The friction between the specimen ends and the platens, which is a function of the length to diameter (L/D) ratio of the specimen, the smoothness of the platen, the end surface condition of the specimen etc., affects the stress distribution in the specimen and hence affects the measured UCS of the specimen. To ensure a more uniform stress distribution during loading, L/D ratio of 2 is commonly adopted for compression test of soil and rock in Hong Kong and elsewhere. Typical diameter and L/D ratio of specimen of soil, concrete and rock for compression tests in Hong Kong are shown in Table 4.

For cement stabilised soil specimen with diameter between 63 mm and 100 mm, difficulties may be encountered in preparing a specimen with L/D ratio of 2. This is because cement stabilised soil cores extracted from the ground are usually not continuous over a sufficient length. Very often, they contain intermittent voids and imperfections (see Figure 2 above). Apart from the discontinuity and imperfections of cement stabilised soil specimen, there are also possible constraints on headroom for placing specimen in the loading system. For example, limited headroom is available in a triaxial test set-up for placing specimen. FHWA (2013) suggested that correction factors given in ASTM C42-03, shown in Table 5, can be applied to the measured UCS of cement stabilised soil specimen if L/D ratio is between 1 and 2.

Table 4 Typical Diameter and L/D Ratio of Soil, Concrete and Rock Specimen

Material	Approx. Diameter of Specimen (mm)	Length to Diameter (L/D) Ratio
Soil	74 , 100	2 ⁽¹⁾
Concrete	preferably be of 100 and shall not be less than 75	1.0 – 1.2 ⁽²⁾
Rock	61, 84	2.0 – 2.5

Note: (1) Length may vary from 8% under-size to 12% over-size in accordance with BS 1377-7:1990 (i.e. equivalent to L/D of 1.84 to 2.24) without significantly affecting the results.

(2) Smaller ratio is adopted so that measured UCS values of concrete cores are comparable with that of concrete cube.

Considering the practicability and limited UCS test results collected so far, a L/D ratio of 2 is recommended for the UCS test for cement stabilised soil specimen. Specimens with L/D ratio between 1.5 (inclusive) and 2 can also be tested provided that lubricated ends are provided and correction factor recommended by FHWA (2013) is applied to the measured UCS. If the specimen is capped, the length of specimen after capping should be used in the computation of L/D ratio.

The correction factors given in ASTM C42-03 is developed for concrete core specimen with higher density ranged between 1.6 and 1.92 Mg/m³ and higher compressive strength between 14 and 42 MPa. Meanwhile, for the purpose of this interim guideline, it is prudent to suggest that the correction factors for specimen with L/D ratio between 1.0 and 1.5 (exclusive) are not adopted for local practice.

Table 5 Strength Correction Factors Given in ASTM C42-03

L/D ratio	2.00	1.75	1.50	1.25	1.00
Strength Correction Factor	1	0.98	0.96	0.93	0.87

Note: Values not specified in the table can be determined by linear interpolation.

3.6 Checking of Flatness, Perpendicularity and Parallelism of Specimen

The definitions and methods of measurement of flatness, perpendicularity and parallelism of specimen are in accordance with CS1:2010. The acceptance criteria (i.e. tolerances) and suggested format of reporting are given in Section 3.10. It is not uncommon to have soft spots and/or voids on the surface of the specimen. An example is shown in Figure 9. The orientation of the measurement can be slightly adjusted to avoid soft spots or surface irregularities. As a reference,

the measurements on flatness, perpendicularity and parallelism should be reported for the designer to interpret test results. If capping is applied at ends of the specimen, measurement after capping should be reported.



Figure 9 Soft Spots on Cement Stabilised Soil Specimen

3.7 Capping of Specimen

Capping, if carefully and properly done, can provide a smooth, parallel and uniform bearing surface to avoid stress concentration at the undue surface of the specimen. However, for cement stabilised soil specimen with UCS value usually less than 5 MPa, there are many potential drawbacks when capping are provided at both ends of the specimen. That is due to the difficulty to select a capping compound which matches the deformation and strength characteristics of the specimen being tested. In addition, the quality of capping can be greatly affected by the workmanship and skill of the technicians.

Having considered the pros and cons of the use of capping, it is suggested that end caps should only be provided as a last resort, e.g. when the specimen could not be tested without capping provided. It is recommended to make reference to CS1:2010 for the materials and preparation of capping.

3.8 Loading Rate for the Determination of Axial Compressive Stress

Table 2 summarises the recommended loading rates for cohesive soil, cement stabilised soil, concrete and rock as given in several international/national and local testing standards. It has also been deliberated in Section 2.1 that strain rate control is more appropriate than stress rate control in the application of axial load to cement stabilised soil specimen. As a preliminary and trial study, to evaluate the effect of strain rates of test on UCS values, six cement stabilised soil cores were prepared in Public Works Central Laboratory. Soil obtained from Chek Lap Kok (i.e. moist light grey CLAY) was mixed with Portland cement in accordance with Japanese Laboratory Mix Test Procedure (Kitazume & Terashi, 2013). The diameter of the specimens was about 50 mm with L/D ratio of about 2.2. Cement content of 300 kg/m³ and water cement ratio of 0.7 were used. Bulk density of the specimens was 1.55 Mg/m³. UCS tests were conducted based on the test method in BS 1377-7:1990 at three different loading rates after specimens were cured for 7 days. UCS values ranged between 0.83 MPa and 1.12 MPa. The results indicate that the effect of loading rates on the measured values of UCS of cement stabilised soil was not significant (Table 6).

Table 6 Results of UCS Tests Under Different Loading Rates

Loading Rate	1 mm/min				0.1 mm/min	10 mm/min
UCS (MPa)	1.05	0.99	1.06	0.83	0.98	1.12
	Average = 0.98					

Within the scope of this interim guideline, the rate of axial strain should be within 0.5 – 2%/min. This recommendation accords generally with BS 1377:1990 Part 7, ASTM D2166-16 and BS 1924-2:1990. It is also recommended that the load should be applied in such a manner as to produce a strain rate as constant as feasible throughout the test.

3.9 Calculation and Plotting

Area correction is normally required for soil, especially for very soft cohesive soil. It is, however, not required for concrete and rock. Cement stabilised soil specimen normally fails in a brittle manner with small failure strain (e.g. less than 1%). Therefore, area correction is not as critical as in soil. However, to cater for testing of potentially weak specimens, e.g. with short curing period or low cement content, it may be prudent to apply area correction routinely.

The axial compressive stress, σ_1 , in the specimen for each set of readings, is calculated from the following equation assuming that the specimen deforms as a right cylinder:

$$\sigma_1 = \frac{P(1 - \varepsilon)}{A_0} \times F$$

where P is the force applied to the specimen for each set of readings; ε is axial strain of the specimen for each set of readings; A_0 is initial cross-sectional area of the specimen and F is the

strength correction factor for specimen with length to diameter ratio between 1.5 (inclusive) and 2.0 (Table 6).

The maximum value of the compressive stress which the specimen can sustain is referred to as UCS of the specimen. Monotonic hardening behaviour was not observed in the UCS test results of cement stabilised soil cores collected from local projects so far. However, to cover potentially weak specimens which may exhibit monotonic hardening behaviour, a strain limit for terminating the test is recommended. The test should be continued until the compressive stress drops to two-thirds of the maximum value, or the axial strain reaches 15% or at a stress level specified by the designer. This recommendation accords generally with BS 1377:1990 Part 7 and ASTM D2166-16.

3.10 Reporting of Results

The stress-strain curve of the specimen and the age of the specimen at test should be provided. Adequate photos should be taken to show the features of the specimen before test. It is recommended to provide a minimum of three photos to cover 360° view of the specimen and two photos on each end. After test, photos should be taken to show the mode of failure.

Suggested format for reporting the measurements of flatness, perpendicularity and parallelism is shown in Tables 7, 8 and 9.

Table 7 Suggested Format for Reporting Flatness Checking of Specimen

Flatness ($< 0.06\%$ of core diameter)	Axis 1 of End 1	Axis 2 of End 1	Axis 1 of End 2	Axis 2 of End 2
Thickness ⁽²⁾ = ____mm	Yes / No ⁽³⁾	Yes / No	Yes / No	Yes / No

Note:

- (1) Soft and weak spots or surface imperfection can be neglected.
- (2) "Thickness" means the maximum allowable thickness (i.e. 0.06% of core diameter).
- (3) "Yes" means the flatness along a particular axis is less than the maximum allowable thickness; "No" means the flatness along a particular axis is more than the maximum allowable thickness.

Table 8 Suggested Format for Reporting Perpendicularity Checking of Specimen

Perpendicularity ($< \pm 1\text{mm}$)		Dial gauge reading (mm)		
		0°	120°	240°
Max. difference of dial gauge reading = ____mm	Upper end			
	Lower end			
	Difference			

Note: (1) Orientation can be slightly adjusted to avoid soft and weak spots or surface imperfection.

Table 9 Suggested Format for Reporting Parallelism Checking of Specimen

Parallelism ($< \pm 2\text{mm}$)	Reading (mm)			
	0°	120°	240°	mean
Max. difference of reading = ____mm				

Note: (1) For specimen with end caps, the length should be the total length of the specimen.
(2) Orientation can be slightly adjusted to avoid soft and weak spots or surface imperfection.

4 Discussion

4.1 Elastic Modulus

The stress-strain relationship of cement stabilised soil specimen is usually non-linear. Several methods are available to determine Elastic Modulus (E) (e.g. tangent modulus at 50% of the maximum strength, average slope of the straight line portion of the stress-strain curve and secant modulus from zero stress to some fixed percentage of the maximum strength, etc). Additional requirements on the equipment may be needed for the measurement of E. For example, calibration should be made to eliminate the effect of apparatus deformation during the course of UCS test. As the test method recommended in this Report focuses on the measurement of UCS, recommendations on the measurement of E would not be made. Nevertheless, it is suggested to provide the measured stress-strain curve in the test report (Section 6 of Appendix B) for the designer to determine the E values, where necessary.

4.2 Presence of Voids and Soft Spots

There may be lots of voids and soft spots on the received cement stabilised soil cores (Figures 9 and 10). Testing these cores may reflect the actual quality of cement mixing works. The designer should decide whether the test results on these cores are representative and applicable to their purposes.



Figure 10 Voids and Soft Spots on Received Cement Stabilised Soil Cores

5 Future Works

The recommendations given in this Report are primarily based on testing standards for soil and to a lesser extent for concrete, together with the limited local experience on UCS tests of cement stabilised soil. The Task Force will endeavour to collect more test data and undertake a review for enhancing the guidelines when more information is available. Following issues are suggested to be further reviewed and studied:

- a) Effect of loading rate on measured UCS values
- b) Effect of length to diameter ratio and capping on measured UCS values
- c) Effect of curing (e.g. curing period, curing temperature etc.) on measured UCS values
- d) Stress-strain behaviour of cement stabilised soil
- e) Measurement and interpretation of elastic modulus of cement stabilised soil

6 Conclusion

This report has recommended a test method for determining UCS of cement stabilised soil cores based on the review of several international/national and local testing standards for soil, concrete and rock, the latest publications and available UCS test results of local cement stabilised soil cores. Explanatory notes of salient items of the recommended test method and future works are documented.

7 References

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Appendix A
Terms of Reference and Membership for Task Force on Testing Unconfined Compressive
Strength of Cement Stabilised Soils in Hong Kong

Terms of Reference

1. Consolidate knowledge, experience and practice in UCS tests of cement stabilised soil
2. Identify testing methodology suitable for local practice
3. Consult stakeholders on their views on the subject
4. Recommend guidelines (including interim guidelines) on UCS tests of cement stabilised soil
5. Promulgate and collect feedback on the recommendations, and refine interim guidelines as necessary

	<u>Organisation</u>
Chairman	
Ir Philip Chung	Geotechnical Engineering Office, Civil Engineering and Development Department (CEDD)
Secretary	
Ir Florence Chu	Geotechnical Engineering Office, CEDD
Members	
Ir Dr Tony Chen	Arcadis Design & Consultancy Ltd.
Ir Dr Johnny Cheuk	AECOM Asia Co. Ltd.
Ir Warren Dou	China Road and Bridge Corporation (HK) Ltd.
Ir Dr Julian Kwan	Geotechnical Engineering Office, CEDD
Dr Fiona Kwok	The University of Hong Kong
Ir Chris Lee	CM Wong & Associates Ltd.
Ir Dr S W Lee	Golder Associates (HK) Ltd.
Ir Dr Chao Li	China Harbour Engineering Co. Ltd.
Ir Dr Sunny So	Hong Kong Island and Islands Development Office, CEDD
Dr Louis Wong	The University of Hong Kong

Appendix B
Test Method for Unconfined Compressive Strength of Cement Stabilised Soil Cores

Test Method for Unconfined Compressive Strength of Cement Stabilised Soil Cores

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1 SCOPE

- 1.1 This method sets out the procedure for determination of unconfined compressive strength of cement stabilised soil cores preferable with diameter between 63 mm and 100 mm and with unconfined compressive strength below 10.0 MPa. Should the customer consider necessary and applicable, the method can be applied on cores with diameter outside the preferable range provided that the apparatus should be checked to ensure that the measured force is within the calibrated range. The method is written in accordance with “Interim Guidelines on Testing for Unconfined Compressive Strength of Cement Stabilised Soil Cores in Hong Kong (October 2017)” prepared by the Task Force on Testing Unconfined Compressive Strength of Cement Stabilised Soil in Hong Kong established under the Geotechnical Division of The Hong Kong Institution of Engineers.

2 TERMINOLOGY

2.1 Definitions

- 2.1.1 Age of specimen – the period between the completion time of mixing cementitious agent to soil and the time of carrying out the test.
- 2.1.2 Core – a cylindrical sample of cement stabilised soil, usually obtained by means of a core drill. It can also be prepared in a laboratory.
- 2.1.3 Specimen – portion of a core sample prepared for testing.
- 2.1.4 Unconfined compressive strength (q_u) – the compressive stress at which an unconfined cylindrical specimen of cement stabilised soil will fail in a simple compression test; in this test method, unconfined compressive strength is taken as the maximum load attained per unit area.

3 APPARATUS

- 3.1 Universal testing machine shall be at least Class I accurate to 1 % and readable to 0.01 kN. The testing machine shall be of sufficient capacity to apply load at a suitable rate of displacement. The actual rate of platen displacement shall not vary by more than ± 20 % of the rate specified in Clause 4.4.6. The axial deformation measuring device of the testing machine shall be readable to 0.01 mm and accurate to 0.02 mm, and capable of providing an axial compression equivalent to axial strain of at least 15% of the specimen tested. Simultaneous readings of the force and the axial displacement at a minimum of 15 load levels that are evenly spaced over the load range of compression shall be recorded.
- 3.2 If a universal testing machine specified in 3.1 is not available, a compression machine with the following ancillary apparatus can be used for the test:
- (a) a calibrated machine shall be of sufficient capacity to apply load at a suitable rate of displacement. The actual rate of platen displacement shall not vary by more than ± 20 % of the rate specified in Clause 4.4.6. The compression machine shall be capable of providing an axial compression equivalent to axial strain of at least 15% of the specimen tested;
 - (b) 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 specimen. It may consist of a calibrated digimatic indicator or displacement transducer; and

- (c) a calibrated force-measuring device which shall be of suitable capacity, at least accurate to 1 % of the measured value and readable to 0.01 kN. The device can be a proving ring coupled with a digimatic indicator or load cell coupled with a digital readout. The device shall be supported by the crosshead of the compression machine so as to prevent its own weight being transferred to the specimen.
- 3.3 Two flat highly polished steel platens of the same diameter of the specimen or larger, through which the axial force is transmitted.
- 3.4 Apparatus for measuring dimensions of the specimen, to an accuracy of 0.1 mm.
- 3.5 Balance of suitable capacity to weigh the specimen to determine the mass of the specimen to within 0.1% of its total mass.
- 3.6 Saw capable of cutting rock cores with water as the cooling fluid.
- 3.7 Apparatus for measuring the perpendicularity of the specimen (an example is shown in Figure 1).
- 3.8 Apparatus for measuring the straightness and the flatness of the specimen.
- 3.9 Steel ruler graduated in millimetres.
- 3.10 Apparatus for providing an environment with relative humidity of at least 95% and with temperature ranged between 20°C and 25°C.
- 3.11 Maximum/minimum thermometer accurate to 0.5°C (continuous recording thermometer is equivalent).
- 3.12 Jig and baseplate for setting core caps.
- 3.13 Thermostatically controlled sulphur melting pot and ladle.
- 3.14 Sulphur capping compound complying with Clause 15.5.2 of CS1:2010.
- 3.15 Engineer square.
- 3.16 Paint brush.
- 3.17 Light oil.
- 3.18 Centre scribe and protractor for cores.
- 3.19 Thermometer capable of measuring 100°C to 200°C and accurate to 0.5°C.

4 PROCEDURE

4.1 On Receipt of Cores

- 4.1.1 The diameter of the core shall preferably be within 63 mm to 100 mm.
- 4.1.2 The prepared specimen shall normally have a length to diameter ratio of 2.0. Any specimen with a length to diameter ratio smaller than 1.5 (exclusive) is not suitable for testing.
- 4.1.3 Each core shall be examined for the presence of voids and cracks. If there is variation in the quality along the core, the customer should advise which portion of the core to be tested.
- 4.1.4 Check whether the customer has marked or provided the identification number and depth on the core.
- 4.1.5 Core which is sealed as received shall be stored within a controlled environment with relative humidity of at least 95% and with temperature between 20°C and 25°C.

4.2 Preparation of Specimen

4.2.1 Cutting and Measurement of Specimen

- 4.2.1.1 Measure the maximum and the minimum lengths (L_{\max} and L_{\min}) of the core as received, and record the readings (Note 7.1). Determine whether the length of the core is sufficient for preparing specimen(s) as requested.
- 4.2.1.2 Mark or by other reliable means indicating the laboratory specimen number on the core, prior to cutting.
- 4.2.1.3 Ensure the angle between the saw blade and the sample fixture is in right angle.
- 4.2.1.4 Inspect the condition of the saw blade visually and determine whether it is suitable for cutting.
- 4.2.1.5 Cut the core so that the ends are approximately flat and perpendicular to the longitudinal axis of the core. Wipe off surface moisture after cutting.
- 4.2.1.6 Mark lines that parallel to the longitudinal axis and around circumference of the specimen at 0°, 120°, and 240° respectively. The orientation can be slightly adjusted to avoid soft and weak spots or surface irregularities.
- 4.2.1.7 Take a set of three photos at 120° intervals showing all the markings and two photos on each end of the specimen.
- 4.2.1.8 Measure the length of the specimen after cutting (L_s) at points around the circumference of the specimen at 120° intervals, and record the readings. Calculate and record the mean of the three measurements to the nearest 0.1 mm.
- 4.2.1.9 Measure the diameter (D) of the specimen by taking two pairs of readings at right angles to each other at each one-third point along the length, and record the readings. The location of measurement can be slightly adjusted to avoid soft and weak spots or surface irregularities. Calculate and record the mean of the four measurements to the nearest 0.1 mm.

4.2.2 **Flatness Checking of Specimen**

- 4.2.2.1 Mark the end surface with two perpendicular axes intersecting at the longitudinal axis of the specimen. Soft and weak spots or surface irregularities can be neglected.
- 4.2.2.2 Clean the end surface of the specimen.
- 4.2.2.3 Check the flatness tolerance, which shall be 0.06% of the core diameter (in millimetres), for the prepared end surface. If the specimen does not meet the tolerance, proceed to Clause 4.2.5 for capping the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.
- 4.2.2.4 Repeat Clauses 4.2.2.3 for the other axis.
- 4.2.2.5 Repeat Clauses 4.2.2.1 to 4.2.2.4 for the other end surface of the specimen.

Note: A method for checking flatness of the specimen is given in Appendix 1 for reference.

4.2.3 **Perpendicularity Checking of Specimen**

- 4.2.3.1 Check the perpendicularity for the prepared end at 0°, 120° & 240° with respect to the longitudinal axis of the specimen. The orientation can be slightly adjusted to avoid soft and weak spots or surface irregularities. The perpendicularity tolerance for the prepared end with respect to the longitudinal axis of the specimen as datum axis shall be ± 1 mm.
- 4.2.3.2 If the specimen does not meet the perpendicularity tolerance, proceed to Clauses 4.2.5 for capping the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.

Note: A method for checking perpendicularity of the specimen is given in Appendix 1 for reference.

4.2.4 **Parallelism Checking of Specimen**

- 4.2.4.1 Check the parallelism for the prepared top surface at 0°, 120° & 240° with respect to the bottom surface of the specimen. The orientation can be slightly adjusted to avoid soft and weak spots or surface irregularities. The parallelism tolerance for the prepared top surface with respect to the bottom surface of the specimen as datum face shall be ± 2 mm.
- 4.2.4.2 If the specimen does not meet the parallelism tolerance, proceed to Clause 4.2.5 for capping the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.

Note: A method for checking parallelism of the specimen is given in Appendix 1 for reference.

4.2.5 **Capping of Specimen (if necessary or as requested by the customer; otherwise proceed to Clause 4.3)**

- 4.2.5.1 Wipe off surface moisture and extraneous matter on the specimen. Weigh the specimen and record the mass (M_1).
- 4.2.5.2 Dry one end of the specimen sufficiently to allow adhesion of the capping compound.
- 4.2.5.3 Cap the specimen according to the requirements in CS1:2010.

- 4.2.5.4 Repeat Clauses 4.2.5.2 to 4.2.5.3 for the other end of the specimen.
- 4.2.5.5 Repeat the test procedures stated in Clauses 4.2.2 to 4.2.4 for checking the flatness, perpendicularity and parallelism of the capped specimen.
- 4.2.5.6 If the capped specimen does not comply with the tolerances given in Clauses 4.2.2 to 4.2.4, the cap shall be removed and repeat the test procedures stated in Clauses 4.2.5.1 to 4.2.5.5.
- 4.2.5.7 Measure the length of the specimen after capping (L_u) at points around the circumference of the specimen at 120° intervals, and record the readings. Calculate and record the mean of the three measurements to the nearest 0.1 mm. Weigh the specimen and record the mass (M_2). Calculate the mass of the cap ($M_3 = M_2 - M_1$).
- 4.2.5.8 Proceed to Clause 4.3.

Note: A method for preparing a capped specimen is given in Appendix 1 for reference.

4.3 **Curing of Specimen**

- 4.3.1 Store the sealed specimen within a controlled environment with a relative humidity of at least 95% and with temperature between 20°C and 25°C until test is carried out.

4.4 **Determination of the Axial Compressive Stress**

- 4.4.1 Remove the specimen from the controlled environment; wipe off surface moisture and extraneous matter on the specimen (Note 7.2). Weigh the specimen and record the mass (M_4).
- 4.4.2 Clean the loading surfaces of the testing machine (both top and base platen).
- 4.4.3 Provide lubricated ends at two ends of the specimen (if the length to diameter ratio is less than 2).
- 4.4.4 Place the specimen on the base platen centrally and check that the specimen axis is vertical.
- 4.4.5 Set the readings of axial force and axial displacement to zero.
- 4.4.6 Select a rate of axial deformation such that the rate of axial strain is within 0.5 - 2 %/min.
- 4.4.7 Apply compression to the specimen without shock and continuously increase the load at the selected rate and record simultaneous readings of the force and the axial displacement at a minimum 15 load levels that are evenly spaced over the load range.
- 4.4.8 Continue the test until the compressive stress (calculated as in Clause 5.2.2) drops to two-thirds of the maximum value, or the axial strain reaches 15% or otherwise at a stress level specified by the customer.
- 4.4.9 Remove the load from the specimen.
- 4.4.10 Remove the specimen from the base platen.
- 4.4.11 Take photos of the specimen to show the mode of failure.

5 CALCULATION AND PLOTTING

5.1 Notations

L_s	: Length of specimen after cutting	(mm)	(Clause 4.2.1.8)
L_u	: Length of specimen after capping	(mm)	(Clause 4.2.5.7)
D	: Diameter of specimen	(mm)	(Clause 4.2.1.9)
M_1	: Mass of specimen without capping	(Mg)	(Clause 4.2.5.1)
M_2	: Mass of specimen after capping	(Mg)	(Clause 4.2.5.7)
M_3	: Mass of cap		
	(a) $M_3 = M_2 - M_1$;	(Mg)	
	(b) $M_3 = 0$ if specimen is not capped.		
M_4	: Mass of specimen before test	(Mg)	(Clause 4.4.1)
A	: Cross sectional area of specimen	(mm ²)	
V	: Volume of specimen	(m ³)	
α	: Length to diameter ratio		
ρ	: Density of specimen	(Mg/m ³)	

5.2 Calculation and Plotting

5.2.1 Calculate the axial strain, ϵ of the specimen for each set of readings from the equation

$$\epsilon_f = \frac{\Delta L}{L_s} \quad \text{if capping is not used; or}$$

$$\epsilon_f = \frac{\Delta L}{L_u} \quad \text{if capping is used.}$$

where

ΔL is the change in length of the specimen (in mm);

5.2.2 Calculate the axial compressive stress, σ_1 (in kPa), in the specimen for each set of readings, on the assumption that the specimen deforms as a right cylinder, from the equation

$$\sigma_1 = \frac{P(1 - \epsilon)}{A_0} \times 1000 \times F$$

where

P is the force, applied to the specimen for each set of readings (in N);

ϵ is axial strain of the specimen for each set of readings;

A_0 is initial cross-sectional area of the specimen (mm²);

F is the strength correction factor for the specimen with length to diameter (L/D) ratio between 1.50 and 2.00. If the specimen is tested with capping, the length of the specimen after capping should be used to compute the L/D ratio. The strength correction factor is shown in following table:

Length to Diameter (L/D) Ratio	2.00	1.75	1.50
Strength Correction Factor (F)	1	0.98	0.96

Note: Values not specified in the table can be determined by linear interpolation.

- 5.2.3 Plot calculated values of compressive stress as ordinates against corresponding values of strain (expressed as a percentage) as abscissae, and draw the stress-strain curve through the points. The initial mobilised strain to fully contact the specimen and the apparatus, if any, should be eliminated by offsetting this initial strain value when plotting the stress-strain curve.
- 5.2.4 Ascertain the point on the graph representing the failure condition, which is the point at which the maximum compressive stress sustained by the specimen occurs.
- 5.2.5 Use that point, determine the compressive stress in the specimen at failure, report as the unconfined compressive strength, q_u (in kPa).
- 5.2.6 Calculate the axial strain, ϵ_f , of the specimen at failure from the equation

$$\epsilon_f = \frac{\Delta L_f}{L_s} \quad \text{if capping is not used; or}$$

$$\epsilon_f = \frac{\Delta L_f}{L_u} \quad \text{if capping is used.}$$

where

ΔL_f is the change in length of the specimen at failure (in mm).

- 5.2.7 Calculate the bulk density of the specimen from the equation

$$A = \frac{\pi D^2}{4} \quad (\text{mm}^2)$$

$$V = L_s A \times 10^{-9} \quad (\text{m}^3)$$

$$\rho = \frac{(M_4 - M_3)}{V} \quad (\text{Mg/m}^3)$$

6 REPORTING OF RESULTS

6.1 Report the following :

- (a) Identification number of the core.
- (b) Date of receipt of the core.
- (c) Condition of the specimen after cutting such as presence of soft spots, surface irregularities and cracks.
- (d) Average diameter of the specimen to the nearest 0.1 mm.
- (e) Length of the specimen to the nearest 1 mm. If capping is applied on the specimen, length of the specimen before and after capping should be reported.
- (f) Measurement of flatness, perpendicularity and parallelism of the specimen. If capping is applied on the specimen, measurement after capping should be reported.
- (g) A set of three photos taken at 120° intervals and two photos on each end of the specimen after cutting.
- (h) Date of test.
- (i) Rate of strain (in %/min) applied.
- (j) Age of the specimen at date of test, if known.
- (k) Unconfined compressive strength of the specimen to the nearest 0.01 MPa.
- (l) Strain at failure (in %), to two significant figures.
- (m) Bulk density of the specimen to nearest 10 kg/m³.
- (n) Photos of the specimen after test.
- (o) The stress-strain curve.

7 NOTES

7.1 The length recorded as 'maximum' shall be the distance between the 'peaks' of two ends of the core, measured parallel to the longitudinal axis. The length recorded as 'minimum' shall be the distance between the 'troughs' of the two ends of the core, measured parallel to the longitudinal axis.

7.2 Specimen with cracked or loose caps shall not be tested. The specimen shall be tested as soon as practicable after it is removed from the controlled environment and the test shall be carried out within the following tolerances of ages for testing:

- (a) ± 30 minutes for ages up to and including 30 hours.
- (b) ± 2 hours for ages above 30 hours and up to and including 4 days.
- (c) ± 8 hours for ages above 4 days and up to and including 60 days.

(d) ± 1 day for ages above 60 days.

Appendix 1
A Method of Checking Flatness, Perpendicularity and Parallelism
of Specimen and Capping Specimen (for reference only)

A. Flatness Checking of Specimen

- A.1 Use the centre scribe, protractor and a sharp pencil to mark the cut face with two perpendicular axes intersecting at the longitudinal axis of the specimen. Soft and weak spots or surface irregularities can be neglected.
- A.2 Clean the cut face of the specimen.
- A.3 Determine the maximum allowable thickness of feeler gauge (0.06% of the specimen diameter) and select a suitable thickness of feeler gauge which shall be smaller than the maximum allowable thickness.
- A.4 Press gently the straight edge on the cut face of the specimen along one of the perpendicular axes.
- A.5 Slide the feeler gauge between the cut face of the specimen and the straight edge along the whole line. Record 'Yes' if the feeler gauge blade cannot pass through the gap between the cut face and the straight edge, otherwise record 'No' and proceed to Clause D for capping the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.
- A.6 Repeat Clauses A.4. to A.5. for the other axis.
- A.7 Repeat Clauses A.1.to A.6. for the other cut face of the specimen.

B. Perpendicularity Checking of Specimen

- B.1 Use the release cable, lift off the spindle of the dial gauge. Put the specimen approximately in the middle of the turn table of the apparatus as shown in Figure 1.
- B.2 Place the dial gauge against the point at near top of the specimen. Care shall be taken to avoid loosening or disturbing the dial gauge mounting.
- B.3 Use the release cable to lift the spindle of the dial gauge off the specimen surface, and align the turntable to the zero degree mark. Release the dial gauge and record the reading.
- B.4 Repeat Clause B.3 with the turn table aligned at 120°, 240° & 360°. The reading recorded at 360° would serve as a check and it shall not differ from the reading at zero degree by more than 0.05 mm. The orientation can be slightly adjusted to avoid soft and weak spots or surface irregularities.
- B.5 Repeat Clauses B.2 to B.4 but with the dial gauge set against the point near the bottom of the specimen.
- B.6 Calculate the maximum difference between the top and bottom measurements at 0°, 120° & 240° as the perpendicularity of the specimen.
- B.7 If the perpendicularity exceeds 1 mm, proceed to Clause D for capping of the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.

C. Parallelism Checking of Specimen

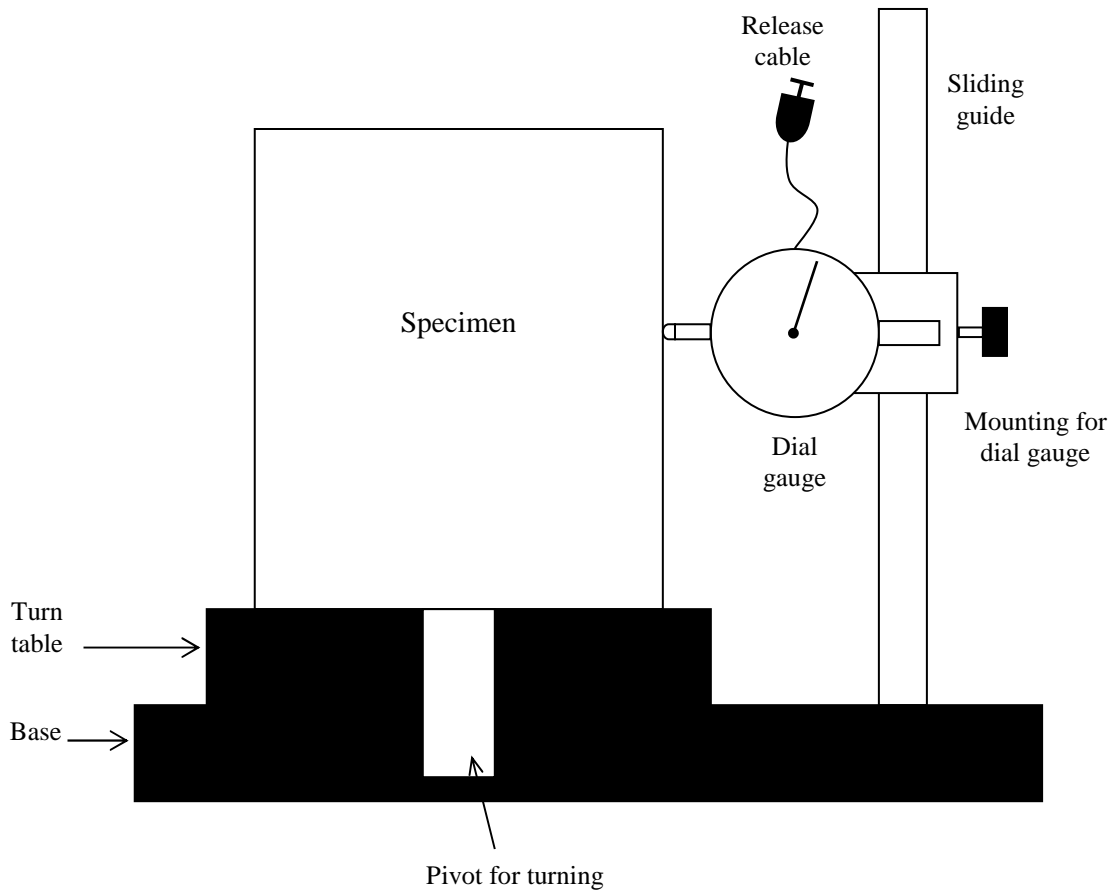
- C.1 Use the caliper to measure the length of the specimen between cut faces, at 0°, 120° & 240° around the circumference as indicated by the axes marked in Clause 4.2.1.6, and record the results to the nearest 0.1 mm.
- C.2 If the difference of the three cut length measurements within 2 mm then the specimen shall be considered parallel. Otherwise, proceed to Clause D for capping of the specimen; or return to Clause 4.2.1.5 for re-cutting the specimen.

D. Capping of Specimen (if necessary or as requested by the customer)

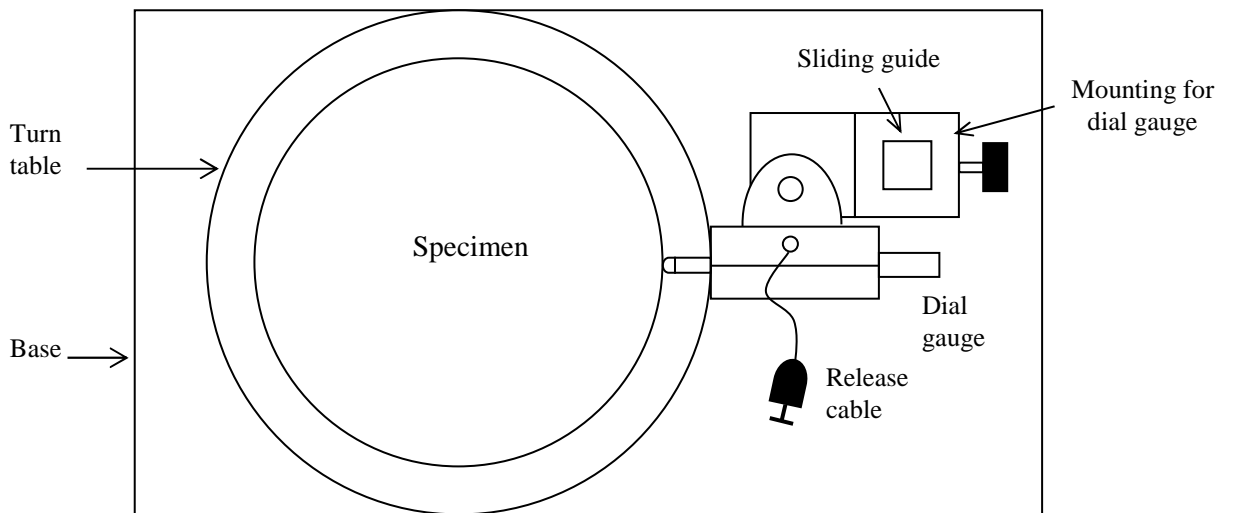
- D.1 Wipe off surface moisture and extraneous matter on the specimen. Weigh the specimen and record the mass (M_1).
- D.2 Dry one end of the specimen sufficiently to allow adhesion of the capping compound.
- D.3 Heat the capping compound to a suitable viscosity for capping (Note 1). Use a suitable thermometer to check the temperature of the compound after stirring. The temperature shall be within the range of 130°C to 150°C.
- D.4 Coat the capping former with a thin film of warm oil. Excess oil may affect the flatness of the cap.
- D.5 Pour the capping compound into the capping former in such a manner to ensure that the finished cap will be as thin as possible.
- D.6 Place the specimen into the capping compound immediately using the former to maintain the axis perpendicular to the cap.
- D.7 Allow the compound to harden, remove any surplus and then remove the specimen from the former. Check the cap for air bubbles or lack of adhesion by tapping.
- D.8 Repeat Clauses D.2 to D.7 for the other end of the specimen.
- D.9 Repeat the test procedures stated in Clauses A to C for checking the flatness, perpendicularity and parallelism of the capped specimen.
- D.10 If the capped specimen does not comply with the tolerances given in Clauses A to C, the cap shall be removed. Repeat test procedures stated in Clauses D.1 to D.9.
- D.11 Use calliper to measure the length of the specimen after capping (L_u) at points around the circumference of the specimen at 120° intervals, and record the readings. Calculate and record the mean of the three measurements to the nearest 0.1 mm. Weigh the specimen and record the mass (M_2). Calculate and record the mass of the cap ($M_3 = M_2 - M_1$).
- D.12 Proceed to Clause 4.3 for curing the specimen.

Note 1: The strength of each new stock of capping compound shall be checked by preparing a cap on a rock core specimen stronger than the compound and then testing it in compression. The capped specimen shall be loaded to at least 20 N/mm² and after the load is released, the capping compound shall be inspected. The stock shall be accepted only if there is no sign of damage on the capping compound.

Figure 1
An Apparatus for Measuring the Perpendicularity of Specimen (for reference only)



Section



Plan

An Apparatus for Measuring the Perpendicularity of Specimen
(for reference only)

