



GUIDEBOOK FOR TESTINGS OF HARDENED REINFORCED CONCRETE

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FOREWORD

The reinforced concrete (RC) structures refers to the members, such as beams, boards, columns, roof trusses, consisting of concrete and steel bars. The durability of RC structure greatly dependent on the quality of the concrete and the steel bar embedded in it. Moreover, its lifetime is also hinged on the durability factors considered by engineers in the design process and degree of adherence towards design specification during construction. Nevertheless, a negligence or faults during design and construction would lead to reduction of RC structures quality. In addition, accidental damages are also able to jeopardize the structural integrity. Therefore, testing of the RC structures plays an important role to know about the strength, durability and condition of the structure.

The test for RC structures can be carried out by several methods; destructive tests (DT) and non-destructive tests (NDT). In this context, the crushing of the samples is the usual DT to determine the RC properties. On the other hand, NDT can be defined as the test method used to determine the properties of concrete used in the actual structures. Currently, numerous test techniques are available at present to assess properties of RC structures. However, all the techniques available have their own limitations which associated with the ambiguity of interpretation. Thus, this guidebook was intended to introduce various DT and NDT method that commonly used for RC structures. In addition, this guidebook also gives an insight into each proposed technique so that the user can choose the best testing method that applicable to the structure condition. The test results can be used to further assess the structural integrity to give confidence to the engineers involved to make further crucial decisions.



1.0 INTRODUCTION

This guidebook outlined the destructive test (DT) and non-destructive test (NDT) to investigate the service life and detect the weakness of design which might not show under normal working conditions. Most of the tests provided in this guidebook is easy to carry out, easier to interpret and would yield more information. Also, for each type of test, a brief description is given that covers the purpose of the test, the equipment required, a step-by-step test procedure, the compliance and a list of references at the end of the description. The tests are as listed below.

- (1) Covermeter Measurement
- (2) Compressive Strength Tests (cores)
- (3) Rebound Hammer
- (4) Ultrasonic Pulse Velocity Test (UPV)
- (5) Penetration Resistance Test (Windsor Probe)
- (6) Carbonation Test
- (7) Half-cell Potential Measurement
- (8) Initial Surface Absorption Test (ISAT)
- (9) Rapid Chloride Penetrability Test
- (10) Water Absorption Test
- (11) Sorption Test
- (12) Impact Echo Test
- (13) Chloride Ponding Test
- (14) Chloride Diffusion Test
- (15) Near-Surface Strength Test
- (16) Ground Penetrating Radar
- (17) Petrographic Test
- (18) Steel Tensile Test

As a simple guide, users can refer to the Table 1.1 below which summarized the appropriate test for each concrete structure assessment and its significance.

Table 1.1: Summary of tests for destructive test (DT) and non-destructive test (NDT).

Test method	Parameter measured	Properties under investigation	Comment	Cost
Compressive Strength Test (Cores) -DT	Compressive strength	Concrete strength	Determination of residual strength of in-situ concrete structure; Usually test correlated with other non-destructive test to minimize coring locations.	High
Water Absorption Test (on cores) -DT	Water absorption of concrete	Porosity	Basically, determine the concrete water tightness. Suitable test to be conducted for water retaining structure	Moderate
Sorption Test (on cores) -DT	Capillary-rise absorption of concrete	Permeability	Basically, determine the effectiveness of waterproofing admixtures in concrete mix. Suitable test for concrete contains water repellent agent	Moderate
Near-Surface Strength Test	Force required to	Concrete strength	To be correlated with compressive	Moderate



Test method	Parameter measured	Properties under investigation	Comment	Cost
Pull-off Pull-out Break-off -DT	pull-out inserted rod in concrete, Force required to pull-off metal adhered to concrete surface Measures the transverse force required to break-off a core drilled into concrete surface Force required to pull-out inserted rod in concrete		strength test result of the particular concrete under investigation to determine estimated concrete compressive strength	
Petrography Test -DT	Investigation of the concrete to determine the composition of concrete (mineralogical & chemical characteristics) Examination of deteriorated and damaged concrete.	Integrity and performance	Require highly trained person for data interpretation; The compliance of concrete to specifications; Fire damaged concrete structure – the assessment of temperature to determine residual loads.	High
Covermeter Measurement	Depth, size and location	Identification of embedded	Test conducted on hardened concrete structure. Normally	Low



Test method	Parameter measured	Properties under investigation	Comment	Cost
-NDT	of embedded steel	steel reinforcement	results used prior to concrete coring	
Rebound Hammer – NDT	Surface hardness of hardened concrete structure	Concrete strength	Quick estimation on concrete compressive strength, but will only represent concrete strength at surface	Low
Ultrasonic Pulse Velocity Test (UPV) -NDT	Pulse velocity passing through concrete.	Integrity and concrete strength.	Commonly used to investigate uniformity and estimation of concrete strength	Moderate
Penetration Resistance Test (Windsor Probe) -NDT	Resistance of concrete to penetration into a concrete surface by a steel rod or probe	Concrete strength	Estimation on concrete compressive strength. To be correlated with compressive strength test result	Moderate
Carbonation Test -NDT	Depth of carbonation in concrete	Carbonated concrete	Test usually conducted for aged concrete structure	Low

Test method	Parameter measured	Properties under investigation	Comment	Cost
Half-cell Potential Measurement -NDT	Identify region or regions in a reinforced concrete structure where there is a high probability that corrosion is occurring	Corrosion of embedded steel	Provides data for assessing the uniaxial water penetration characteristic of a concrete surface. This test not applicable to specimens or areas showing obvious porosity, honeycombing or cacking	High
Initial Surface Absorption Test (ISAT) -NDT	Concrete surface permeability	Concrete quality, durability and deterioration	Basically, determine the permeability of concrete surface. Usually test conducted for compliance to weathering performance	Moderate
Rapid Chloride Penetrability Test (RCPT) -NDT	Chloride ion penetration into concrete based on charge passed	Concrete durability and deterioration	Fast result output. Suitable for assessment of chloride ingress in concrete structure especially those located near marine environment	Low
Impact Echo Test -NDT	Presence and depth of flaws in concrete	Integrity and performance	Usually conducted on suspicion of flaws inside concrete	Moderate
Chloride Ponging Test	Penetration of chloride ion into concrete	Concrete quality,	Determination of chloride content can only be done at	Moderate

Test method	Parameter measured	Properties under investigation	Comment	Cost
-NDT		durability and deterioration	least by 3 months of ponding. Normally, this will be conducted for concrete structure located near marine environment	
Chloride Diffusion Test (on cores)-NDT	Apparent chloride diffusion coefficient for hardened cementitious mixture	Concrete quality and durability	Applicable only to laboratory test specimen in which the cementitious mixture	Moderate
Ground Penetrating Radar (GPR) -NDT	Detailed mapping of steel reinforcement in concrete by using radar pulses to image the subsurface	Mapping	Require highly trained person for data interpretation; GPR can be used to detect subsurface objects, changes in material properties, voids and cracks	High
Steel Tensile Test -DT	Determination of tensile strength of sampled steel reinforcement	Steel tensile strength	Usually conducted when tensile strength of embedded reinforcement steel in concrete are in doubt. Commonly, this test carried out on damaged concrete	High

2.0 COVERMETER MEASUREMENT

2.1 INTRODUCTION

A covermeter is an instrument to locate rebar and measure the exact concrete cover. Rebar detectors are less sophisticated devices that can only locate metallic objects below the surface. The pulse-induction method is one of the most commonly used solutions techniques. The concept of covermeter which using the pulse indication method are as illustrated in Figure 2.1. The covermeter can be used for:

- a) Quality control - to ensure correct location and cover to reinforcing bars after concrete placement.
- b) Investigation of concrete members for which records are not available or need to be checked.
- c) Location of reinforcement as a preliminary to some other form of testing in which reinforcement should avoid or its nature to taken account.
- d) Location of buried ferromagnetic objects other than reinforcement such as water pipe, steel joist, etc.

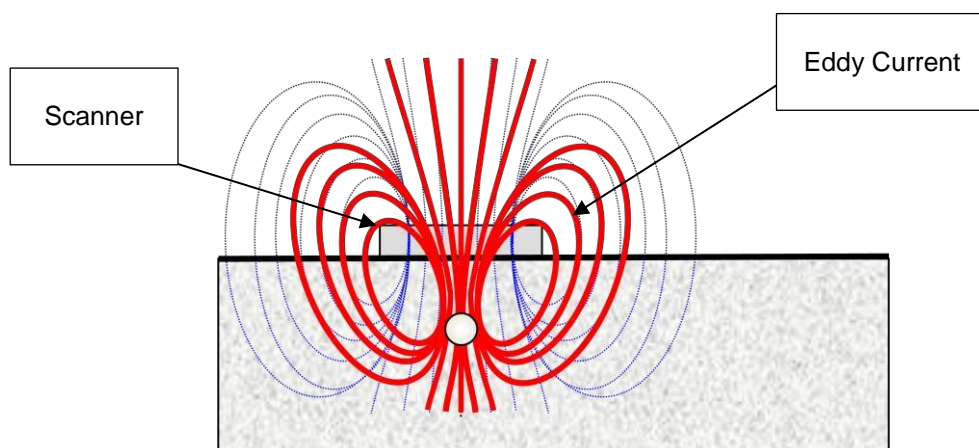


Figure 2.1: The concept of pulse induction method.

The pulse-induction method is based on electromagnetic pulse induction technology to detect rebar. Coils in the probe are periodically charged by current pulses and thus generate a magnetic field. On the surface of any electrically conductive material which is in the magnetic field Eddy current are produced. They induce a magnetic field in opposite directions. The resulting change in voltage can be utilized for the measurement. Rebars that are closer to the probe or of larger size produce a stronger magnetic field. Modern rebar detectors use different coil arrangement to generate several magnetic fields. Advanced signal processing supports not only the localization of rebars but also the determination of the cover and the estimation of the bar diameter. This method is unaffected by all non- conductive materials such as concrete, wood, plastics, bricks etc.

2.2 EQUIPMENT

The covermeter equipment as in Figure 2.2 are stipulated by BS 1881: Part 204. The description of equipment are as follows:

- 1) Search head/scanner - for scanning concrete surface
- 2) Meter - to indicates an analogue or digital means by the reinforcement proximity.
- 3) Interconnecting cable



Figure 2.2: Covermeter probe.

2.3 PROCEDURE

- a) Calibration of the covermeter should be carried out to establish the accuracy of the instrument. A basic calibration method is given in BS4408: Part 1 involving a cube of concrete of given proportions with reinforcing bars with specified distances from surface.
- b) If different search heads are to be used with the same meter, calibration checks should be carried out for each head.
- c) The covermeter is switched on and the meter adjusted so that the needle on the indicator dial corresponds to the appropriate calibration mark as indicated by the manufacturer.
- d) The search head is then scanned over the surface of the concrete to examine for the presence of reinforcement. If reinforcement exists below the surface and within the working range of the covermeter, the device can then predict the location and depth of the reinforcing bar. The head used to scan over the concrete are shown as in Figure 2.3.



Figure 2.3: The position of head to scan over the concrete surface.

2.4 COMPLIANCE

There are limitations of using covermeter as non-destructive test for reinforced concrete structure. The limitations are listed as follows:

- a) It is very slow and labour intensive.
- b) The results are affected by the presence of more than one reinforcing bar in the test area. For example, the reinforcing bar that exist by laps, by second layers, by metal tie wires and by bar supports.
- c) For maximum accuracy it has to be calibrated for concrete used in the structure. This procedure conducted to eliminate the influence of iron content of the aggregate and cement used.
- d) The method is unsuitable in the case of closely packed of reinforcement bar assemblies.
- e) The accuracy will be reduced if rough or undulating surfaces are present; such as exposed on aggregate finishes. The effect on the indicated cover will be similar in magnitude to the surface irregularities within the area of the search head.
- f) Calibrated meter scales are generally valid for a particular grade of reinforcing steel. The effect of different types of steel on the readings obtained is generally small. However, in special cases such as high tensile prestressing bars, it may include errors as high as $\pm 5\%$ or more. If the high tensile prestressing bars being tested, the covermeter should be calibrated for such material by constructing a calibration curve.
- g) For accurate measurement of cover and size, the bar must be straight and parallel to the concrete surface.
- h) Where significant corrosion of reinforcement has occurred, in particular, scaling and migration of corrosion products would lead to cover indication reading.



- i) Interference effects will occur in the neighbourhood of metallic structures of significant size, such as window fixings, scaffolding and steel pipes, especially when they are immediately behind the search head. The degree of influence will depend on the particular covermeter used but all are affected by either stray magnetic fields, electric fields or both. If such cases exist, reliable use of the instrument may be severely restricted.

REFERENCES

1. British Standard. (1988). *Recommendations on the use of electromagnetic covermeters* (BS 1881-204:1988).

3.0 COMPRESSIVE STRENGTH TEST (CORES)

3.1 INTRODUCTION

Compression test of concrete cores extracted from existing structures is the most reliable method of assessing in-situ compressive strength of concrete. Under this method, a cylindrical core is cut from the hardened concrete by diamond-tipped drill and later tested by crushing with the compression testing machine in the laboratory. The maximum load that the core sample can sustain is recorded and divided by the sample's cross-section area to obtain compressive strength of the sample, expressed in Newton per millimeter square (N/mm²).

Sampling of core specimen shall refer to MS EN12504-1:2009. The concrete core shall be tested in accordance with MS EN 12390-3:2012 and its subsequent assessment shall be guided by MS EN 13791:2014 and MS 1242:2014.

3.2 APPARATUS

3.2.1 CORING APPARATUS

The apparatus used extraction of samples are illustrated in Figure 3.1 below.

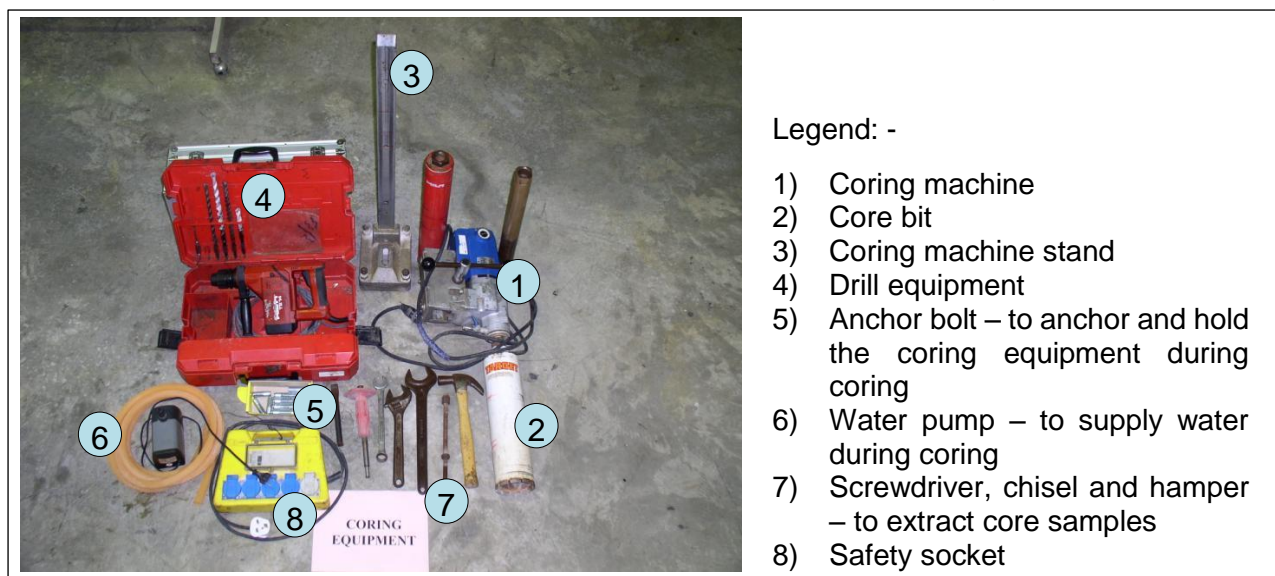


Figure 3.1: Coring apparatus.

3.2.2 TESTING APPARATUS

The equipment used to test the samples are described below:

- a) Compressive testing machine
- b) Balance or scale – to weigh the mass of the core sample
- c) Calipers and / or rules – to measure the dimensions of the core samples and steel reinforcements (if any)
- d) Gauge – to check the flatness of the end surface of core samples
- e) Squares and gauge – to check the perpendicularity and straightness of the end surface of core samples



Figure 3.2: Compression testing machine

3.3 DIMENSION OF CORE SAMPLES

3.3.1 Diameter

- a) The preferred diameter of core samples shall be between 100 mm to 150 mm.
- b) Where a smaller diameter (less than 100 mm) is required, it is compulsory to take three (3) times as many cores as are used when performed on bigger cores.

3.3.2 Length

The preferred length to diameter ratio (after end-capped or grinded) is as follows:

- a) 1.0 if the strength result is to be compared to cube strength
- b) 2.0 if the strength result is to be compared to cylinder strength

3.4 NUMBER OF SAMPLINGS

For the purpose of assessment of in-situ compressive strength for a particular test region, the number of core samples shall be at least 3 cores. MS EN 13791:2007 give guidance on two approaches (Approach A and Approach B) of concrete strength assessment which depends on the number of cores taken. Approach A applies where at least 15 cores are available, and Approach B applies where 3 to 14 cores are available.

3.5 LOCATION OF CORE SAMPLES

Cores should preferably be taken:

- a) at points away from joints or edges of the concrete element with little or no reinforcement.
- b) at points where there will be no structural implication to the elements tested.
- c) away from any embedded reinforcements, wherever possible. As such, the location of reinforcement shall be determined and marked out at site using ferrous detector equipment prior to the drilling of cores.

- d) at points where it is presumed to have the best compacted homogeneous concrete area.

3.6 DRILLING PROCEDURE

The procedures for sample extraction are described below. The procedures described are presumed that the setting out for coring location is finalized and that all safety procedures are strictly adhered to.

Determine the steel reinforcement location inside the selected structure member by using steel bar scanner. Position the core drill so as to avoid the determined steel reinforcement and core on the selected structure member perpendicularly using diamond core bit. Keep the drill rigidly position during coring, as shown in Figure 3.3.



Figure 3.3: Positioning core drill on concrete structure member.

After the coring process reach the required depth, extract out the core sample manually using chisel and hammer, as shown in Figure 3.4.



Figure 3.4: Extracting core from the structure.

Carry out visual examination of the core samples to identify any abnormality. If transverse reinforcement is encountered, record its diameter and position in mm, for correction purposes later.

Measure the diameter and length of as-received cores in mm, for record purposes.

Cored holes shall be reinstated with approved repair mortar, preferably polymer modified cementitious repair mortar with same or higher strength than the actual concrete strength.

If the determination of core density is required, weigh the as-received cores to an accuracy of 0.01% of its mass prior to capping the ends of the cores. Record the value indicated in kilogram (kg).

Immerse the as-received cores in water at a temperature of 20 ± 2 °C until saturated for grinding or capping procedures.

3.6 GRINDING OR CAPPING OF CORED SAMPLES

If it is necessary to reduce the length of a cored sample, it shall be ground or sawn, as illustrated in Figure 3.5. However, if grinding is impractical (i.e. core samples below

the required diameter/length ratio), samples shall be capped, as shown in Figure 5.6 at both ends by using either:

- i. Calcium aluminate cement mortar composed of three (3) part by mass of calcium alumina cement and one (1) part by mass of fine sand (3:1); or,
- ii. Sulphur mixture composed of equal part by mass of Sulphur and fine siliceous sand (1:1) together with a small proportion of carbon black (up to 2% by total mass).



Figure 3.5: Grinding of specimen using grinding machine.

The samples shall be in saturated condition before undergoing grinding or capping using calcium aluminate mortar. The diameter and length of finished samples shall be measured in mm, for record purpose. The finished samples also shall be maintained immersed in water at a temperature of 20 ± 2 °C, as shown in Figure 3.7 until it is in saturated condition for testing.



Figure 3.6: Capping the ends of specimen.



Figure 3.7: Store the specimen in water.

3.7 TESTING PROCEDURE

The procedures for core samples testing are described as below. The procedures described are presumed that the equipment used are fully calibrated and all safety procedures are strictly adhered to.

- a) Test the samples in compression for not less than 48 hours after the end preparation (ground or capped). Test the core immediately on removal from the water and while it is still in wet condition.
- b) Do not test cores with cracked, hollow or loose caps.
- c) Wipe all testing machine bearing surfaces clean and remove any loose grit or other extraneous material from the surface of the samples that will be in contact with the platens.
- d) Wipe off excess moisture from the surface of the samples before placing it in the testing machine.
- e) Position the samples so that the load applied is perpendicularly to the direction of casting.
- f) Center the samples with respect to the platen to an accuracy of 1% of the designated diameter of cylindrical samples.
- g) If auxiliary platens are used, align them with the top and bottom face of the samples.
- h) Apply and increase the load continuously at a constant rate within the range of $0.6 \pm 0.2 \text{ N/mm}^2.\text{s}$ until no greater load can be sustained. Figure 5.8 illustrates a compression test in progress.
- i) Record the maximum load indicated in kilonewton (kN).



Figure 3.8: Testing for core compressive strength.

REFERENCES

1. Malaysian Standard. (2013). *Testing concrete in structure part 1: cored specimens – taking, examining and testing in compression (2nd rev)* (MS EN 12504 – 1: 2013).
2. Malaysian Standard. (2012). *Testing hardened concrete part 3: compressive strength of test specimens (second revision)*. (MS EN 12390 – 3: 2012).
3. Malaysian Standard. (2014). *Assessment of in-situ compressive strength in structures and precast concrete components*. (MS EN 13791: 2014).
4. Malaysian Standard. (2014). *Assessment of in-situ compressive strength in structures and precast concrete components – Complementary guidance to that given in MS EN 13791*. (MS 1242:2014).

4.0 REBOUND HAMMER

4.1 INTRODUCTION

Rebound hammer, also known as Schmidt Hammer or Impact Hammer, is the most popular test device to study and measures the surface hardness of concrete. The test operates/works on physical principle where the extent of rebound of an elastic mass depends on the hardness of the surface against which of the mass strikes. The rebound is read off along a graduated scale and is expressed as 'Rebound Number'.

In any case, the rebound hammer test measures the properties of only the surface zone of concrete, which is about 30 mm according to MS EN 12504: Part 2 – 2012. Some of the usage of the surface hardness method include:

- a) Checking the uniformity of the concrete;
- b) Comparing a given concrete with a reference;
- c) Determining the properties of the concrete surface which have a direct influence on its performance; and,
- d) Estimation of the strength of concrete in structures.

Despite its simplicity, the method might leave surface marks. and results are influenced by many factors. Rebound hammer test is sensitive to local variation in the concrete internal composition, for instance the presence of large aggregate right under the plunger would lead to/result in higher rebound number. For this reason, MS EN 12504: Part 2 – 2012 recommends that at least 9 readings should be taken in an area of approximately 300 mm by 300 mm. While a variety of hammers are available to suit particular concrete types, each of the hammer comes with its respective calibration chart.

4.2 APPARATUS

The components of rebound hammer test equipment used for the hardened concrete are described below. Figure 4.1 illustrate each of the component.

- a) Rebound Hammer – consists of a spring-loaded steel hammer which strikes a steel plunger to the concrete surface when released.
- b) Abrasive stone – consists of medium-grain texture silicone carbide.
- c) Marker – to mark the rebound points.

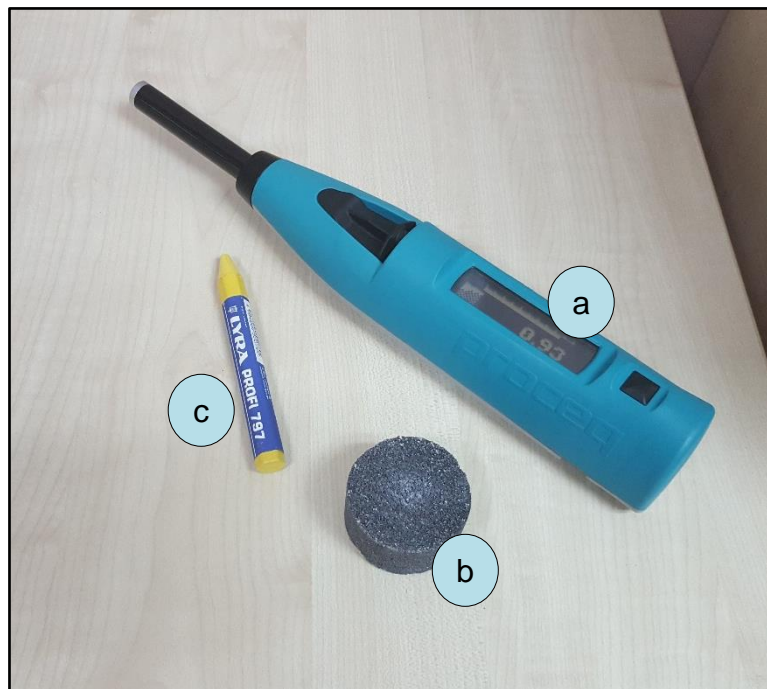


Figure 4.1: Components Rebound Hammer.

4.3 PROCEDURE

- a) Before performing this test, remove any plaster or coating covering, serious roughness and small voids by brushing with abrasive stone. Avoid testing at areas exhibiting honeycombing, scaling or high porosity.
- b) After brushing, mark the test points according to grid of 20-50 mm apart. Nine (9) points for an area of 300 x 300 mm are recommended.
- c) Hold the hammer firmly so that the plunger is perpendicular to the surface.
- d) Gradually push the hammer strongly and steadily towards the test surface until the hammer impacts, i.e. the spring-loaded mass is triggered from its locked position.
- e) After the impact, maintain the hammer on its location and, if necessary, lock the plunger in its retracted position by depressing the button on the side of the hammer.
- f) Read and record the scale index from the hammer, which is known as the rebound number (N).
- g) Convert rebound number (N) to compressive strength value using the calibration chart established for a particular device.

4.4 COMPLIANCE

Indication of the surface hardness of concrete is represented by the median rebound number. Thus, a typical relationship between rebound number and cube compressive strength is shown in Figure 4.2.

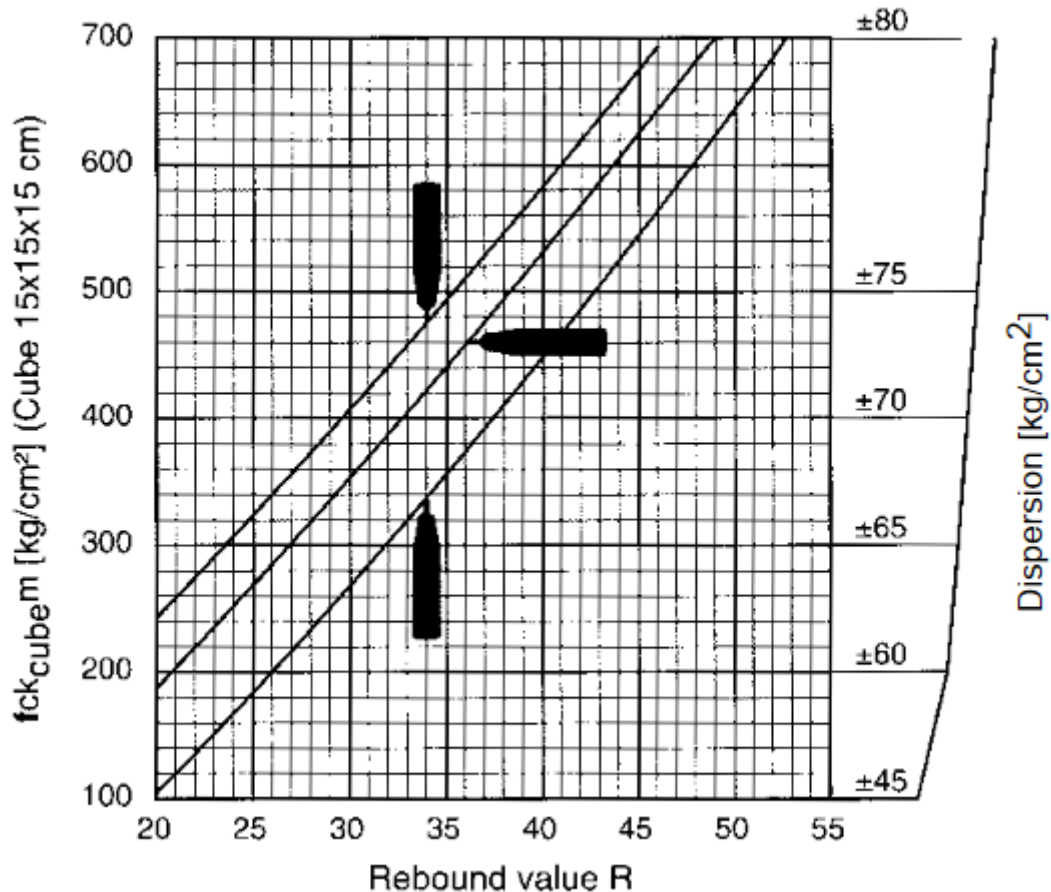


Figure 4.2: Typical relationship between rebound number and cube compressive strength. Reprinted from <https://www.proceq.com>. Copyright 2017 by Proceq SA.

The results may be correlated with compressive strength results of cored samples for assessment of in-situ compressive strength for particular structure in accordance to MS EN 13791:2007. However, the limitation of Rebound Hammer test should be recognized, to not be considered as a substitute for compression testing alone, unless preceded with correlation test.



REFERENCES

1. Malaysian Standard. (2012). *Testing concrete in structure – non-destructive testing – determination of rebound number*. (BS EN 12504-2:2012).
2. Malaysian Standard. (2014). *Assessment of in-situ compressive strength in structures and precast concrete components*. (MS EN 13791: 2014).
3. Malaysian Standard. (2014). *Assessment of in-situ compressive strength in structures and precast concrete components – Complementary guidance to that given in MS EN 13791*. (MS 1242:2014).

5.0 ULTRASONIC PULSE VELOCITY TEST

5.1 INTRODUCTION

Ultrasonic Pulse Velocity (UPV) test is a well-established non-destructive method to access the modulus of elasticity and correlated strength of concrete. This is a non-destructive quick to use method which requires the access on opposite concrete member surface in order to obtain the best results.

Pulses of compressional waves are generated by an electro-acoustical transducer that is held in contact with one surface of the concrete. After traversing through the concrete, the received pulse signals are converted into electrical energy by a second transducer located at a measured distance between transmitting and receiving transducers placed on the concrete surface. The transit time is measured electronically, and the pulse velocity is calculated by dividing the distance by transit time. This provides a measurement of the mean ratio of elastic stiffness to density along the path and has been found to be a useful index of concrete quality.

5.2 EQUIPMENT

The components of UPV test equipment used for the hardened concrete are described below and illustrated in Figure 5.1.

1. Voltmeter – digital direct-reading display with an interval timer
2. Calibrator block – to check the proper operation of the time-measuring circuit
3. Transmitter and Receiving Transducer – generate and receive pulses of voltage
4. Grease oil – as a coupling agent for the transmission of pulses
5. Connecting wire – connecting the transducers with voltmeter
6. Battery charger



Figure 5.1: UPV test components.

5.3 PROCEDURE

The procedure for carrying out ultrasonic pulse velocity (UPV) test is described in the following sub-sections. The procedures described below assume that the setting out of location for test is in place and that all safety procedures are strictly adhered to.

- a) After defining test location, chip off plaster (if any) and clean the surface of test location. When the concrete surface is very rough or uneven, the area of the surface should be smoothed and levelled by grinding or by the use of quick-setting epoxy resin.
- b) Apply coupling agent (grease or lubricant) to the transducer diaphragms and structure surface to avoid entrapped air between contact surface of the diaphragms and structure, as shown in Figure 5.2.



Figure 5.2: Applying coupling agent to transducers and structure surface.

- c) Press the transducers against concrete surface. There are three different ways of placing the transducers as stated below:
- i. Direct Transmission
Transducers are placed on direct opposite faces of concrete, as in Figure 5.3, resulting in the receiving-transducer receiving maximum energy from the transmitted pulse.



Figure 5.3: Arrangement of transducers for direct transmission.

ii. Semi-direct Transmission

Transducers are placed on adjacent faces, as shown in Figure 5.4, thus reducing the accuracy of measurement of path length.



Figure 5.4: Arrangement of transducers for semi-direct transmission.

iii. Indirect Transmission

Transducers are placed on same face of concrete, as illustrated in Figure 5.5. It is used where only one face of the concrete is accessible.



Figure 5.5: Arrangement of transducers for indirect transmission.

- d) Turn on the power supply, and the ultrasonic waves travel from the emitter transducer through the structure to the receiving transducer.
- e) The time taken by the waves to travel between the two transducers is displayed on the recording device. The transit time is measured, and the ultrasonic pulse velocity is calculated from the following formula:

$$\text{UPV} = \frac{\text{PATH LENGTH}}{\text{TRANSIT TIME}} \quad (\text{km/s}) \quad (1)$$

- f) The UPV value is applicable to determine the uniformity of concrete in or between members; detection of the presence and approximate extent of cracks,

voids and other defects; correlation of pulse velocity and strength to measure concrete quality; and determination of dynamic modulus and Poisson ratio, using specific formula.

5.4 COMPLIANCE

High pulse velocity readings are generally indicative of good quality concrete. Classification concrete quality based on pulse velocity may be guided by Figure 5.6.

UPV results may be further correlated with concrete core test result to establish relationship for assessment of in-situ concrete compressive strength (refer MS 1242:2014 and MS EN 13791:2014).

Longitudinal pulse velocity		Quality of concrete
km/s	ft/s	
>4.5	>15	excellent
3.5-4.5	12.15	good
3.0 – 3.5	10 – 12	doubtful
2.0 – 3.0	7 – 10	poor
<2.0	<7	very poor

Figure 5.6: Classification of the quality of concrete based on pulse velocity. Adapted from Table 11.3 in IAEA, 2002.



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2. International Atomic Energy Agency. (2002). *Guidebook on non-destructive testing of concrete structure*. Vienna, Austria: IAEA.
3. Bungey, J.H., Millard, S.G., & Grantham, M.G. (2006). *Testing of concrete in structures (4th ed.)*. Oxon, OX14: Taylor & Francis.

6.0 CARBONATION TEST

6.1 INTRODUCTION

Concrete carbonation may be simply identified by spraying a concrete core's surface with a suitable indicator to detect the loss of alkalinity, which is related to the protection of the steel reinforcement bars in the concrete structure.

Knowledge of the penetration depth of carbonation below the surface of a concrete member would be useful when assessing the risk of reinforcement corrosion. Future progression of carbonation may also be predicted. Phenolphthalein solution is commonly used to indicate the boundary between the alkaline and acid zone by colour observation on the sprayed concrete surface. Phenolphthalein simply gives purple colour when reacts with alkaline or remain colourless if not encounter with alkaline. For more detail, multi-coloured indicator can identify range of alkalinity/acidity by pH number.

6.2 EQUIPMENT

Apparatus and materials used for carbonation test in accordance to BS EN 14630:2006 are described below and shown in Figure 6.1:

1. Phenolphthalein (normally use 1 gram in powder form)
2. Ethyl alcohol – To mix with phenolphthalein to form a chemical indicator.
3. Spray bottle – for spraying the indicator solution to concrete surface.
4. Distilled water – To mix with phenolphthalein to form a chemical indicator.
5. Beakers – for measuring and mixing phenolphthalein solution.

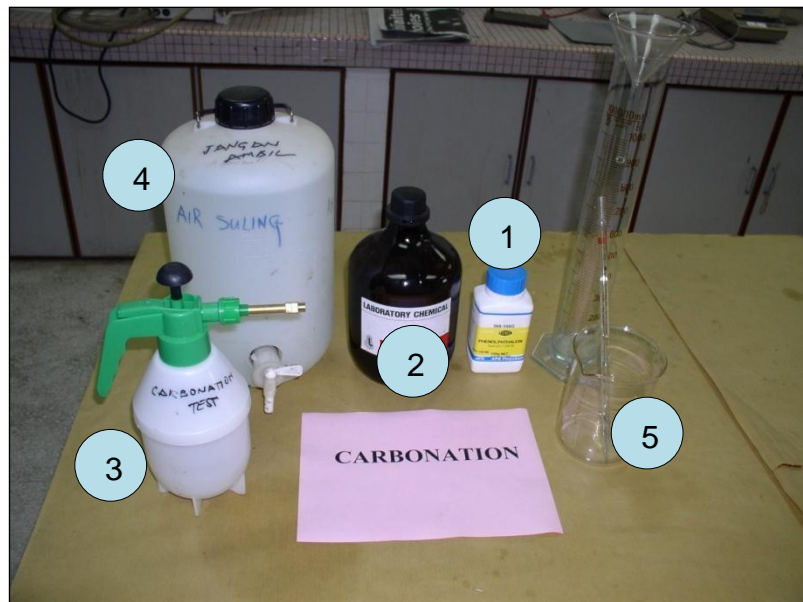


Figure 6.1: Carbonation test apparatus.

6.3 PROCEDURE

- a) Prepare a solution of phenolphthalein indicator by dissolving 1 gram of phenolphthalein in 70 ml ethyl alcohol and dilute to 100ml with distilled or deionized water. Put the solution into the spray bottle.
- b) Clean the obtained core sample by rinsing with clean water to wash away core dust at the surface immediately upon extraction or receipt. The core sample shall have marking indicating their location and orientation with respect to the original concrete surface.
- c) Air-dry the core sample. One typical concrete core sample for carbonation test is shown in Figure 6.2.



Figure 6.2: Core sample ready for carbonation test.

- d) Using the spray bottle, spray the indicator solution on the surface of the core sample after air-dried, as illustrated in Figure 6.3.



Figure 6.3: Spraying phenolphthalein solution on a core sample.

- e) Visually observe the colour changes of core surface. If core surface immediately undergoes colour change to purple red (red violet), this indicates the presence of alkaline, i.e. $\text{Ca}(\text{OH})_2$, hence no carbonation. If portion of the core is not experiencing colour change it means the loss of alkalinity caused by the presence of carbonation.
- f) Measure the length of colourless portion on sample surface, as shown in Figure 6.4, preferably on both sides of the core-through concrete sample. The dimension measured is also equivalent to the carbonation penetration at the sample element.



Figure 6.4: Measuring the carbonation depth of a core sample



REFERENCES

1. British Standard. (2006). *Products and systems for the protection and repair of concrete structures – test methods – determination of carbonation depth in hardened concrete by the phenolphthalein method.* (BS EN 14630:2006).
2. Roberts, M. H. (1981). *Carbonation of concrete made with dense natural aggregates* (IP 6/81). Glasgow: Building Research Establishment.

7.0 HALF-CELL POTENTIAL MEASUREMENT

7.1 INTRODUCTION

Half-cell potential measurements are conducted to measure the probability of corrosion of steel bars in the concrete elements. By measuring concrete surface electrical potentials relative to a standard reference electrode on a pre-determined grid, the probability of future corrosion can be assessed. Such diagnosis identifies areas where corrosion is occurring or about to proceed prior any physical damage is visible.

This test traditionally consists of a copper/copper sulphate half-cell connected through a high impedance voltmeter into the steel reinforcement. The half-cell is then contacted to the surface of the concrete via a sponge or porous plug and contact fluid (water with detergent or alcohol). Electrical potential of embedded reinforcement relative to a half-cell placed on the concrete surface is measured by the voltmeter.

7.2 EQUIPMENT

Half-cell potential test for the hardened concrete comprises of a few equipment described below, and illustrated in Figure 7.1:

1. Half-cell voltmeter – measure and record electrical potential
2. Crocodile clip – to connect the reinforcement steel to voltmeter
3. Half-cell probe – move about on surface to measure potential of reinforcing steel at various location.
4. Rod – to support half-cell probe for testing on soffit at high level e.g. slab



Figure 7.1: Half-cell potential test equipment.

7.3 PROCEDURE

- a) Hack and remove a small portion of concrete to expose reinforcing steel and make direct connection between steel bar and positive terminal of the voltmeter with a crocodile clip, as illustrated in Figure 7.2.



Figure 7.2: Connecting reinforcing steel with crocodile clip.

- b) Connect one end of the lead wire to the half-cell and the other end of the same wire to the negative (ground) terminal of the voltmeter.
- c) Determine whether pre-wetting of the concrete surface is required by placing the half-cell on the concrete surface without moving it and observe the voltmeter for one of the following conditions (Figure 7.3):
 - i. If the measured value of half-cell does not change or fluctuate with time, pre-wetting process is not necessary; or
 - ii. If the measured value of half-cell changes or fluctuates with time, pre-wetting process is required by either:
 - a. spraying the entire concrete surface with an electrical contact solution, composed of a mixture of 95 *ml* wetting agent or a liquid household detergent thoroughly mixed with 19 *litre* of potable water; or
 - b. saturating the sponge with the electrical solution described above and place it on the concrete surface until condition in para (c)i is achieved and continue maintain it on the surface until half-cell reading is made.



Figure 7.3: Placing the half-cell probe on the concrete surface.

- d) Perform horizontal and vertically upward measurements exactly as vertically downward measurement. However, ensure that the copper/copper sulphate solution in the half-cell shall be in contact with the porous plug and the rod.
- e) Record the electrical half-cell potentials to the nearest 10 mV.

7.4 COMPLIANCE

The probability of steel corrosion according to volt relative to copper/copper sulphate half-cell is presented in Table 7.1.

Volts relative to copper/copper sulphate reference electrode (mV)	Probability of active corrosion of steel
< -350	95%
-200 to -350	50%
>200	5%

*Table 7.1: Probability of steel corrosion as referring to copper / copper sulphate half-cell voltage. Adapted from *Diagnosis of deterioration in concrete structures: Technical Report No.54*, (Table 26), by The Concrete Society, 2000. Copyright 2000 by The Concrete Society.*



REFERENCE

1. ASTM International. (2015). *Standard test method for corrosion potentials of uncoated reinforcing steel in concrete.* (ASTM C876-15).
2. The Concrete Society. (2000). *Diagnosis of deterioration in concrete structures* Technical Report No.54. Berkshire: The Concrete Society.

8.0 INITIAL SURFACE ABSORPTION TEST (ISAT)

8.1 INTRODUCTION

Initial surface absorption is defined as the rate of flow of water into concrete per unit area at a stated interval from the start of the test at a constant applied head pressure and temperature. The application of this method is usually as a quality control test for precast concrete unit, where the results obtained may be compared with predetermined acceptance limit; to assess the compliance of in-situ concrete with specification for weathering performance; and as a mean of comparative assessment of surface finishes and quality of the concrete in the surface zone.

Results are expressed as millilitre per square meter per second ($\text{ml}/\text{m}^2/\text{s}$) at a stated time from the start of test.

In this method, the rate of flow of water per unit area into a concrete surface when subjected to a constant head of 200 mm is measured. A watertight cap is sealed to the concrete surface to provide a water contact area of at least 5000 mm^2 ($> 71 \text{ mm} \times 71 \text{ mm}$) and connected to a reservoir and calibrated horizontal capillary tube and scale. At specified intervals from the start of test (10 mins, 30 mins, 1 hour) the tap between cap and reservoir is closed and movement of water in the capillary caused by surface absorption is measured over a specified period.

8.2 EQUIPMENT

Testing for Initial Surface Absorption involves a few apparatuses as described below and illustrated in Figure 8.1:

1. Cap – of impermeable material with a minimum contact area of 5000 mm^2 and complete with inlet and outlet connection.
2. Reservoir (with connection to the cap) – a funnel made of glass or plastic of about 100 mm diameter with a connection to the inlet to the cap by flexible tube

3. Capillary tube and scale – a length of precision bore glass capillary tubing, 100 - 1000 mm long with a bore of 0.4 - 1.0 mm radius and fixed to a calibrated scale
4. Sealant – for sealing cap onto concrete surface
5. De-aerated water
6. Stopwatch – for recording time during observation of movement in scale
7. Reservoir holder/stand – for holding reservoir on a height of 200 mm from concrete surface.

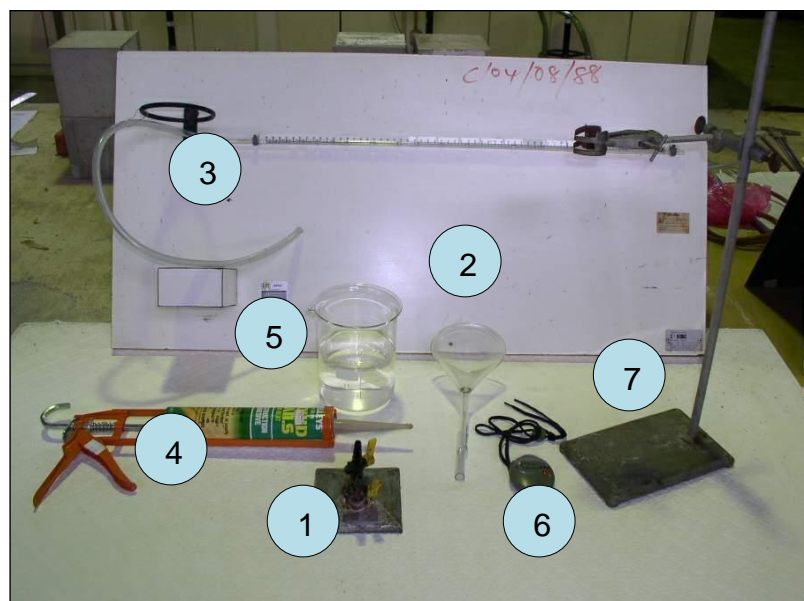


Figure 8.1: Initial surface absorption test apparatus

8.3 PROCEDURE

- a) Prepare one concrete cube specimen to be tested.
- b) Fix or clamp the cap into position on test location. Apply sealant or other suitable materials to seal the connection between concrete surface and the edges of the cap to provide a watertight assembly, as illustrated in Figure 8.2.



Figure 8.2: Fixing the cap onto concrete surface.

- c) Set the reservoir and capillary at a head of $200\text{mm} \pm 20\text{mm}$ above surface, with the reservoir connected to the inlet of the cap while capillary connected to the outlet. A complete set-up of the test is shown in Figure 8.3.



Figure 8.3: Complete set-up of ISAT test.

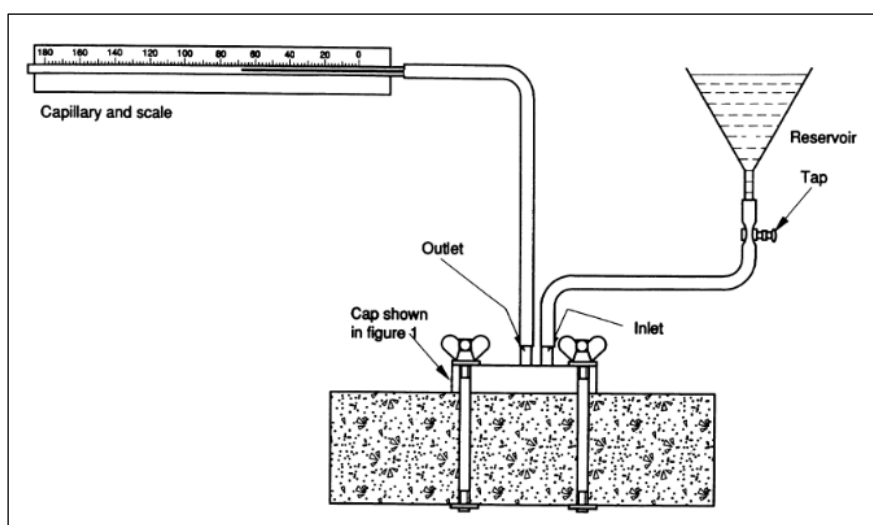


Figure 8.4: Typical assembly of absorption test apparatus.
Reprinted from Figure 1, BS 1881-208:1996.

- d) Close the tap from reservoir and fill the reservoir with water maintained at $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$.
- e) Start recording the time and open the reservoir tap to allow the water to flow into the cap until no more air escapes.

- f) Connect the outlet tube to the capillary tube and flush out any trapped air by allowing the capillary to overflow.
- g) At the intervals of 10 minutes, 30 minutes, 1 hour and 2 hours, close the inlet tap and start recording time when water starts to flow along the capillary tube.
- h) Record the number of scale division moved during the period selected from Table 8.1. Note the number of scale unit's movement in the first five seconds. If the movement is less than 3 divisions, measurements to be continued for two minutes; if 3-9 divisions, continue for one minute; or if 10-30 divisions, continue for 30 seconds. If the movement is more than 30 divisions in five seconds, the result can be noted as more than 3.60 ml/m²/s.

Number of scale units moved in 5 seconds	Period during which movement is noted
Less than 3	2 minutes
3 – 9	1 minute
10 – 30	30 seconds
More than 30	Record initial surface absorption as 3.60 ml/m ² /s

Table 8.1: Determination of period of movement.

- i) Just before each specific interval, adjust the position of the capillary tube to completely fill it with water. Between test intervals leave the tap open and maintain the level of water in the reservoir at the specific height.
- j) If the reading taken 10 minutes after the start of the test is below 0.05 ml/m²/s, stop the test and record the result with the comment - concrete too impermeable to be sensitive to a longer-term test. Similarly, where the 10 minutes reading is above 3.60 ml/m²/s, stop the test and record the result with the comment - concrete too permeable to be within the sensitivity of the test method.

8.4 COMPLIANCE

Values for 10 minutes of surface absorption of low, average and high concrete permeability/absorption as recommended by the Concrete Society, Technical Report No.54:

Low concrete permeability	< 0.25	ml/m ² /s;
Average concrete permeability	0.25-0.50	ml/m ² /s;
High concrete permeability	>0.50	ml/m ² /s

REFERENCES

1. British Standard. (1996). *Testing concrete-Part208: Recommendation for the determination of the initial surface absorption of concrete.* (BS 1881-208:1996).
2. Neville, A.M. (2004). *Properties of Concrete: (4th Ed.)*. Harlow, England: Pearson Education Limited.
3. The Concrete Society. (2000). *Diagnosis of deterioration in concrete structures* Technical Report No.54. Berkshire: The Concrete Society.

9.0 RAPID CHLORIDE PENETRABILITY TEST

9.1 INTRODUCTION

This test method is carried out to determine the resistance of concrete to the penetration of the chloride ions by evaluating the electrical conductance of concrete samples. This property is important to determine the concrete's resistance to chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in strength, serviceability, and aesthetic of the structure.

There are currently two test methods to carry out the test. One of them is ASTM C1202, which is developed by American Society of Testing and Materials. The other one is a modified ASTM C1202 method, which is developed by Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

The ASTM C1202 test method consists of monitoring the amount of electrical current passed through 51 mm thick and 102 mm diameter cores or cylinders during a 6 hours period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, is recorded as the chloride ion penetrability of the concrete sample.

The modified ASTM C1202 method involves performing an additional test using curing water as electrolyte, which improves the binder independency of the results. The difference in the total charges passed obtained between standard test and test performed in curing water is used as an indicator of the concrete quality.

9.2 EQUIPMENT

1. Vacuum Saturation Apparatus (desiccators and vacuum pump) – for sample preparation.
2. Applied Voltage Cell – Two symmetric poly (methyl methacrylate) chambers, each containing electrically conductive mesh and external connectors.
3. Voltage application and Data Readout Apparatus – e.g. Voltmeter.
4. Core case – for coring sample.
5. Diamond saw – for slicing sample.

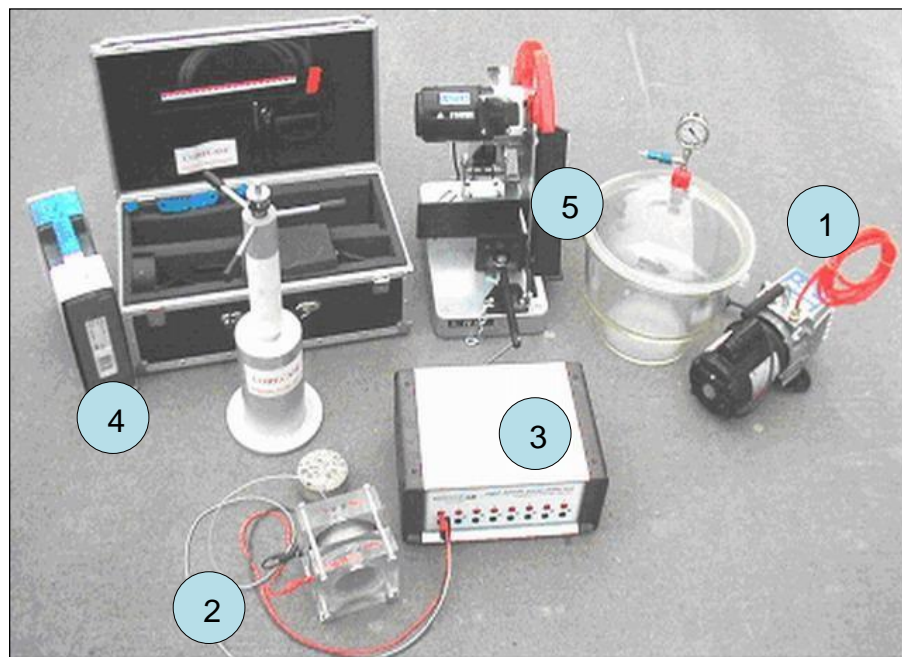


Figure 9.1: A complete set of chloride penetrability test kit.

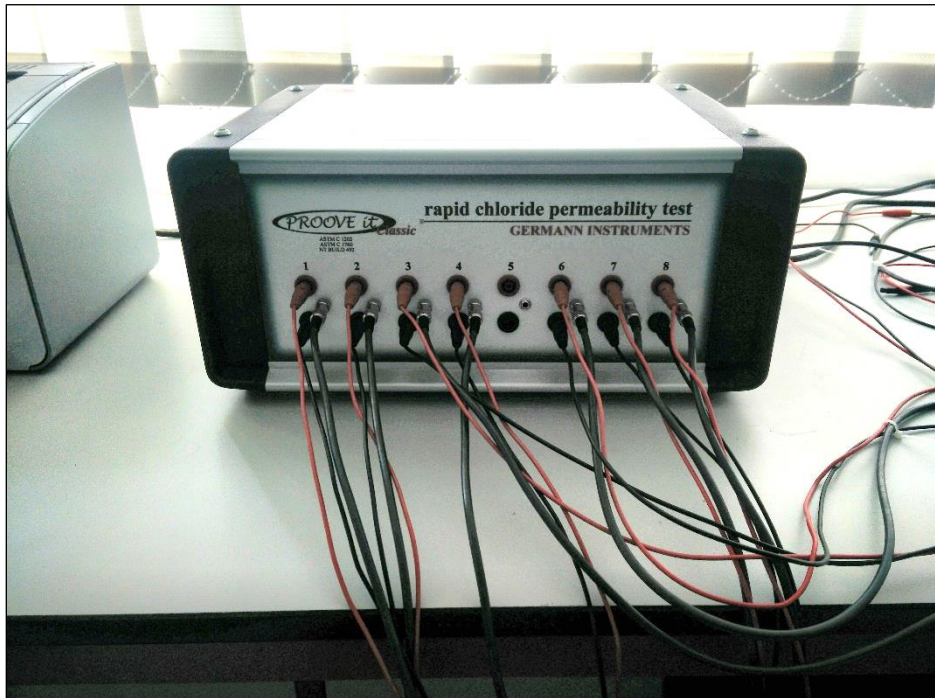


Figure 9.2: Voltage power supply.



Figure 9.3: Two symmetric poly (methyl methacrylate) chambers.

(A) RAPID CHLORIDE PENETRABILITY TEST TO ASTM C1202**9.3 PROCEDURE**

- a) Prepare cylinder specimen of 100mm in diameter either by coring or casting.
- b) Using a water-cooled diamond saw, cut (50 ± 3 mm) slice from the top of the cylinder. Remove any burrs on the end of the specimen. Allow specimen to surface dry in air for at least 1 hour.
- c) Prepare approximately 10 g of rapid setting coating and brush onto the side surface of the specimen. Allow coating to cure according to the manufacturer's instructions until it is not sticky to the touch.
- d) Place the specimen in a beaker with both ends exposed and place it in the vacuum desiccator.
- e) Seal the desiccator and start vacuum pump. Maintain vacuum for 3 hours.
- f) Fill separator funnel with de-aerated water. With vacuum pump still running, open water stopcock and drain sufficient water into beaker to cover specimen (do not allow air to enter desiccator through this stopcock).
- g) Close stopcock and allow vacuum pump to run for an additional one hour.
- h) Close vacuum line stopcock and turn off pump. Turn vacuum line stopcock.
- i) Soak the specimen under de-aerated water for 18 ± 2 hours.
- j) Remove specimen from water and blot off excess water. Then transfer specimen to a sealed container that maintains the specimen in a 95% or higher relative humidity.
- k) Mount both ends of specimen with either:
 - i. *Low viscosity specimen-cell sealant 20–40 g* – if filter paper is necessary, centre filter paper over one screen of the applied voltage cell. Trowel sealant over brass shims adjacent to applied voltage cell body. Carefully remove filter paper. Press specimen onto screen.

- Remove or smooth excess sealant which has flow out of specimen-cell boundary;
- ii. *High viscosity specimen-cell sealant 20–40 g* –set specimen onto screen. Apply sealant around specimen-cell boundary; or
 - iii. *Rubber gasket* – place a 100 mm outside diameter and 75 mm inside diameter by 6 mm circular vulcanized rubber gasket in each half of the test cell. Insert specimen and clamp the two halves of the test cell together to seal.
- l) Cover exposed face of specimen with impermeable materials such as rubber or plastic sheeting. Place rubber stopper in cell filling hole to restrict moisture movement. Allow sealant to cure according to manufacturer's instructions.
 - m) Fill the side of the cell containing the top surface of the specimen with 3.0% NaCl solution and connect to the negative terminal of the power supply.
 - n) Fill the other side of the cell with 0.3N NaOH solution and connect to the positive terminal of the power supply. The completed cell is shown in Figure 9.2.

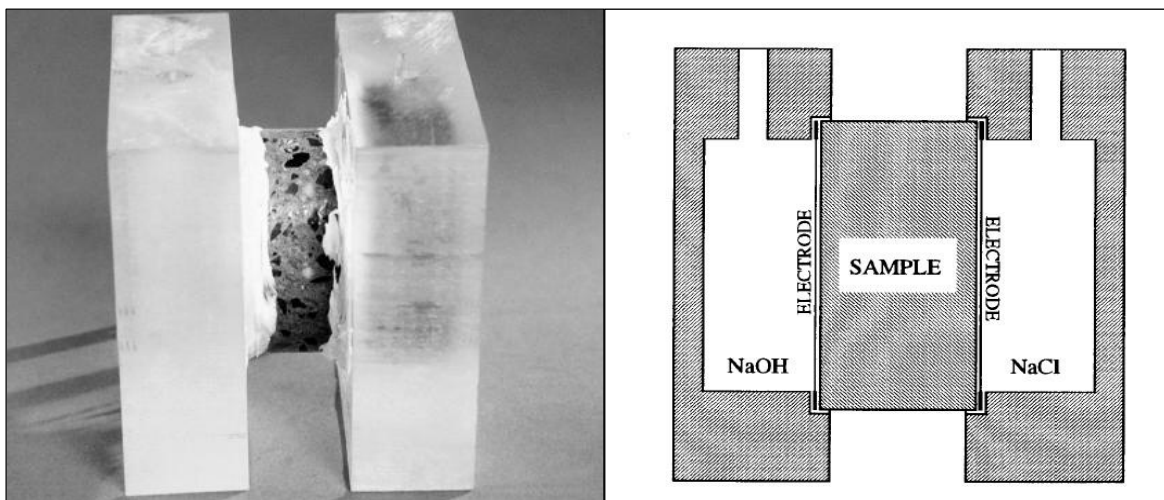


Figure 9.2: Concrete specimen between two halves of the test cell.

- o) Attach lead wires to cell banana posts. Make electrical connections to voltage application and voltmeter. The complete set-up of test equipment is shown in Figures 9.3 and 9.4.

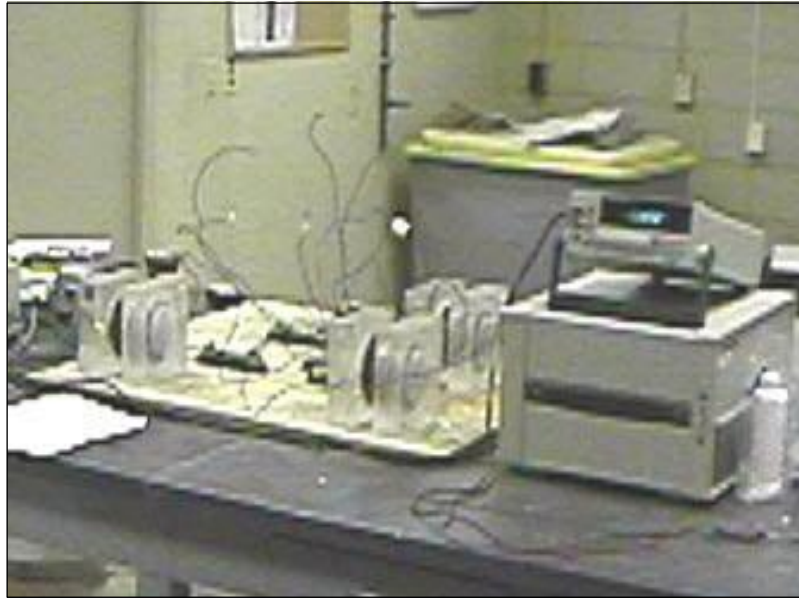


Figure 9.3: Complete set-up of ASTM C1202 Chloride Penetrability Test.

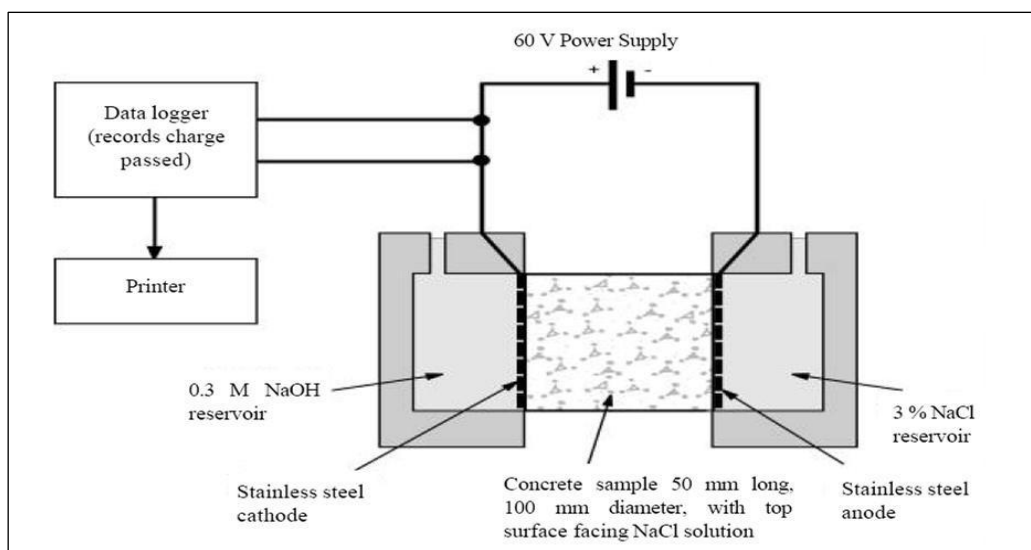


Figure 9.4: A schematic view of the test set-up showing relative position of the sample and the electrodes.

- p) Turn on power supply and set to 60.0 ± 0.1 V. Record initial current reading.
- q) Read and record current at least every 30 minutes. Each half of the test cell must remain filled with the appropriate solution for the entire period of the test.
- r) Terminate test after 6 hours. However, if the temperature of the solution exceeds 190 °F (90 °C), terminate the test and the concrete rated as having very high chloride ion penetrability.
- s) Remove specimen. Rinse cell thoroughly in tap water; strip out and discard residual sealant.
- t) The total charges passed that are recorded are a measure of the electrical conductance of the concrete during the period of the test.

9.4 COMPLIANCE

The chloride penetrability of concrete based on charge passed as referred to ASTM C1202-97 is presented in Table 9.1.

Charge Passed (coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000 – 4,000	Moderate
1,000 – 2,000	Low
100 – 1,000	Very low
< 100	Negligible

Table 9.1: Chloride ion penetrability based on charge passed to ASTM C1202.

(B) RAPID CHLORIDE PENETRABILITY TEST TO MODIFIED ASTM C1202

9.5 PRINCIPLE

The modified ASTM C1202 test method and its predecessor, ASTM C1202 are accelerated indirect testing method. As compared to ASTM C1202 method, the principles of the modified method are:

- a) The total charge passed obtained by standard ASTM C1202 procedures contains the contribution by chloride ion movement and contributions by movement of other ions and other effects;
- b) The total charge passed obtained by the test performed in curing water contains the contributions by the movements of ions other than chloride ions and some contributions by other effects;
- c) The modified total charge passed, i.e. the difference between the two total charges passed, would reflect more of the contributions of chloride ion movement and would be less dependent on the pore solution chemistry.

9.6 TEST DESCRIPTION

The modified ASTM C1202 test involves the performance of two parallel tests on similar samples, which retains the standard test as an integral part of its procedure. The test procedure can be described as follows:

- a) Testing is carried out on pair of samples, i.e. from same batch and curing or from same cylinder;
- b) One sample is tested according to the standard (ASTM C1202) procedures, i.e. using NaCl and NaOH solutions. The total charge passed is obtained as per standard, TCP_S (*Standard Total Charge Passed*);
- c) The other sample is tested with curing water as electrolyte in both test chambers, and other items are kept as per ASTM C1202 method. The curing water is referred to the water used in saturation of sample. The total charge passed in this case is termed TCP_W (*Total Charge Passed of Water*) and is less than TCP_S ;

- d) The sample preparation procedures and test variables, i.e. 60V dc and 6 hours are kept according to ASTM C1202 method;
- e) The difference in the total charge passed between the two tests, i.e. TCP_S TCP_W , represent the movement of chloride ion through the concrete sample, and is used as a criterion for classification of concrete (instead of TCP_S according to ASTM C1202).

9.7 COMPLIANCE

The compliance for concrete's resistance to chloride ion penetration is shown in Table 9.2 as recommended by ASTM C1202.

Charge Passed (coulombs)	Chloride Ion Penetrability
> 3,000	Poor
2,000 – 3,000	Reasonable
1,000 – 2,000	Good
500 – 1,000	Very Good
< 500	Excellent

Table 9.2: Limits for chloride ion penetrability based on charge passed to modified ASTM C1202.



REFERENCES

1. ASTM International. (2017). *Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. (C1202-17a)*.
2. Sirivivatnanon, V., Meck, E. and Cao, H.T., "Performance Based specifications in Harmonization of Durability Standard", 1st Asia/Pacific Conference on Harmonization of Durability Standards and Performance Tests for Components in Buildings and Infrastructure, Bangkok, Thailand, 8 -10 September 1999.

10.0 WATER ABSORPTION TEST

10.1 INTRODUCTION

A water absorption test is carried out to determine the water absorption value of concrete, expressed in percentage. This property is particularly important in concrete used for water-retaining structure or watertight basement, as well as being critical for durability.

The test is intended as a durability control of routine quality control of precast products such as paving flags, slabs or kerb (curb) units. Besides that, it is applicable to test concrete quality used in marine environment.

This test is performed on a 75 mm diameter cylindrical specimen prepared in laboratory. Water absorption of the concrete sample is measured by drying the sample to a constant mass and followed by submerging it in water. After submersion in water for 30 minutes, the weight of wet specimen is measured. The absorption of the concrete is the increased weight resulted from the submersion, expressed as a percentage of the mass of the dry specimen.

10.2 EQUIPMENT

Apparatus to carry out water absorption test as referred to BS 1881: Part 122 is listed as follows and in Figures 10.1 - 10.4:

1. Scale – capable of weighing up to 5 kg with an accuracy of 0.001 kg.
2. Well ventilated drying oven – with temperature controlled at $105\pm 5^{\circ}\text{C}$ for the specimen's drying process.
3. Tank – to contain water for submersion of sample.
4. Desiccator – sufficient to take three specimens to be tested.

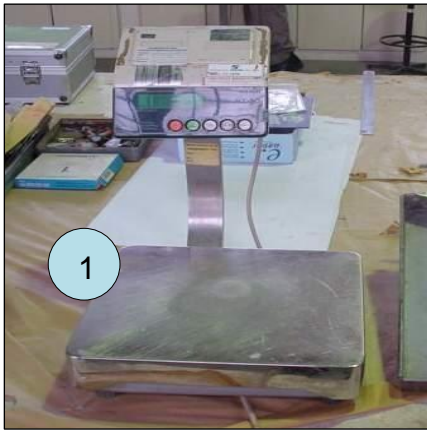


Figure 10.1: Weighing Scale.

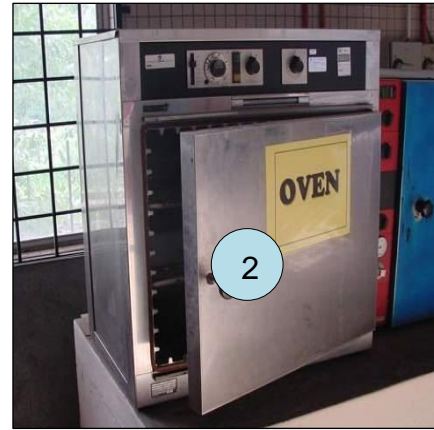


Figure 10.2: Oven.



Figure 10.3: Water tank



Figure 10.4: Desiccator

10.3 PROCEDURE

- a) Prepare at least three 75 ± 3 mm diameter cylinder specimens with 75 mm in length as shown in Figure 10.5.

Note: If specimens are obtained by coring, the length shall be in full concrete thickness if the concrete thickness is between 32 mm and 150 mm; or 75 mm in length if the concrete thickness is greater than 150 mm.

- b) After preparation, place these three specimens in a drying oven so that each specimen is not less than 25 mm from any heating surface or from each other. Dry the specimens in the oven for 72 ± 2 hours.



Figure 10.5: Cylinder specimens ready for water absorption test.

- c) Upon removal from the oven, cool each specimen for 24 ± 0.5 hours in the desiccator, as illustrated in Figure 10.6.



Figure 10.6: Storing specimens in a desiccator.

d) Remove the specimens from the desiccator and weigh each specimen as in Figure 10.7 to the nearest 0.001 kg, as W_d .



Figure 10.7: Weighing the specimen on a scale.

- e) After weighing, immediately submerge the specimens completely in the tank filled with clean water and at a depth such that there is 25 ± 5 mm of water over the top of the specimen, as illustrated in Figure 10.8.



Figure 10.8: Submersion of specimen in water.

- f) Leave the specimen submerged in the water for 30 ± 0.5 minutes.
- g) Remove the specimen, shake to remove the excess water and dry it with a cloth as rapidly as possible until all free water is removed from the specimen surface.
- h) After removal of excess water, weigh each specimen again to the nearest 0.001 kg, as W_s .
- i) Calculate the absorption of specimens, as the increase in mass resulting from the submersion, expressed as a percentage of the mass of the dry specimen, with the formula:

$$\text{Absorption (\%)} = \frac{W_s - W_d}{W_d} \times 100\% \quad (1)$$

13.4 COMPLIANCE

Values for 30 minutes absorption of low, average and high absorption concrete as recommended by the Concrete Society (1988) are as follows:

Low absorption concrete	<	3%
Average absorption concrete		3-5%
High absorption concrete	>	5%

REFERENCES

1. British Standard. (2011). *Testing concrete - Method for determination of water absorption*. (BS 1881-122:2011).
2. Concrete Society. (1988). TR31 Permeability of concrete - a review of testing and experience. Surrey: The Concrete Society.

11.0 SORPTION TEST

11.1 INTRODUCTION

The sorption test is carried out to determine the rate of capillary-rise absorption of the outer 50 mm layer of a concrete specimen. This test can be carried out to determine the uniformity of concrete porosity, the effectiveness of waterproofing admixtures or curing systems.

In this test, concrete specimen is oven-dried before putting to rest on a tray with water, in a manner such that only the lowest 1-2 mm of the specimen is submerged. The increase in the mass of the prism with time is recorded. In this test, several measurements are taken over a period of up to 4 hours. Upon completion of test, a graph of increase in mass per unit area versus the square root of time is then plotted. The gradient of the best fitted straight line passing through origin is termed the sorptivity of the sample in $\text{mm}/\text{min}^{1/2}$. It has been found that the amount of water absorbed is proportional to the square root of time. A typical plot showing the relation between volumes of water absorbed by concrete sample placed just in contact with water and the time used to calculate sorptivity is shown in Figure 11.1.

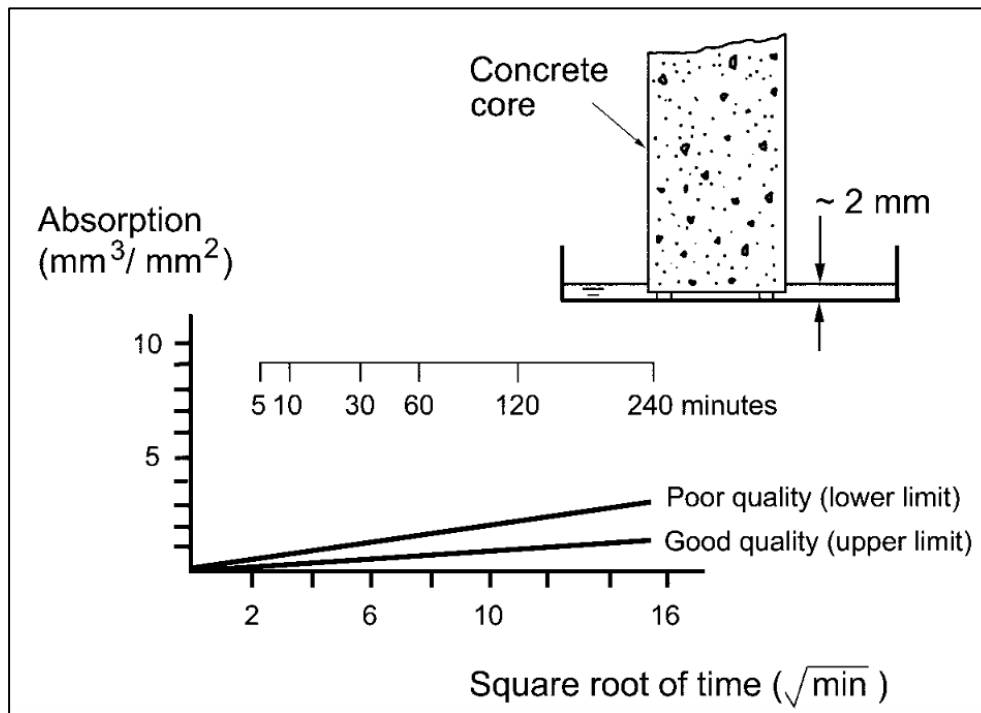


Figure 11.1: Typical relationship between volume of water absorbed by concrete and time. Reprinted from *Fundamentals of Durable Reinforced Concrete*, by Spon Press, 2002. Copyright 2002 by M.G. Richardson.

11.2 EQUIPMENT

Apparatus used for sorption test for the hardened concrete are described below, and illustrated in Figures 11.2 and 11.3:

1. Scale – to weigh the specimen
2. Calliper – to measure specimen's dimension
3. Tray – as a water container
4. Drying Oven – to dry the specimen before test
5. Desiccator – to maintain specimen temperature before test

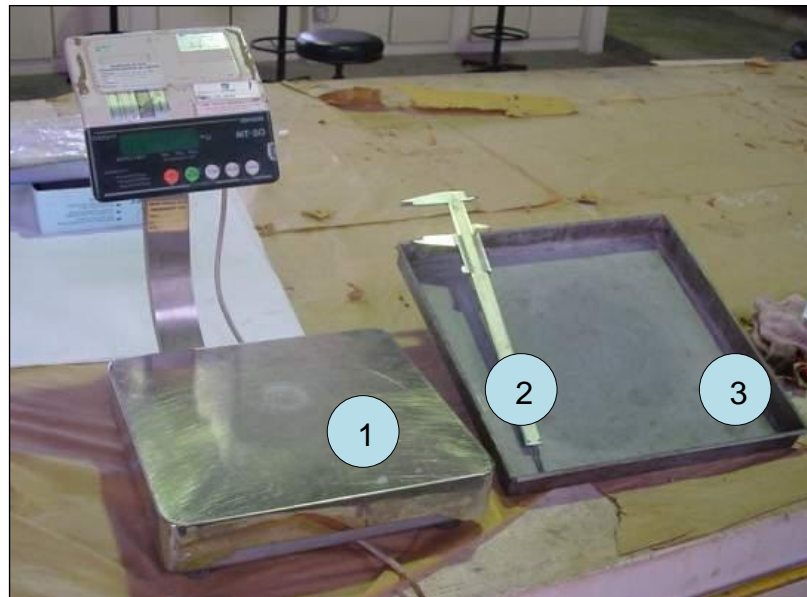


Figure 11.2: Sorption test apparatus.



Figure 11.3: Sorption test apparatus.

11.3 PROCEDURE

- a) Prepare the specimen with a height of at least 100 mm and a minimum weight of 200 g, as shown in Figure 11.4. Record the cross-sectional area (A) to the nearest 1 mm².
- b) Clean the specimen surface before weighing.



Figure 11.4: Specimen ready for sorption test.

- c) Oven dries the specimen at a temperature of 105°C to a constant weight and then allows cooling to 20°C in a desiccator. Measure the specimen weight to the nearest 0.01g as W_d by using a balance as in Figure 11.5.



Figure 11.5: Weigh the specimen on a balance.

- d) Immerse the selected face in a tray of water at 30°C to a depth of 1-2mm, by resting the specimen on glass rod to permit free water movement, as illustrated in Figure 11.6. Record the time of starting of the soaking procedure.



Figure 11.6: Placing specimens on the tray with water at 1-2mm height.

- e) After 5 minutes, remove the specimen from the tray, dry off surplus water, weigh the specimen as W_t and draw the water profile on the specimen surface, as shown in Figure 11.7.



Figure 11.7: Draw water rising profile on specimen surface.

- f) Repeat step (e) at intervals of 10, 30, 60, 120 and 140 minutes.
- g) Calculate the volume of water absorbed per unit cross-section at each intervals time, i_t by using the formula:

$$i_t = \frac{W_t - W_d}{A} \times 10^3 \text{ mm}^3 / \text{mm}^2 \quad (1)$$

- h) Plot the graph of i_t vs. \sqrt{t} . Determine the gradient of the best fitted straight line passing through the origin.
- i) The gradient obtained from the plot is termed the sorptivity of the specimen in $\text{mm}/\text{min}^{1/2}$.



11.4 COMPLIANCE

Some typical values of sorptivity are: $0.09 \text{ mm/min}^{1/2}$ for concrete with a water/cement ratio of 0.4, and $0.17 \text{ mm/min}^{1/2}$ at a water/cement ratio of 0.6.

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12.0 IMPACT ECHO TEST

12.1 INTRODUCTION

Impact Echo Test is a method for non-destructive evaluation of concrete and masonry structures. It is based on the use of impact-generated compression waves that propagate through concrete and masonry and are reflected by internal flaws and external surfaces.

The test is intended to determine the location and extent of flaws such as cracks, delamination, voids, honeycombs, debonding in plain concrete, reinforced concrete and post-tensioned concrete structures. The concrete structures include plates (like slabs, pavements, walls and decks), layered plates (including concrete with asphalt overlays), columns and beams (round, square, rectangular, “I” and “T” cross-sections) and hollow cylinders (pipes, tunnels, mineshaft liners, tanks). This test can be used to locate voids in the grouted tendon ducts of many types of post-tensioned structures. It can also provide thickness measurements of concrete slabs with an accuracy better than 3% and can trace any voids in the subgrade directly beneath slabs and pavements. In masonry structures, the Impact Echo Test is used to define thickness or to detect cracks, voids and other defects. Impact Echo is not adversely affected by the presence of steel reinforcing bars.

12.2 OBJECTIVE OF EXAMINATION

The probable usefulness of this examination generally depends on the objectives set by the user. The objectives for which Impact Echo Test is required are given below:

- a) Evaluate thickness of a concrete member
- b) Locate poor consolidation and voiding in reinforced
- c) Detect areas of delamination in concrete
- d) Detect debonding of an overlay
- e) Detect degree of grouting in post-tensioning ducts

12.3 EQUIPMENTS

An impact echo test system is composed of three components which are an impact source receiving transducer and a data acquisition system with appropriate software for signal analysis and data management.

1. Impact source.

- a) For testing of thin structure such as slab or wall, small steel sphere or spring-loaded spherically tipped impactors for its shorter-duration impacts (20 to 60 μ s).

2. Receiving transducer.

- a) For testing of slab or wall structures, use conically tipped, piezoelectric displacement transducer. For test according to ASTM C1383: Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method use two (2) transducers.

3. Data acquisition system.

A portable computer with data acquisition hardware and software.



Legends: -

- | | |
|---|--|
| 1 Impactors: a set of 10 hardened steel spheres on spring rods. | 7 Two BNC Cables: for connecting transducer units to data acquisition system. |
| 2 Hand-Held Transducer Units. | 8 Serial/USB Port Cable |
| 3 Dual-Head Transducer: used to measure wave speed | 9 Battery Charger |
| 4 Analog/Digital Data Acquisition System: receives and digitizes voltage-time signals from the transducers and sends them to computer. | 10 DC Power Supply. |
| 5 Notebook Computer | 11 Printed materials for reference. |
| 6 Computer Software: to analyse signals, performs calculations and displays test results on computer screen. | |

Figure 12.1: Typical equipment to carry out impact echo test. (Adopted from Impact-Echo Instruments, 2005)

12.4 PROCEDURE

The general procedure test is conducted by making an impact on a surface close to the transducer and recording the spectral amplitude on a portable computer which is received from the transducer. Prior to this, the thickness of the slab has to be known by measuring the slab thickness or by coring method. If the thickness cannot be known, one may refer to the ASTM C1383: Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method. The procedures are as follows.

- 1) Typical procedure to determine flaws in concrete slab.
 - i. The procedures of conducting an impact echo test provided here may vary according to manuals from manufacturers of impact echo test kit. The manual from the respective manufacturer shall be referred for specific procedures.
 - ii. The thickness of slab structure must be known by direct measurement or by coring method and subsequently measured. The thickness, T is recorded.
 - iii. The test surface shall be cleaned and dried.
 - iv. Mark a regularly spaced points along 'scan' lines on the surface.
 - v. Ready the data acquisition system.
 - vi. Position the transducer at the location of test surface.
 - vii. Perform an impact using the impactor.
 - viii. Examine the acquired waveform and corresponding amplitude spectrum.
 - ix. Determine the amplitude frequency, f and calculate the P-wave speed, C_{pp} :
$$C_{pp} = f \cdot 2T \quad (1)$$
 - x. Repeat step (vi) to (viii) for the next test location along the 'scan' lines.
 - xi. Determine the amplitude frequency, f and calculate the thickness, T at the test location. P-wave speed is from the previous calculation.

$$T = \frac{c_{pp}}{2f} \quad (2)$$

xii. Change in thickness indicates presence of flaw or void in concrete slab.

2) Procedure guided by ASTM C1383.

- i. Impact Echo test guided by the ASTM C1383 uses two procedure named Procedure A to measure the P-Wave speed and Procedure B to determine the thickness frequency using impact-echo method from which the plate thickness is calculated using the measured P-wave speed from Procedure A. Both Procedure A and Procedure B must be performed at each point where a thickness determination is made. The procedures must be read with ASTM C1383 which can be sourced from ASTM websites or by others.
- ii. The test surface shall be dried. Remove dirt and debris from the surface where the P-wave speed is to determine.
- iii. If the test surface is extremely rough as such that it is difficult to achieve good contact between the transducer tips and the concrete, grind the surface so that

good contact is achievable. Remove loose material prior to coupling the transducers to the surface.

- iv. Procedure A. Setup the apparatus (transducers, spacer device and impactor) as in Figure 12.2A.

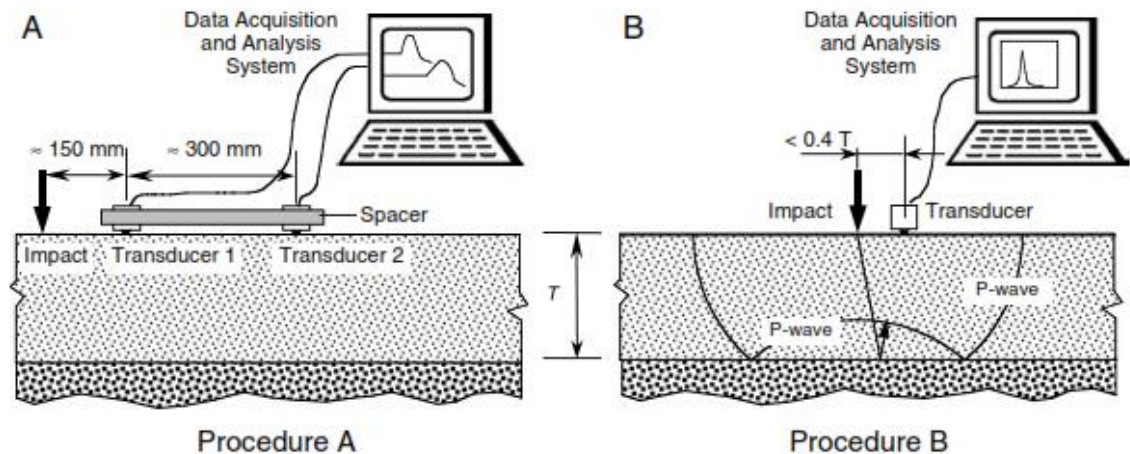


Figure 12.2: ASTM C1383 procedures for measuring thickness of slab like concrete structures: (A) procedure to determine P-wave speed, and (B) procedure to determine thickness frequency.

- v. Position the apparatus on the concrete surface and position the impactor to strike on a line passing through the two transducers and at a distance of $150 \pm 10 \text{ mm}$ from the first (triggering) transducer.
- vi. Perform the impact. Examine the acquired waveforms.
- vii. Display the waveforms on the screen of the data acquisition system from the two transducers so that they are plotted against the same time axis.
- viii. Identify the arrival time of the direct P-wave in each waveform. Display the voltage and time readings at the points corresponding to the P-wave arrivals. Determine the time difference, Δt , between the arrival of the P-wave in each waveform. This time difference is the travel time.
- ix. Use the measured travel time Δt , and known spacing between the transducers, L , to calculate the P-wave speed, C_p :

$$C_p = \frac{L}{\Delta t} \quad (3)$$

- x. Calculate the apparent P-wave speed in plate, $C_{p, plate}$:

$$C_{p, plate} = 0.96 C_p \quad (4)$$

- xi. Procedure B. Setup the apparatus according to Figure 12.2B. Position the transducer on the concrete surface where thickness is to be measured. Position the impactor to strike at a distance less than 0.4 of the nominal plate thickness away from the transducer.
- xii. Ready the data acquisition system with correct data acquisition parameters. Data acquisition shall be triggered by the transducer signal.
- xiii. Perform the impact. Examine the acquired waveform and corresponding amplitude spectrum.
- xiv. Determine the frequency of the high amplitude peak in the amplitude spectrum.
- xv. Calculate the thickness of the plate, T , using:

$$T = \frac{C_{p,plate}}{2f} \quad (5)$$

Where, f = frequency of the P-wave thickness mode of the plate obtained from the amplitude spectrum.

12.5 OBSERVATION

The thickness measurement of the solid plates is shown by the spectrum of solid part of testing plate which is dominated by a single large-amplitude peak which is the plate thickness frequency (see Figure 12.3). The main application of this technique was the need to identify the presence and depth of anomalies in concrete structures which are accessible only from one side (see Figure 12.4).

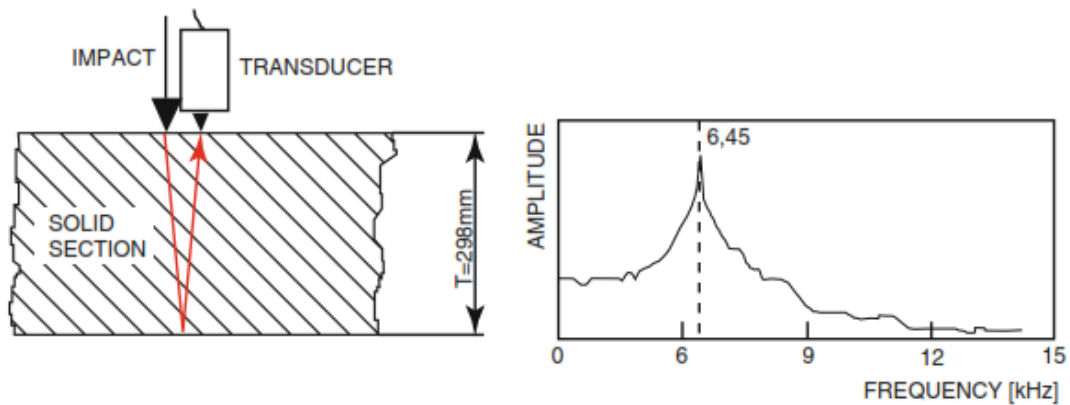
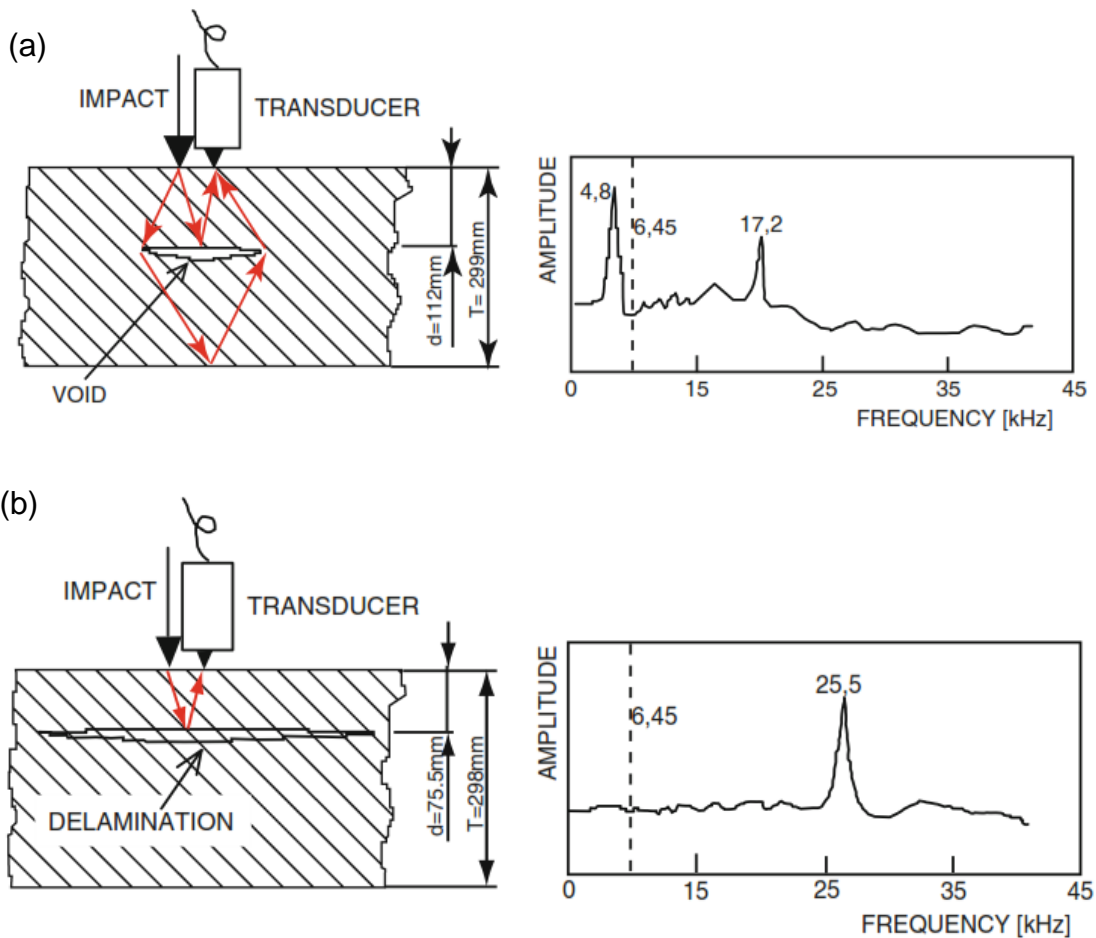


Figure 12.3: Amplitude shown on acquisition system used for solid plate thickness measurement. Reprinted from *Non-Destructive Assessment of Concrete Structures: Reliability and Limits of Single and Combined Techniques* (p. 48), by RILEM Technical Committee 207-INR, 2012, London: Springer. Copyright 2012 by RILEM.



*Figure 12.4: (a) Amplitude spectrum with two peaks, giving defect depth and total thickness and (b) Amplitude spectrum with screening effect of a large defect. Reprinted from *Non-Destructive Assessment of Concrete Structures: Reliability and Limits of Single and Combined Techniques* (p. 49), by RILEM Technical Committee 207-INR, 2012, London: Springer. Copyright 2012 by RILEM.*

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13.0 CHLORIDE PONDING TEST

13.1 INTRODUCTION

Chloride ponding test is conducted to determine the penetration of chloride ion into concrete from a sodium chloride pond. This method is applicable to all types of concrete as well as to concretes treated with sealants, penetrating sealers or thin-bonded overlays. It is suitable for evaluation of materials and material proportions for construction purposes and for research and development. This test can also be used to establish the correlation between indirect measures of the chloride-ion penetration of concrete (ASTM Test Method C 1202) and the actual chloride-ion penetration under controlled conditions. This test is not intended to provide a measure of the length of service that may be expected from use of a specific concrete mixture or sealing material.

13.2 EQUIPMENT

1. Glass Plates or Polyethylene Sheets of sufficient size to cover the ponded surface of the specimen.
2. Moulds of the proper size for the test specimens to be used and conforming to the applicable requirements of Practice ASTM C 192/C 192M.
3. Ponding Solution - 3% reagent grade (NaCl) by mass in distilled water
4. Specimens
 - 4.1. The ponding specimens are of slabs having a surface area of at least 0.03m^2 and $90 \pm 15\text{mm}$ thickness. At least two replicate specimens shall be made for each combination of variables to be tested.
 - 4.2. Fabricate and cure moulded ponding specimens in accordance with applicable sections of ASTM Test Method C 672/C 672M, unless otherwise specified.

- 4.3. Obtain a sample of concrete for use in determining the background chloride content. Cast a 100 x 200 mm cylinder from the concrete mixture for this purpose when fabricating ponding specimens.
- 4.4. Provide a dike approximately 20 mm high along the perimeter of the top surface of the specimen to retain the ponding solution. The dike shall be made of a material that adheres to the specimen or integrally cast as a part of the specimen. It shall serve to keep the top of the specimen covered completely by ponding solution throughout the period of the ponding.
- 4.5. Coat the sides of specimens with a suitable material to prevent lateral moisture migration. Do not coat the bottom of the specimen. Allow the coating to cure according to the manufacturer's instructions.

13.3 PROCEDURE

1. Following completion of curing, cover the surface of the specimen with the ponding solution to a depth of 15 ± 5 mm.
2. Place a glass plate or polyethylene sheet over the ponded specimen to retard evaporation of water from the solution.
3. Store the ponded specimens at $23.0 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ relative humidity. Provide for air circulation around sides and bottom of specimens.
4. Periodically monitor the depth of solution on the surface of the specimen and maintain at the specified depth by adding additional fresh solution. At 2-month intervals during the ponding, remove the solution and replace with fresh solution.
5. Select the duration of the ponding period and the sampling intervals to be appropriated for the purposes for which the tests are being made.
6. Sampling

- 6.1 Prior to sampling, remove the ponded solution and allow the specimen surface to dry. After drying is completed, remove the salt crystals from the surface by brushing with a wire brush.
- 6.2 Sample the specimen by coring. The diameter of the core shall be at least three times the nominal maximum aggregate size.
- 6.3 Alternatively, obtain powdered sample by rotary-impact hammer as described in ASTM Test Method C 1152/C 1152M (3).
- 6.4 Space the sampling point at least 25 mm away from the inside edge of the dike or the edge of any previous sampling point. Samples shall be obtained from at least the following depths to provide a profile of the chloride penetration:

Sampling intervals, mm

10-20

25-35

40-50

55-65

- 6.5 If the purposes of the test require a precise profiling of the chloride penetration, the sampling shall be accomplished by removing a core from the specimen. The core shall be profiled by precision milling to obtain powdered concrete from horizons of the desired depth and thickness.

- 6.6 If the specimen is to be re-ponded after sampling, patch the hole with a suitable low permeability repair material. The location of the sampling point shall be clearly identifiable so it can be avoided during subsequent sampling.
- 6.7 Determine the chloride content of the sample from each depth of the ponded specimens and the background sample in accordance with ASTM Test Method C 1152/C 1152M. The background chloride content is subtracted from the value obtained for each depth of the ponded specimen to determine the penetrated chloride value.

13.4 COMPLIANCE

The chloride content of a concrete, expressed as the percentage of chloride ions by mass of cement, shall not exceed the value for the selected class given in Table 13.1.

Concrete use	Chloride content class ^a	Maximum Cl ⁻ content by mass of cement ^b %
Not containing steel reinforcement or other embedded metal with the exception of corrosion-resisting lifting devices	CL 1.00	1.00
Containing steel reinforcement or other embedded metal	CL 0.20	0.20
	CI 0.40 ^c	0.40
Containing prestressing steel reinforcement in direct contact with concrete	CI 0.10	0.10
	CI 0.20	0.20

- a For a specific concrete use, the class to be applied depends upon the provisions valid in the place of use of the concrete.
- b Where additions are used and are taken into account for the cement content, the chloride content is expressed as the percentage chloride ion by mass of cement plus total mass of additions that are taken into account.
- c Different chloride content classes may be permitted for concrete containing CEM III-cements according to provisions valid in the place of use.

Table 13.1: Maximum chloride content of concrete. Adopted from Table 15, MS EN 206:2016.

REFERENCE

1. ASTM International. (2002). *Standard test method for determining the penetration of chloride ion into concrete by ponding* (ASTM C 1543-02).
2. ASTM International. (2012). *Standard test method for acid-soluble chloride in mortar and concrete* (ASTM C1152/C1152M-04).
3. Malaysia Standards. (2016). *Concrete – specification, performance, production and conformity* (MS EN 206:2016).

14.0 CHLORIDE DIFFUSION TEST

14.1 INTRODUCTION

This test is for determination of the apparent chloride diffusion coefficient for hardened concrete and is conducted in a laboratory. This method is applicable to cementitious mixtures that have not been exposed to external chloride ions. The calculation procedure described in this method is applicable only to laboratory test specimens exposed to sodium chloride solution and is not applicable to cyclic wetting and drying.

14.2 EQUIPMENTS

1. Balance (at least ± 0.01 g accuracy)
2. Thermometer (at least ± 1.0 °C accuracy)
3. Controlled Temperature Laboratory or Chamber. It shall maintain the temperature of water bath at 23 ± 2 °C.
4. Plastic Container with tight-fitting lid.
5. Equipment for grinding off and collecting powder from concrete, mortar or grout specimens in layers of approximately 2 mm thickness.
6. Resealable Polyethylene Bags (200-300mm wide, 250-300mm long, not less 0.1mm thick)
7. Equipment for crushing concrete, mortar or grout.
8. Equipment for chloride analysis. (Described in Test Method ASTM C 1152/C 1152M).
9. Slide calliper (± 0.1 mm accuracy).
10. Reagents and Materials
 - 10.1. Distilled or De-ionized Water
 - 10.2. Calcium Hydroxide [Ca(OH)₂]
 - 10.3. Calcium Hydroxide Solution, saturated, (approx. 3g/L)

- 10.4. Sodium Chloride (NaCl)
 - 10.5. Exposure Liquid. An aqueous NaCl solution prepared with a concentration of 165 ± 1 g NaCl per L of solution.
 - 10.6. Two-component Polyurethane or Epoxy-resin based paint, capable of forming a barrier membrane that is resistant to chloride ion diffusion.
11. Test Specimens
- 11.1 Drilled cores, moulded cylinders or moulded cubes are acceptable test specimens.
 - 11.2 One sample consists of at least two test specimens representative of the cementitious mixture under test.
 - 11.3 Specimens must be free of defects such as voids or cracks visible to the unaided eye.
 - 11.4 The minimum dimension across the finished surface of each test specimen must be at least 75 mm, but not less than three times the nominal maximum aggregate particle size.
 - 11.5 The specimen depth must be at least 75 mm.
 - 11.6 Provide 28 days of laboratory standard moist curing in accordance with Practice ASTM C31/C31M or ASTM C 192/C 192M prior to sample preparation for immersion in the exposure liquid.
 - 11.7 For drilled cores obtained, prepare the test specimen by cutting off the outermost 75 mm of the core. Thus, the test specimen obtained has one face that is the original finished surface and the other face that is a sawn surface as shown in Figure 14.1.

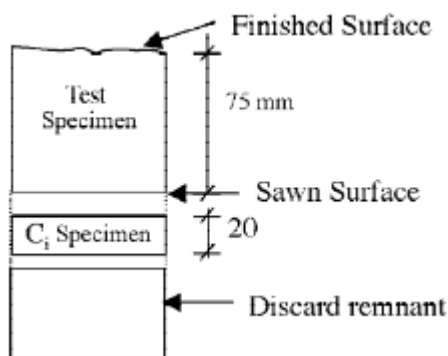


Figure 14.1: Sketch of specimens obtained from typical sample.

- 11.8 Rinse the specimens with tap water immediately after cutting. Scrub the surface with a stiff nylon brush and rinse again. Prior to sealing specimen surfaces, air dry until no moisture can be removed from the surface with a dry paper towel.
- 11.9 Exposed specimens must be surface-dry but internally moist prior to sealing. This condition is satisfied by standard moist-cured specimens allowed to air dry for no more than 24 hours in laboratory air maintained at $23 \pm 2^{\circ}\text{C}$ and $50 \pm 3\%$ RH.
- 11.10 Seal all sides of the exposed specimen except for the finished surface following the procedure described in ASTM Test Method C 1202.
- 11.11 Determine the initial mass of the test specimen when the coating has hardened.
- 11.12 Immerse the test specimen in the saturated calcium hydroxide water bath at $23 \pm 2^{\circ}\text{C}$ in a tightly closed plastic container. The container must be filled to the top to prevent carbonation. After 24 hours of immersion, remove the specimen, blot the surface dry with a paper towel and determine the mass of the specimen in the surface-dry condition.

11.13 The test specimen is immersed in a saturated calcium hydroxide water bath until the mass does not change by more than 0.1% in 24 hours. An acceptable alternative procedure is to vacuum saturate the specimens with saturated calcium hydroxide solution using a vacuum chamber similar the system described in ASTM Test Method C 1202.

14.3 PROCEDURE

1. Exposure

- 1.1. Remove the saturated test specimen from the calcium hydroxide water bath, immediately rinse the specimen surface with tap water, place the specimen in the exposure container, fill the container with the exposure liquid and then seal the container. Place the container in a temperature-controlled chamber or room maintained at $23 \pm 2^{\circ}\text{C}$. Record the start date and start time to the nearest hour.
- 1.2. It is permitted to place multiple specimens in a single container as long as the specimens are placed in the container such that the entire exposure surface is unobstructed. Maintain the exposed surface area to exposure liquid volume ratio within the range of $50 \pm 30 \text{ cm}^2/\text{L}$.
- 1.3. The specimens must remain in the exposure liquid for at least 35 days.
- 1.4. If evaporation of water from the exposure liquid or a container leak allows the specimen surface to dry during the exposure time, the test is not valid.
- 1.5. Record the exposure time to the nearest hour.
 - 1.5.1. Profile Grinding
 - 1.5.1.1. Remove the test specimen from the exposure liquid, rinse with tap water and dry for at least 24 hours in laboratory air maintained at $23 \pm 2^{\circ}\text{C}$ and 50 ± 3 % RH.

- 1.5.1.2. If a delay between exposure and grinding longer than 24 hours is expected, place the specimens in watertight resealable polyethylene bags prior to grinding.
- 1.5.1.3. Obtain the powder samples by grinding off material in layers parallel to the exposed surface. Do not grind closer than 5 mm from the edge of the specimen to avoid edge effects and disturbances from the coating.
- 1.5.1.4. For the minimum exposure time of 35 days, grind off eight layers in accordance with Table 14.1. For longer exposure times, select depth increments such that a minimum of 6 points span the range from 1 mm below the exposed surface to a depth with a chloride-ion content equal to, or slightly greater than the initial chloride-ion content.

w/cm	0.25	0.30	0.35	0.40	0.50	0.60	0.70
Depth 1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
Depth 2	1-2	1-2	1-2	1-3	1-3	1-3	1-5
Depth 3	2-3	2-3	2-3	3-5	3-5	3-6	5-10
Depth 4	3-4	3-4	3-5	5-7	5-8	6-10	10-15
Depth 5	4-5	4-6	5-7	7-10	8-12	10-15	15-20
Depth 6	5-6	6-8	7-9	10-13	12-16	15-20	20-25
Depth 7	6-8	8-10	9-12	13-16	16-20	20-25	25-30
Depth 8	8-10	10-12	12-16	16-20	20-25	25-30	30-35

^A Luping, Tang and Sørensen, Henrik, "Evaluation of the Rapid Test Methods for Measuring the Chloride Diffusion Coefficients of Concrete," NORDTEST Project No. 1388-98, Swedish National Testing and Research Institute, SP Report 1998:42.

NOTE—For cementitious mixtures with pozzolan or slag, the depth intervals in the column one place to the left should be applied. For example, use the depth intervals for w/cm = 0.35 for silica fume concrete with w/cm = 0.40.

Table 14.1: Recommended Depth Intervals (in mm) for Powder Grinding. (Adopted from Table 1, ASTM C1556-11a).

- 1.5.1.5. The following alternate profiling procedure is permitted if the exposure time is sufficient to allow chloride penetration deeper than 40mm. Slice the test specimen parallel to the exposed surface using a water-cooled diamond saw in 5-6 mm increments, minimizing the time specimens are exposed to water. Dry the slices for 24 hours in laboratory air, then crush and prepare the powder sample as described in ASTM Test Method C 1152/C 1152M.

- 1.5.1.6. Obtain a sample of at least 10 g of powder from each layer. Determine the distance from the exposure surface to the mid-depth of each layer. For example, the layer thickness and mid-depth are determined from measurements of the specimen before and after powder sample collection.
- 1.5.1.7. Calculate the depth below the exposed surface as the average of five uniformly distributed measurements using a slide calliper.
- 1.5.2. Chloride Analysis.
- 1.5.2.1. Determine the acid-soluble chloride-ion content of the powder samples, C_x (mass %), to ± 0.001 % according to ASTM Test Method C 1152/C 1152M.
- 1.5.2.2. Obtain the initial chloride-ion content, C_i (mass %), from the 20 mm thick slice by crushing and prepare a powder sample as described in ASTM Test Method C 1152/C 1152M.
- 1.5.2.3. Record any deviations from the requirements of this method.
- 1.5.3. Calculations
- 1.5.3.1. Test Result
- 1.5.3.2. Determine the values of surface concentration and apparent chloride diffusion coefficient by fitting Eq.1 below to the measured chloride-ion contents by means of a non-linear regression analysis using the method of least squares.

$$C_{(x,t)} = C_s - (C_s - C_i) \cdot \operatorname{erf}\left(\frac{x}{\sqrt{4 \cdot D_a \cdot t}}\right) \quad (1)$$

where,

$C_{(x,t)}$ = chloride concentration, measured at depth x and exposure time t , mass %

C_s = projected chloride concentration at the interface between the exposure liquid and test specimen that is determined by the regression analysis, mass % (stated to three significant digits)

C_i = initial chloride-ion concentration of the cementitious mixture prior to submersion in the exposure solution, mass % (stated to three significant digits)

x = depth below the exposed surface (to the middle of a layer), m

D_a = apparent chloride diffusion coefficient, m²/s (stated to two significant digits)

t = the exposure time, s

erf = the error function,

$$erf(z) = \frac{2}{\sqrt{\pi}} \cdot \int_0^z \exp(-u^2) du \quad (2)$$

1.5.4. Non-linear Regression Analysis

1.5.4.1. Perform the regression analysis by minimizing the sum given in Eq.3 (Refer Figure 14.2 for clarification)

$$S = \sum_{n=2}^N \Delta C^2(n) = \sum_{n=2}^N (C_m(n) - C_c(n))^2 \quad (3)$$

where,

S = sum of squares to be minimized, (mass %)²

N = the number of layers ground off

$\Delta C(n)$ = difference between the measured and calculated chloride concentration of the n th layer, mass %

$C_c(n)$ = calculated chloride concentration in the middle of the n th layer, mass %

1.5.4.2. Other calculations

1.5.4.2.1. Plot the measured chloride contents at all points versus depth below the surface. Plot the best-fit curve on the same graph (Figure 14. 2).

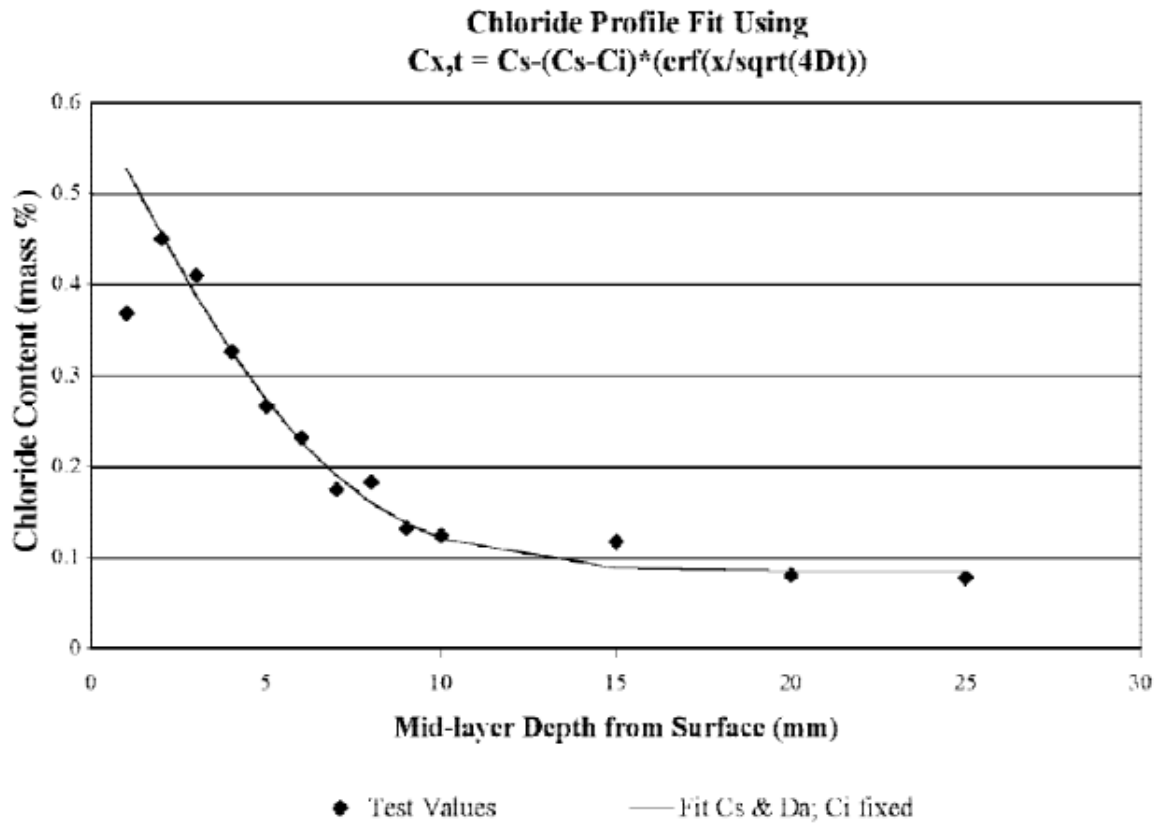


Figure 14.2. Sample Regression Analysis. (Adopted from Figure 4, ASTM C1556-11a)

14.4 COMPLIANCE

The chloride content of a concrete, expressed as the percentage of chloride ions by mass of cement, shall not exceed the value for the selected class given in Table 14.2.

Concrete use	Chloride content class ^a	Maximum Cl ⁻ content by mass of cement ^b %
Not containing steel reinforcement or other embedded metal with the exception of corrosion-resisting lifting devices	CL 1.00	1.00
Containing steel reinforcement or other embedded metal	CL 0.20	0.20
	CI 0.40 ^c	0.40
Containing prestressing steel reinforcement in direct contact with concrete	CI 0.10	0.10
	CI 0.20	0.20
<p>^a For a specific concrete use, the class to be applied depends upon the provisions valid in the place of use of the concrete.</p> <p>^b Where additions are used and are taken into account for the cement content, the chloride content is expressed as the percentage chloride ion by mass of cement plus total mass of additions that are taken into account.</p> <p>^c Different chloride content classes may be permitted for concrete containing CEM III-cements according to provisions valid in the place of use.</p>		

Table 14.2: Maximum chloride content of concrete. Adapted from Table 15, MS EN 206:2016.



REFERENCE

1. ASTM International. (2011). *Standard test method for determining the apparent chloride diffusion coefficient of cementitious mixtures by bulk diffusion* (ASTM C 1556-11a).
2. Malaysian Standard. (2016). *Concrete – specification, performance, production and conformity* (3rd Rev.). (MS EN 206:2016).

15.0 NEAR SURFACE STRENGTH TESTS

15.1 INTRODUCTION

There are various near-to-surface test methods which can be used to assess strength. Pull-out, pull-off and break-off are of the few tests that can be done as described in BS 1881: Part 207.

Pull-out test measures the force to pull an insert which consist of a disc and a rod which were casted in concrete during pouring or fixed on hardened concrete. The tensile strength is then derived and correlated with concrete compressive strength from cube or cored concrete to determine the estimated compressive strength of the concrete.

The pull-off test is based on the concept that the force required to pull a metal block, together with a layer of concrete or mortar, from the surface to which it has been attached, is related to the strength of the concrete. The break-off method is based upon breaking off a cylindrical specimen of in-place concrete. The test specimen has a 55 mm diameter and 70 mm height. The test specimen is created in the fresh concrete by means of a disposable tubular plastic sleeve, which is cast into the fresh concrete and then removed at the planned time of testing, or by drilling the hardened concrete at the time of the break-off test. Break-off force and compressive strength can be correlated to determine estimated compressive strength of the concrete under investigation.

The correlation curve should be drawn through the points plotted from the mean test results and the mean strength of each corresponding set of nominally identical specimens. The equation of this curve can be determined by any standard curve fitting procedure.

15.2 PULL-OUT TEST

15.2.1 EQUIPMENT

- 1) Cast-in insert consist of disc and rod device casted into the concrete.
 - i. The disc shall have a circular head with a diameter of 25 ± 0.1 mm.
 - ii. The rod shall have a diameter of not more than 0.6 times of the disc.
 - iii. The rod's length shall be equal to the diameter of the disc.
 - iv. The sides of the rod shall be smooth and tapered.
 - v. The device may be coated with a release agent to prevent bonding

- 2) Insert consists of disc and rod device installed after the concrete has hardened.
 - i. Drilling and under reaming equipment which is available from proprietary manufacturers.
 - ii. The disc, when mechanically expanded shall have a circular head of diameter (25 ± 0.1) mm.
 - iii. The rod's length shall equal to the diameter of the disc.

- 3) Bearing ring having an inside diameter of 55 ± 0.1 mm and outside diameter of 70 ± 0.1 mm.

- 4) Loading system shall be capable of applying a tensile force to the insert with the reaction being transmitted to the concrete surface through the bearing ring.

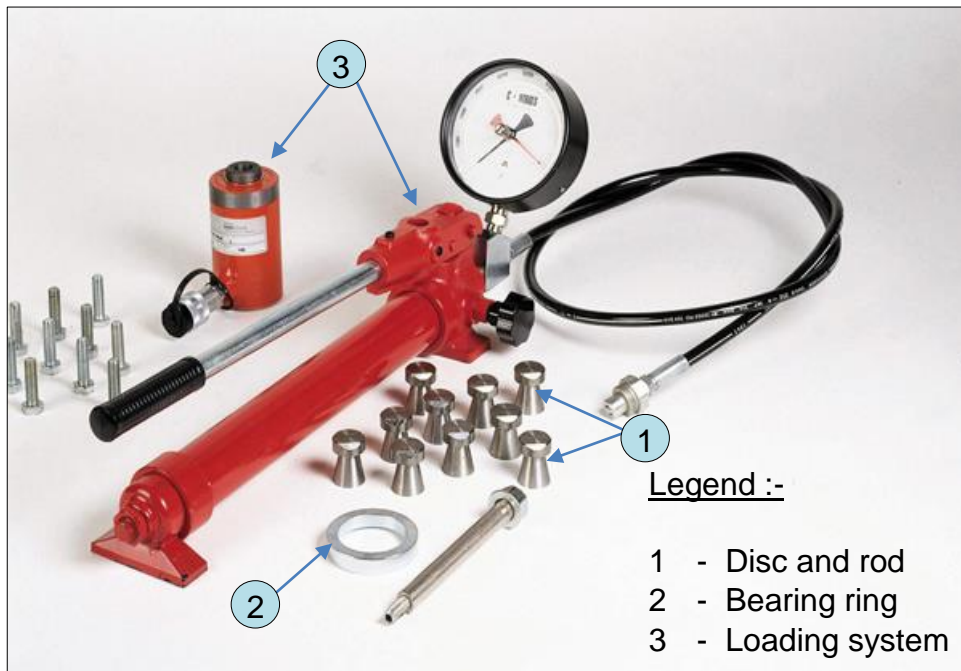


Figure 15.2.1: Pull-out testing for inserts to be cast-in with concrete.



Figure 15.2.2: Pull-out testing equipment for inserts on hardened concrete.

15.2.2 PROCEDURE

1. The cast-in inserts.
 - i. Fix securely the insert to a test position on the formwork before pouring of concrete. At least four tests required at a location. The centres of test positions shall be at least eight times the insert's head diameter apart and shall be at least four times the insert's head diameter from the edge of the concrete.
 - ii. Place the insert so that all reinforcement is outside the conical failure surface by at least one bar diameter or the maximum aggregate size whichever is greater. The minimum thickness of the concrete to be tested shall be at least four times the insert's head diameter.
 - iii. After few days of curing from commencement of concrete pouring, remove the tapered rod and then connect the loading system to the disc in accordance with the manufacturer's instructions. (Refer Figure 15.2-3).
 - iv. Apply the load and increase it at a steady rate without shock, until fracture occurs.
 - v. Record the maximum indicated force and it shall be expressed to the nearest 0.5 kN.
2. The inserts for hardened concrete.
 - i. At least four tests are required at a location. The centres of test positions shall be at least eight times the insert's head diameter apart and shall be at least four times the insert's head diameter from the edge of the concrete. The minimum thickness of the concrete to be tested shall be at least four times the insert's head diameter.
 - ii. Place the insert so that all reinforcement is outside the conical failure surface by at least one bar diameter or the maximum aggregate size whichever is greater. Reinforcement bar scanning device shall be used to locate reinforcement bar in concrete.
 - iii. The hole for insert shall be drilled and under-reamed.

- iv. The insert is assembled according to the manufacturer's instruction.
- v. Connect the loading system to the disc in accordance with the manufacturer's instructions.
- vi. Apply the load and increase it at a steady rate without shock, until fracture occurs.
- vii. Record the maximum indicated force and it shall be expressed to the nearest 0.5 kN.

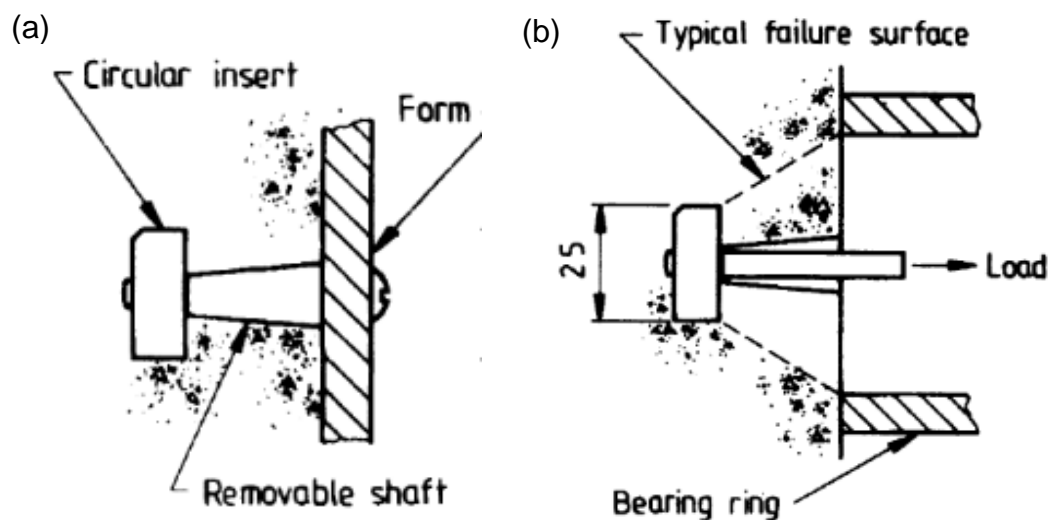


Figure 15.2.3: Assembly of cast-in insert for pull-out test. (a) Removable shaft (tapered rod) cast inside concrete, (b) Removable shaft (tapered rod) is removed and part of loading system fixed to the circular insert (disc). (Based on Figure 1, BS 1881-207:1992).

15.2.3 COMPLIANCE

The pull-out force can be empirically related to the compressive strength of the concrete as determined by compressive strength of concrete cubes or compressive strength of concrete cores to determine the estimated compressive strength of concrete.

15.3 PULL-OFF TEST

15.3.1 EQUIPMENT

1. Cylindrical metal blocks. Thickness of not less than 40% of its diameter.
2. Resin adhesive
3. Bearing ring or tripod.
4. Calibrated loading system. Includes measuring load device capable of recording maximum load after force release has occurred.

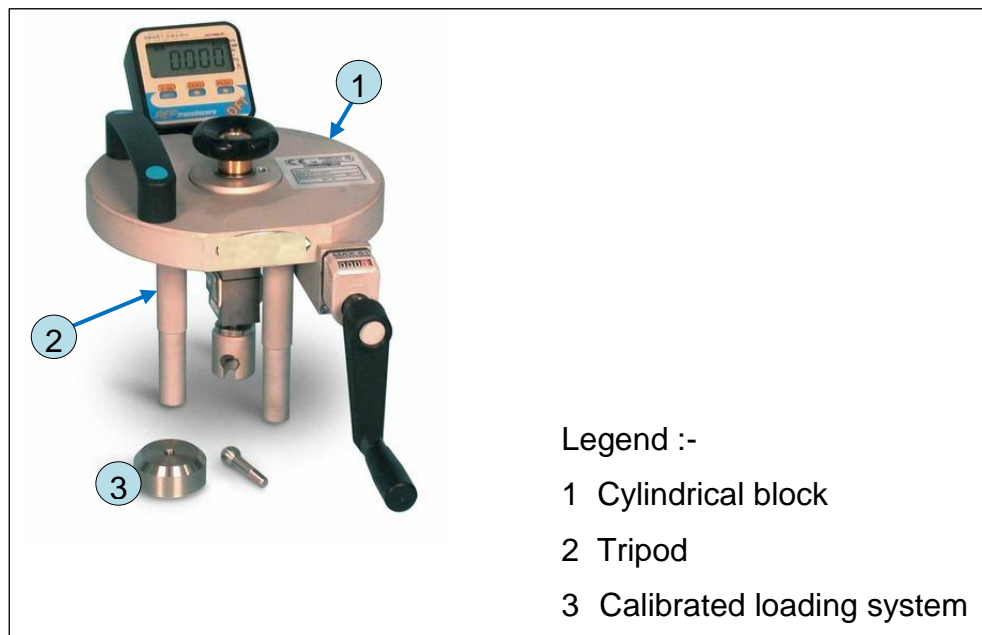


Figure 15.3.1: Typical Pull-off test equipment. Equipment may vary to manufacturers.

15.3.2 PROCEDURE

1. Test carried out on a plain flat surface.
 - i. Six valid tests are usually sufficient in each location. The centres of test positions should be at least two block diameters apart and at least one diameter from an edge.
 - ii. Clean off any laitance to expose the top of the coarse aggregate by abrasion to produce a flat surface with a texture suitable for bonding.
 - iii. Remove all grease and dust from the surface of the metal block liable to impair bonding of the two surfaces.
 - iv. Apply a thin uniform layer of adhesive over the entire contact area and any excess adhesive squeezed out round the edges of the block. Sufficient time should be allowed as according to the product manufacturer's recommendation to enable the adhesive to cure prior to load application.
 - v. Connect the loading system to the block.
 - vi. Apply tensile load to the block and increase load at a steady rate of 0.05 ± 0.03 N/mm² without jerking to cause failure.
 - vii. Record the maximum load and mode of failure whether failure on concrete or adhesive. (Refer to Figure 18.3-1 and Figure 15.3-2).
 - viii. Calculate the pull-off stress by dividing the maximum load by the cross-sectional area of the block.
 - ix. Report the test results as the failure stress to the nearest 0.1 N/mm².

2. Test carried out after partial coring on concrete.
 - i. Six valid tests are usually sufficient in each location. The centres of test positions should be at least two core diameters apart and at least one diameter from an edge.
 - ii. Reinforcing steel should neither lie within the annulus nor within a depth equal to the maximum aggregate size from the base of the annulus.
 - iii. Partially core the concrete to a required depth. Use a core diameter equal to the block diameter. The coring must be perpendicular to the surface.
 - iv. Clean off any laitance to expose the top of the coarse aggregate by abrasion to produce a flat surface with a texture suitable for bonding.
 - v. Remove all grease and dust from the surface of the metal block liable to impair bonding of the two surfaces.
 - vi. Apply a thin uniform layer of adhesive over the entire contact area and any excess adhesive squeezed out round the edges of the block. Sufficient time should be allowed as according to the product manufacturer's recommendation to enable the adhesive to cure prior to load application.
 - vii. Connect the loading system to the block.
 - viii. Apply tensile load to the block and increase load at a steady rate of 0.05 ± 0.03 N/mm² without jerking to cause failure.
 - ix. Record the maximum load and mode of failure whether failure on concrete or adhesive. (Refer to Figure 15.3.2 and Figure 15.3.3).
 - x. Calculate the pull-off stress by dividing the maximum load by the cross-sectional area of the block.
 - xi. Report the test results as the failure stress to the nearest 0.1 N/mm².

15.3.3 COMPLIANCE

The pull-off causes tensile failure of the concrete. Correlation between pull-off stress and compressive strength are influenced by the aggregate type, block material and thickness. A correlation should therefore be established for the particular concrete under investigation and the apparatus being used.

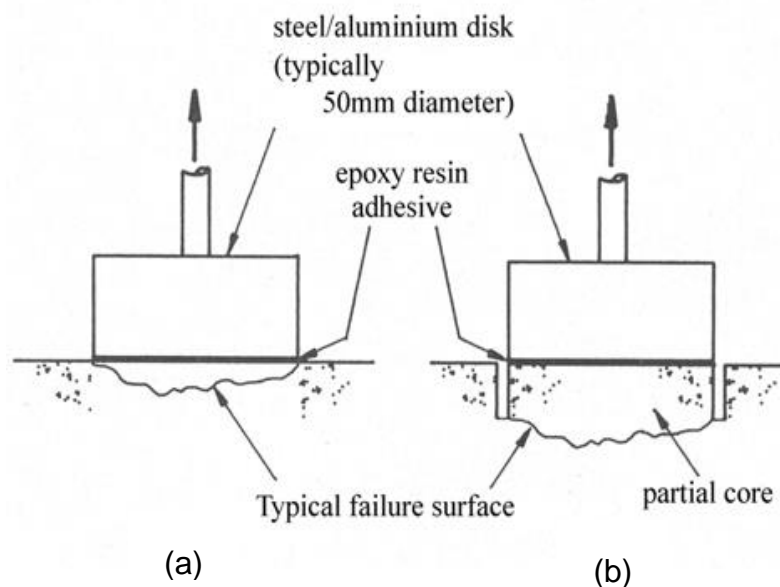


Figure 15.3.2: Typical failure surface (a) pull-off test at surface; (b) pull-off test on partial coring at sub-surface.

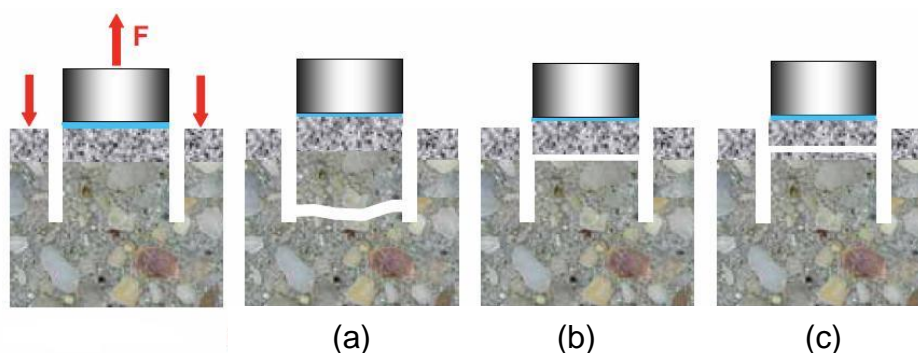
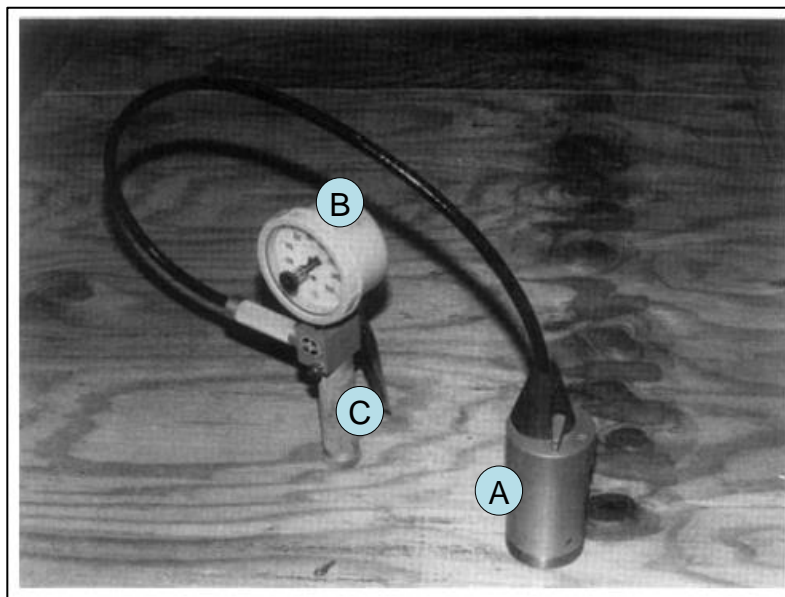


Figure 15.3.3: Type of failure mode. (a) Failure in substrate; (b) Bond failure; (c) Failure in overlay.

15.4 BREAK-OFF TEST

15.4.1 EQUIPMENT

1. Core cutter for use on hardened concrete. Diamond tipped drill bit capable of producing a cylindrical core 55±1 mm diameter and 70±3 mm deep, along with a reamed ring at the top of hardened concrete approximately 10 mm wide and 10 mm deep.
2. Hole former for use on fresh concrete, disposable tubular plastic sleeve with internal diameter of 55±1 mm and length of 70±1 mm.
3. Loading system. It consists of a load cell (low strength, 20 N/mm² or high strength, 60 N/mm²), a manometer and a hydraulic hand pump.



*Figure 15.4.1: Break-off test equipment. (A) Load cell, (B) Manometer, (C) Hydraulic hand pump. Reprinted from *The Break-off Test Method*, by Tarun R. Naik, Copyright 2004 by CRC Press LLC*

15.4.2 PROCEDURE

a) Inserting Sleeves in Fresh Concrete

1. Lubricate the plastic sleeves with heavy grease or other similar material for easier removal after the concrete hardens.
2. Push in-place the sleeves at a location centre to centre and at edge distance of minimum 150 mm by a rocking and twisting action.
3. Finger tap the sleeves to insure good compaction for the break-off specimen. Move the sleeves gently up and down and bring to the same level as the concrete surface at its final position. Sometimes this process may have to be repeated until the uplift movement stops after the initial setting has occurred. A small weight may be placed on the sleeve in order to prevent its upward movement.

b) Preparation for Core Drilling from Hardened Concrete.

1. Place the core barrel perpendicular to the concrete surface.
2. Commence the drilling process and continue until reaching the full depth required to produce a cantilever cylindrical core of 70 mm deep with a groove at the top of the core for setting the break-off tester load cell. A slightly longer drilled core will not affect the break-off reading, while a slightly shorter drilled core will affect the break-off reading.

c) Conducting the break-off test.

1. Remove the inserted plastic sleeve by using the key supplied with the tester. Leave the plastic ring in-place.
2. Remove loose debris from around the cylindrical slit and the top groove.
3. Select the desired range setting and place the load cell in the groove on the top of the concrete surface so that the load is applied. The load should be applied to the test specimen at a rate of approximately one stroke of the hand

pump per second. This rate is equivalent to about 0.5 N/mm² of hydraulic pressure per second.

4. After breaking off the test specimen occur, record the break-off manometer reading. This manometer reading can then be translated to the concrete strength using curves relating to the reading of desired concrete strength (i.e., flexural and/or compressive).

15.4.3 COMPLIANCE

The break-off test results are then correlated to concrete compressive testing results which need to be conducted to determine the estimated concrete compressive strength of the particular concrete under investigation. The following precautions should be taken when developing data for correlations.

- i. Keep the centre-to-centre and the edge distances of at least 150 mm (6 in.) in the process of inserting sleeves or drilling break-off cores.
- ii. Obtain a minimum of five break-off readings and three corresponding standard strength tests specimen values, i.e., cubes for compressive strength, and beams for flexural strength, for each test age.
- iii. An average of the five break-off readings and the average of the three standard cubes test results represent one point on the graph relating reading to the desired standard strength of the concrete.
- iv. Cover the range of concrete strengths expected in the project, at early as well as at later ages, such as 1,3,5,7,14, and 28 days.

15.50 PENETRATION RESISTANCE TEST (WINDSOR PROBE)

15.5.1 INTRODUCTION

This technique is commercially known as the Windsor Probe test. It determines the concrete strength by testing the resistance of concrete to penetration by a steel rod, or probe, driven by a fixed amount of energy. This test method may be used to:

- a) assess the uniformity of concrete and to delineate zones of poor quality or deteriorated concrete in structures; and
- b) estimate in-situ strength, provided that a relation has been experimentally established between penetration resistance and concrete strength

The underlying principle is that, for standard test conditions, a hardened steel alloy probe is fired into the concrete surface using a standardized powder cartridge. The exposed length is measured to derive the depth of penetration which is usually between 20-40 mm. The test is essentially semi-destructive, since concrete and structural members can be tested in-situ, with only minor patching of holes on exposed faces.

15.5.2 EQUIPMENT

The components of Windsor Probe test equipment used for the hardened concrete are described below, and illustrated in Figure 15.5.1:

1. Driver Unit – e.g. powder-actuated device that capable of driving the probe into the concrete with an accurately controlled energy
2. Probe – or bolt of hardened steel alloy. Generally, 6.35 mm in diameter and 79.5mm in length and can penetrate up to 40 mm into the concrete
3. Measuring unit – to measure and record the exposed length (above original surface) of probe to the nearest 0.5 mm.



Figure 15.5.1: Windsor Probe test apparatus.

15.5.3 PROCEDURE

- a) Set the test position to be at least 200 mm apart and a minimum distance of 150mm from the edge of the concrete surface.
- b) Place the positioning device on the surface of test location.
- c) Mount the probe in the driving unit, position the driver in the positioning device, as illustrated in Figure 15.5.2, and then fire the probe into the concrete.



Figure 15.5.2: Positioning the driving unit with probe before fire into the concrete.

- d) Remove the positioning device and tap the probe on the exposed end with a small hammer to firmly embed it. The partly exposed probe embedded in concrete structure to be measured is shown in Figure 15.5.3.



Figure 15.5.3: Exposed probe embedded in concrete structure.

- e) Eject the loose probe and place the measuring baseplate over the probe. Position it to bear firmly on the surface of the concrete without movement.
- f) Install probe-measuring cap and the measuring device, as illustrated in Figure 15.5.4. The measuring device will measure the distance from the reference plate to the end of the probe, to the nearest 0.5mm.



Figure 15.5.4: Measuring the exposed probe length.

15.5.4 COMPLIANCE

In-situ concrete strength is given by a linear relationship with exposed probe length as shown in Figure 15.5.5.

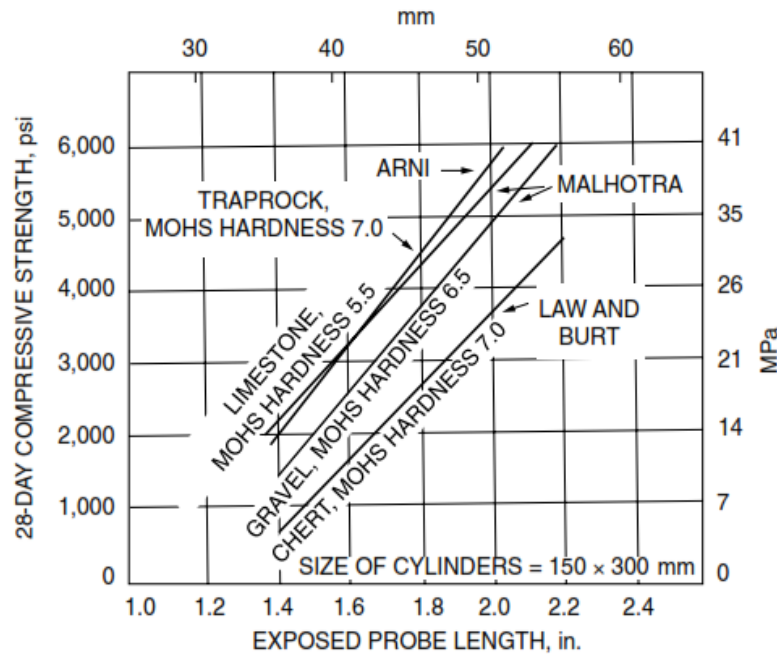


Figure 15.5.5: Relationship between exposed probe length and 28-day compressive strength of concrete. Reprinted from *Penetration Resistance Methods*, by V. M. Malhotra & G. G. Carette, Copyright 2004 by CRC Press LLC

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16.0 GROUND PENETRATING RADAR

16.1 INTRODUCTION

Ground Penetrating Radar (GPR) is a type of non-destructive testing for buildings, bridges, and other type of structures as well as used for general concrete testing applications. GPR is an effective testing in the study of non-electro conducting materials and in detecting the presence of metal objects inside reinforced concrete. Overall, it can be used to carry out imaging reinforced concrete structure and make an assessment on the quality of the concrete. It is also known as surface penetrating radar, electromagnetic reflection method or radar. The main advantages of this method are:

- a) non-destructive,
- b) fast (hundreds of measurements per second), and
- c) can be used in non-contact mode.

The radar method can be applied to a wide range of problems such as:

- a) determining layer thicknesses, including concrete cover of rebar, asphalt pavement, concrete tunnel walls, and sub-base and geological layers;
- b) locating of structures such as tendons or tendon ducts, anchors, dowels, and cavities;
- c) determining material properties, including humidity, chloride content, voids, and air content.

16.2 EQUIPMENTS

A wide range of GPR equipment is available from various manufacturers. In general, GPR equipment consist of the following. Figure 6.1 shows the component of typical GPR system.

1. Power source (internal rechargeable battery / external 12 volt battery / main A.C)
2. Control unit
3. Display screen
4. Antenna
5. Inter-connecting cables



Figure 16.1: Typical equipment for GPR system. Adapted from *Structure Scan Pro*, by Geophysical Survey System Inc, Retrieved from <https://www.geophysical.com/>.

16.3 PROCEDURE

GPR processing routines varies in accordance to the type of equipment used and site location. The basic procedures are as outlined below.

- a) Mark survey lines on the surface, consist of X and Y direction in close spacing typically 5cm between line.
- b) Turn on the GPR equipment.
- c) Move the antenna according to the survey lines to scan.
- d) Mark additional information on the surface (e.g. reinforcement bar location)
- e) Make sure reading is captured by the controller unit.
- f) The readings can be displayed as radargram on the monitor.
- g) Transfer the radargram to the computer software which comes together with the GPR equipment.
- h) Document the radargram for further analysis.

16.2 DATA PROCESSING AND INTERPRETATION

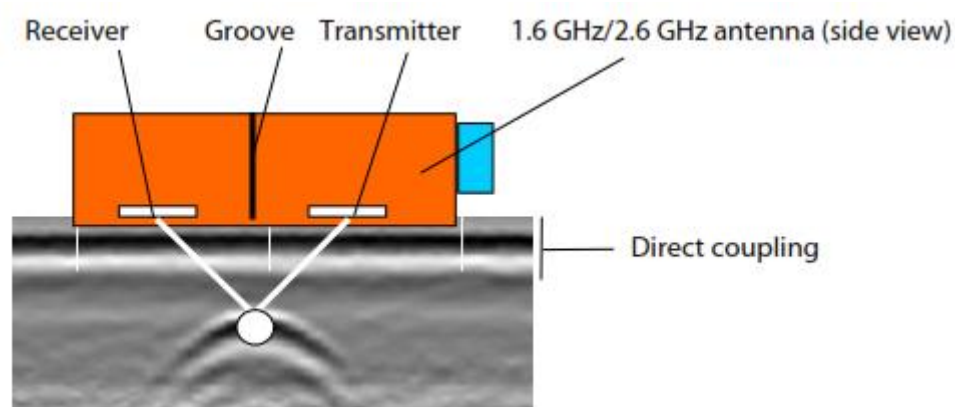


Figure 16.2: Locating the target. Reprinted from Concrete Handbook, by Geophysical Survey Systems Inc, Retrieved from <https://www.geophysical.com> Copyright 2000-2017 by Geophysical Survey System Inc.

1. GPR results are interpreted by recognizing diagnostic reflection patterns on the radargrams.
2. When the antenna crosses a pipe-like target, (pipe, cable, steel bar) at a right angle, the resulting image looks like an inverted U or V, called hyperbola.
3. The summit of the hyperbola as can be seen from Figure 16.2 is exactly where the target is.
4. Targets of larger diameter produce brighter reflections.
5. The target size can be roughly estimated from the width of the hyperbola's flat top.
6. A hyperbola may also appear distorted or incomplete when the survey line crosses the target diagonally. If the antenna moves parallel to it, the target looks like a continuous layer. Thus, the best way to verify its nature and to locate it is to scan in the transverse direction (across the suspected target) to see if a hyperbolic reflection appears.
7. Where the data has been recorded as multiple lines on a grid, then the results can be processed and displayed as a 3D plot, with time-slice sections made at user specified depths to show the relative orientations of subsurface targets.

16.3 LIMITATION

- a) Lack of complete understanding of the relationship between radar signatures and various types of defects that are encountered in concrete structures and how these signatures are affected by the condition in the structure, especially moisture content.
- b) Data gathered suffered problems such as poor signal to noise ratios, reverberations of the radar waves and mispositioning of objects in the subsurface layers.
- c) Testing for interior of metal ducts is not possible with radar because radar waves can never penetrate through metals.

- d) The conversion from time to a depth scale depends on the velocity of light.
- e) Test to be done by a competent person.

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17.0 PETROGRAPHIC TEST

17.1 INTRODUCTION

The major applications of petrography are in characterization, quality assurance, evaluation and failure investigation of construction materials. Since proper diagnosis of a problem is the key to the formulation of a successful repair scheme, petrography is gaining a significant acceptance in the concrete repair industry.

This guideline is intended to provide guidance on the minimum requirements for a full petrographic report on concrete samples and other cementitious construction materials containing Portland cement and calcium aluminate cements. Suggested procedures are given for the preparation of thin sections and for the techniques of examining thin section with the petrological microscope. It is assumed that the user of this guideline understands the basic principles of petrographic examination of concrete and associated materials.

Depending on the precise objectives of a particular investigation some sections of this guide may not be required while others may require more elaborate investigation.

17.2 OBJECTIVE OF EXAMINATION

The probable usefulness of this examination generally depends on the objectives set by the user. The objectives of the petrographic examination are to determine:

- a) the detail of the condition of concrete
- b) the causes of inferior quality, distress or deterioration of concrete
- c) the probable future performance of the concrete
- d) the quality control aspect of the concrete
- e) the cementitious matrix
- f) the existence of reaction between contaminants and the cementitious matrix
- g) the presence of chemical attack, such as chloride and sulphate attack
- h) the effects to concrete due to fire attack
- i) the performance of the coarse and fine aggregates in the structure

- j) the presence and nature of surface treatments

17.3 EQUIPMENTS

17.3.1 Equipment for thin section preparation

In optical mineralogy and petrography, a thin section (or petrographic thin section) is a laboratory preparation of a concrete, rock, mineral, soil, pottery, bones, or even metal sample for use with a polarizing petrographic microscope, electron microscope and electron microprobe (refer Figure 17.1).

The following list includes the equipment generally used:

- 1) Diamond saw cutter
- 2) Vacuum impregnation equipment

A vacuum chamber capable of containing large concrete samples up to 5 kg and means of introducing epoxy resin after the sample is evacuated is required.

- 3) Polishing, lapping and grinding equipment
- 4) Ovens

The curing of such resins should be carried out at temperature not exceeding 45 °C. Ovens of this type are also suitable for drying specimens prior to their vacuum impregnation with epoxy resin.

- 5) Cleaning equipment

An ultrasonic cleaning bath is useful for the cleaning of impregnated and polished surface. The use of ultrasonic cleaners should be avoided in impregnated samples because of the risk of losing materials such as ettringite or gel from voids and cracks.

- 6) Consumable

- i. Low viscosity epoxy resin
- ii. Fluorescent dye that can be dissolved in epoxy resin
- iii. Coloured dyes that can be dissolved in epoxy resin

- iv. Solvent for cleaning purposes
- v. Coolant as cutting oil
- vi. UV-curing adhesive for mounting and covering of thin section
- vii. Carborundum abrasive of various grades

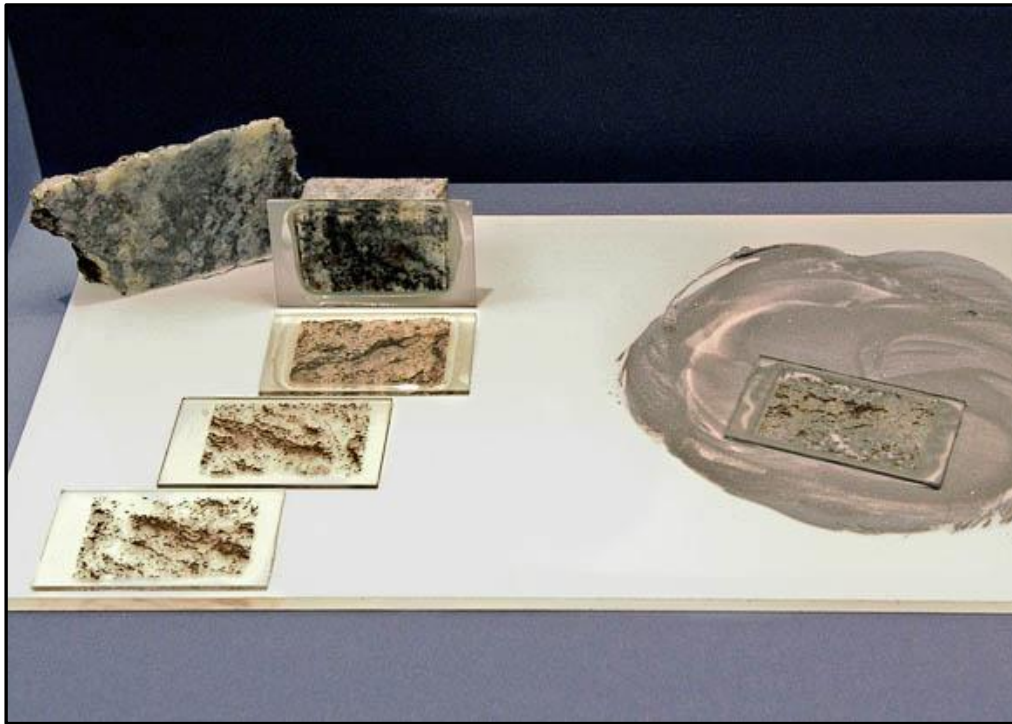


Figure 17.1: Examples of thin sections.

17.3.2 Equipment for the petrographic examination of concrete samples

a) Essential equipment

These items are indispensable and need to be of high quality:

- i. A zoom stereo binocular microscope
- ii. A high-quality petrological photomicroscope fitted with a digital camera
- iii. A point counting stage for the petrological microscope to enable point counting of thin sections. This equipment may also be replaced by computer image analysis methods.

b) Recommended equipment

- i. For more detailed petrographic studies, the following equipment is desirable:
- ii. A petrological microscope with appropriate filters and light source allowing the ability to carry out fluorescence observation to be carried out in either reflected or transmitted light
- iii. A petrological microscope with the facility to work in reflected as well as transmitted light
- iv. Point counting equipment for the measurement of the air content of hardened concrete in accordance with ASTM C457.

c) Specialist equipment

The following equipment shall be used in conjunction with more conventional petrographic techniques to investigate some of the more detailed aspects of concrete composition and deterioration:

- i. A scanning electron microscope with X-ray microanalysis capability for examining uncovered thin section, broken surfaces or specially prepared polished surfaces. This equipment can quantify GGBS or PFA contents in hardened concrete and can be used to investigate chemical attack, chloride penetration and alkali-silicate gel composition.
- ii. X-ray diffraction equipment for identifying the reaction products for chemical attack and identifying deleterious materials in aggregates.
- iii. An infra-red spectrometer to determine the presence of some types of concrete admixtures.

17.4 SAMPLES

The ideal sample for petrographic examination is diamond-drilled cores. The preferred diameter of cores shall be at least three times the maximum size of coarse aggregate in the concrete, ideally no less than 70 mm in diameter and 200 mm in length. Where smaller diameters are unavoidable, two or more cores may be needed to represent each sampling location.

The samples obtained should be labelled, their orientation (vertically, horizontally or oblique drilled) clearly marked and wrapped in cling film as soon as practicable after sampling. The samples should be accompanied by a sampling certificate giving details of the sample locations and the specific objectives of the petrographic examination.

17.5 PETROGRAPHIC EXAMINATION

17.5.1 Recording of results

The examination of petrographic samples consists of four (4) stages of inspection, namely:

- a) Preliminary macroscopic examination
- b) Polished surfaces examination
- c) Thin section examination
- d) Broken surfaces examination

It is recommended that all data from these four stages of examination be collected and recorded systematically in table to those given in this guideline.

17.5.2 Preliminary macroscopic examination

The samples should be examined with a binocular microscope as received and their dimensions and main features should be recorded using photographs and drawings.

The features observed should include the following:

- a) The presence and position of reinforcement
- b) The extent to which reinforcement is corroded
- c) The nature of external surfaces of the concrete
- d) The features and distribution of macro and fine cracks
- e) The distribution and size range and types of aggregate
- f) The type and condition of the cement paste
- g) Any superficial evidence of deleterious processes affecting the concrete

17.5.3 Polished surfaces examination

A polished surface is a large section of a sample, ideally the full length of the core (see Figure 17.2).

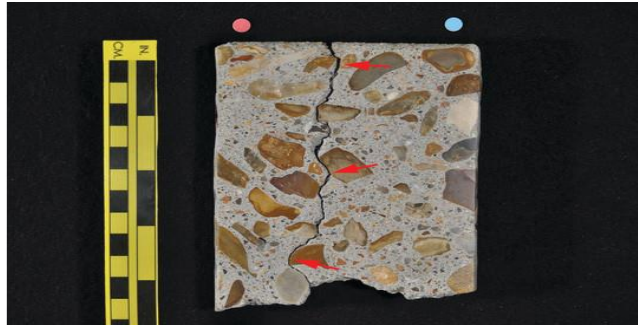


Figure 17.2: Example of a polished surface of a core sample from slab.

Large area polished typically can be examined with a binocular microscope to obtain valuable information about the concrete and are relatively quick and inexpensive to prepare compared to thin section. The features recorded shall include but not limited to the following items:

- a) The size, shape and distribution of coarse and fine aggregate
- b) The coherence, colour and porosity of the cement paste
- c) The distribution, size, shape and content of voids
- d) The composition of the concrete in terms of the volume proportions of coarse aggregate, fine aggregate, paste and void
- e) The distribution of fine cracks and microcracks. Often the surface is stained with penetrative dye, so that these cracks can be seen. Microcracks frequency may be measured along lines of traverse across the surface and the orientation of the traverses recorded
- f) The relative abundance of rock types in the coarse aggregate
- g) The presence of gel or other exudation.

17.5.3 Thin section examination

At least one (1) thin section and preferably more depending on the specific objectives of the investigation should be prepared for each core sample as appropriate. Each thin section should measure at least 45 mm x 70 mm.

The location and number of thin sections required should be decided by the petrographer during the preliminary macroscopic examination. It is advantageous that at least one thin section be made from a plate cut at the right angle to the external surface of the core sample. If the objective is to determine the existence of reaction between contaminants i.e. Alkali Silica Reaction (ASR) or Alkali Aggregate Reaction (AAR), and the cementitious matrix, it would be appropriate to make the section from the inner part of the core sample.

The features observed using the thin sections should include the following:

- a) Details of the rock types present in the coarse and fine aggregates
- b) Details of the aggregate's properties
- c) The size, distribution and abundance of phases in the cement paste i.e the occurrence of calcium hydroxide and the amount of residual un-hydrated clinker
- d) The presence of cement replacement phases such as slag, PFA, high alumina cement or types of cement clinkers
- e) The measurement of volume proportions
- f) The water/cement (w/c) ratio

17.6 REPORTING OF RESULTS

A petrographic report by a qualified petrographer should include a summary of the information provided about the nature of the structure from which the samples were obtained. The report should list the requirements of the client / reason for the examination for the samples if advised.

The report should include the factual observation of the samples in tabular form or any form deemed satisfactorily by the client. The report should also include a photograph of the samples as received with close-up photographs illustrating features of interest.



It also should include photomicrographs of the thin sections illustrating the principal feature of the samples.

The report should include the summary of the findings and recommendations for further works.

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18.0 STEEL TENSILE TEST

18.1 INTRODUCTION

Tensile testing is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces.

Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics

Steel reinforcing bar, or rebar, is embedded in concrete to improve the overall strength of the concrete that surrounds it. Material products standards exist to help ensure that rebar produced throughout the world exhibits the same physical, chemical, and mechanical properties regardless of the source.

Proper mechanical testing is then necessary for determining if the rebar meets its published specifications, ensuring the quality of the product.

18.2 EQUIPMENTS

Apparatus to carry out steel tensile test as follows and illustrated in Figure 18.1.

1. Testing machine consist of grips and extensometer
2. Test piece (steel)
3. Software and hardware
4. Test Control (automatic or manual)
5. Calculation of Results (automatic or manual)
6. Graph Analysis

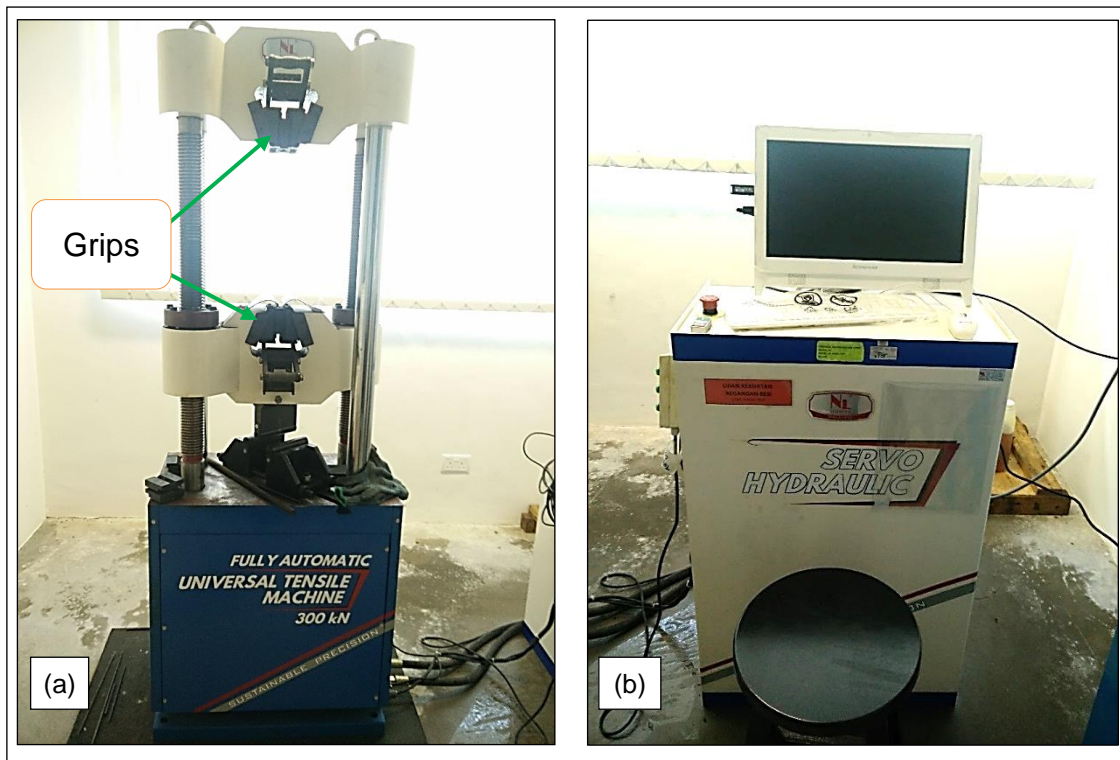


Figure 18.1: (a) Fully automatic universal tensile machine connected with (b) computer.

18.3 PROCEDURE

18.3.1 STEEL SAMPLING FROM CONCRETE

- Locate and mark out the steel location and size of bar by using bar scanner on a concrete surface.
- Carefully hack the marked-out concrete to expose reinforcement bar by using mechanical concrete breaker or manual tools. Extra precaution needed to prevent damage to the reinforcement bar.
- Cut the reinforcement bar by using diamond cutter grinder or steel saw.
- The steel sample is properly labelled and prepared for tensile test.
- Same size of reinforcement that was cut from the concrete have to be reinstated to the concrete by either lapping or welding. Table 18.1 shows the appropriate lap length and welding length for reinstating reinforcement bar.

Bar size (mm)	By weldings : Double Flare V-Groove Weld (mm)	By lapping: Lap length (mm)
10	80	42 x bar diameter at each end
12	100	
16	130	
20	160	
25	200	
32	260	

Table 18.1: Lapping length of reinforcement bar according to bar sizes.

18.3.2 STEEL TENSILE TESTING

- a) Determine the test piece's cross-sectional area, S_o and original gauge length, L_o (refer Figure 18.1). Relationship between L_o and S_o is

$$L_o = k\sqrt{S_o} \quad (1)$$

where

$k = 5.65$ (for proportional test pieces) , 11.3 (for non-proportional test)

- b) Mark the original gauge length, L_o at the test piece. Each end of the marking shall be marked by means of fine marks, scribed lines or punch marks, but not by marks which could result in premature fracture.
- c) Set the force-measuring system to zero after the testing loading train has been assembled.
- d) Grip the test piece in the jaws of the test machine. Ensure that test pieces are held in such a way that the force is applied as axially as possible.
- e) Apply load by prescribed rate of stressing. The rate of stressing shall be within the limits given in Table 18.1. To determine lower yield strength, R_{eL} the straining rate shall be between 0.00025 s^{-1} and 0.0025 s^{-1} . To determine upper yield strength of yield strength and $0.008/\text{s}$ for determination of tensile strength.

Modulus of elasticity of the material E MPa	Stress rate R Mpa s ⁻¹	
	Min.	Max.
< 150,000	2	20
≥ 150,000	6	60

Table 18.2: Stress rate. Adopted from Table 3, MS EN ISO 6892-1:2017.

- f) After fracture, put down the maximum force, F_m , and measure the final gauge length, L_u and minimum diameter after fracture. From stress-strain diagram, find the force at point of yield, F_y .
- g) Determine the tensile strength R_m , upper yield strength R_{eH} , lower yield strength R_{eL} (refer Figure 18.2).
- h) Determine the proof strength, plastic extension, R_p . (Refer Figure 18.3)
 - i. Obtain R_p by finding the force at intercept of a parallel line, at a distance prescribed plastic percentage extension, e.g. 0.2% to the linear portion of the plotted force-extension curve and dividing the force with original cross-sectional area, S_o .
 - ii. Alternatively, R_p can be obtained by using computer-controlled tensile testing machines.
- i) Determine the proof strength, total extension, R_t (Refer Figure 18.4)
 - i. Obtain R_t by finding the force at intercept of a parallel line, at a distance of prescribed total percentage extension to the ordinate axis (force axis) of the plotted force-extension curve and dividing the force with original cross-sectional area, S_o .
 - ii. Alternatively, R_t can be obtained by using computer-controlled tensile testing machines.
- j) Determine the percentage of yield point extension, A_e (Refer Figure 18.5)
 Determine A_e from the force-extension curve by horizontal line method or

by regression method. It is expressed as a percentage of the extensometer gauge length, L_e .

- k) Determine the percentage total extension at maximum force, A_{gt}

$$A_{gt} = \frac{\Delta L_m}{L_e} \times 100 \quad (2)$$

where,

ΔL_m = the extension at maximum force

L_e = the extensometer gauge length

- l) Determine the percentage total extension at fracture, A_t

$$A_t = \frac{\Delta L_f}{L_e} \times 100 \quad (3)$$

where,

ΔL_f = the extension at fracture

L_e = the extensometer gauge length

- m) Determine percentage of elongation after fracture A , and percentage reduction of the area, Z .

$$A = \frac{L_u - L_o}{L_o} \times 100 \quad (4)$$

where,

L_u = final gauge length

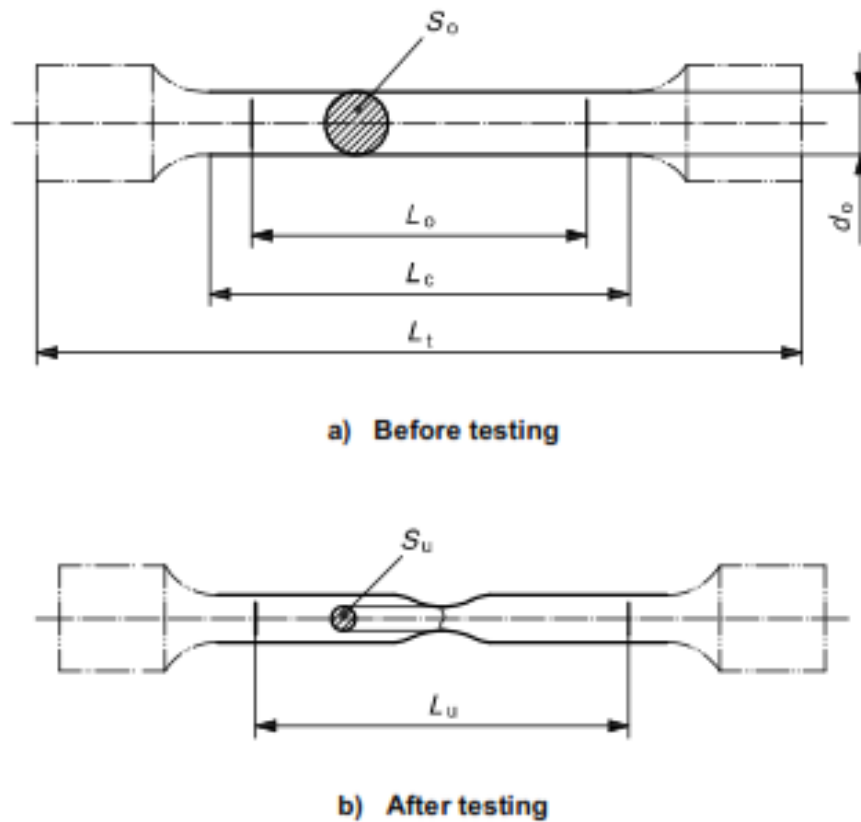
L_o = original gauge length

$$Z = \frac{S_o - S_u}{S_o} \times 100 \quad (5)$$

where,

S_o = original cross-sectional area of the parallel length

S_u = minimum cross-sectional area after fracture

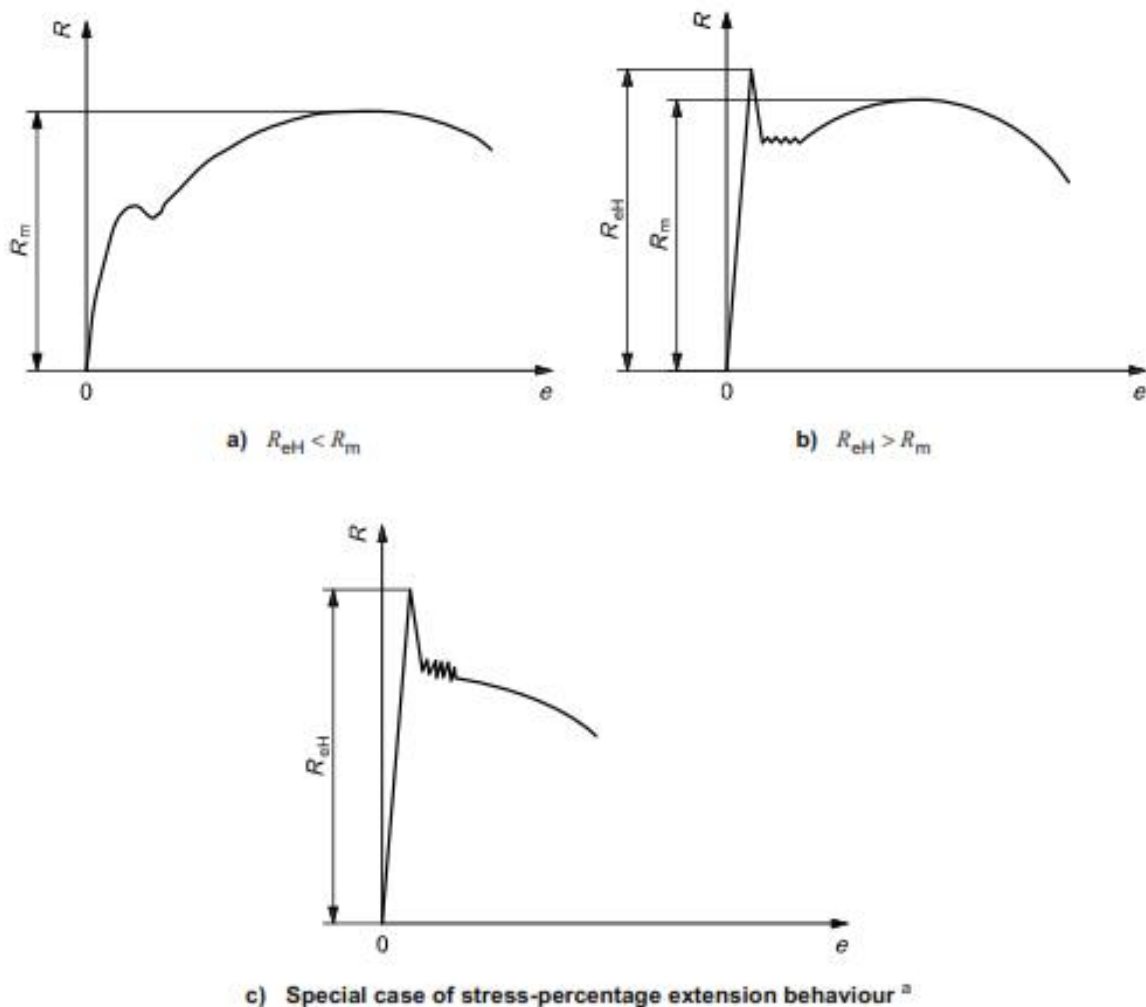


Key

- d_0 original diameter of the parallel length of a circular test piece
- L_c parallel length
- L_0 original gauge length
- L_t total length of test piece
- L_u final gauge length after fracture
- S_0 original cross-sectional area of the parallel length
- S_u minimum cross-sectional area after fracture

NOTE The shape of the test-piece heads is only given as a guide.

Figure 18.1: Machined test pieces of round cross-section. Reprinted from Figure 13, MS ISO 6892-1:2017)



Key

e percentage extension

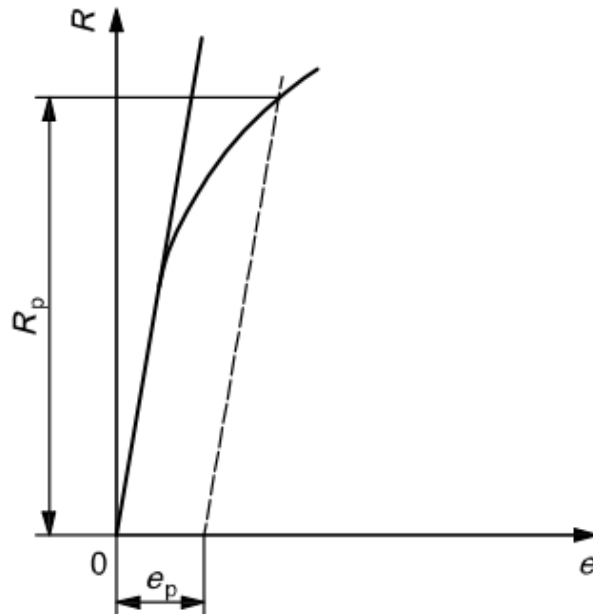
R stress

R_{eH} upper yield strength

R_m tensile strength

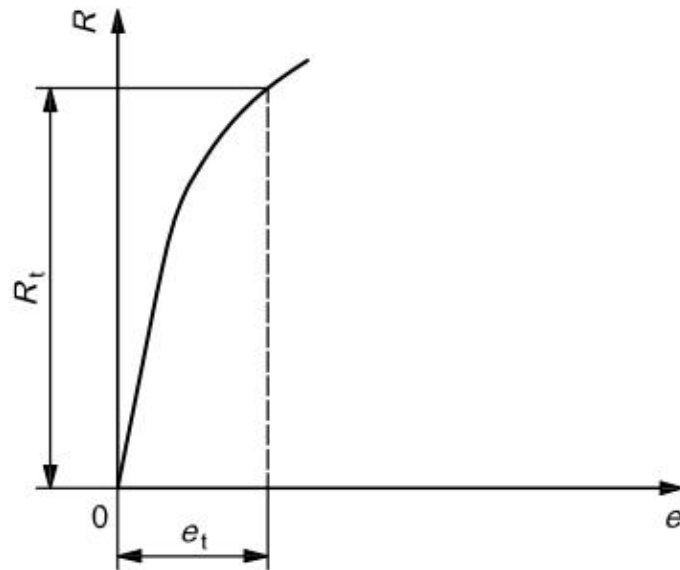
^a For materials which display this behaviour, no tensile strength is defined according to this part of ISO 6892. If necessary, separate agreements can be made between the parties concerned.

Figure 18.2: Different types of stress-extension curve for determination of tensile strength, R_m . Reprinted from Figure 8, MS ISO 6892-1:2017.

**Key**

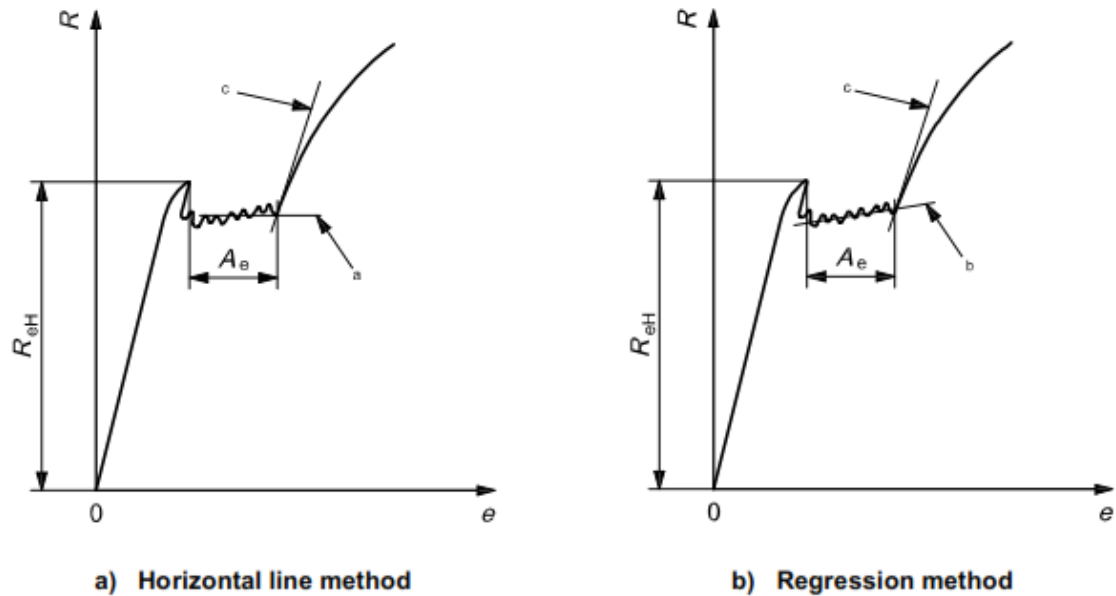
- e percentage extension
- e_p specified percentage plastic extension
- R stress
- R_p proof strength, plastic extension

Figure 18.3: Proof strength, plastic extension R_p . Reprinted from Figure 3, MS ISO 6892-1:2017.

**Key**

- e percentage extension
- e_t percentage total extension
- R stress
- R_t proof strength, total extension

Figure 18.4: Proof strength, total extension R_t . Reprinted from Figure 4, MS ISO 6892-1:2017.



Key

A_e percentage yield point extension

e percentage extension

R stress

R_{eH} upper yield strength

- ^a Horizontal line through the last local minimum point, prior to uniform workhardening.
- ^b Regression line through the range of yielding, prior to uniform workhardening.
- ^c Line corresponding to the highest slope of the curve occurring at the start of uniform workhardening.

Figure 18.5: Horizontal and regression method for percentage yield point extension, A_e . Reprinted from Figure 7, MS ISO 6892-1:2017.

18.4 COMPLIANCE

a) For steel Grade 500, the results shall be in accordance to Table 18.2.

Performance characteristic	Minimum value			Maximum value		
	B500A	B500B	B500C	B500A	B500B	B500C
R_e , MPa	485	485	485	650	650	650
R_m/R_e	1.03 ^a	1.06	1.13	N/A	N/A	1.38
A_{gt} , %	2.0 ^b	4.0	6.0	N/A	N/A	N/A

^a 1.01 for sizes below 8 mm.
^b 0.8 % for sizes below 8 mm.

Table 18.2: Absolute minimum and maximum values of tensile properties.
Reprinted from Table 10, MS 146:2014.

b) For steel Grade 250, 410 and 460, the results shall be in accordance to Table 18.3 below.

Grade	Nominal size of bar	Specified characteristic strength	Minimum elongation on gauge length L_o (see note 6)
	mm	N/mm^2	%
250	All sizes	250	22
410	All sizes	410	14
460	All sizes	460	12

NOTE 6. $L_o = 5.56 / S_o$

where,

L_o is the gauge length of the test piece;
 S_o is the original cross-sectional area of the test piece.

Table 18.3: Tensile properties of steel Grade 250, 410 and 460. Reprinted from Table 8, MS 146:1988

- c) Figure 18.6 shows further information regarding the stress-strain relationship under uniaxial tensile loading.

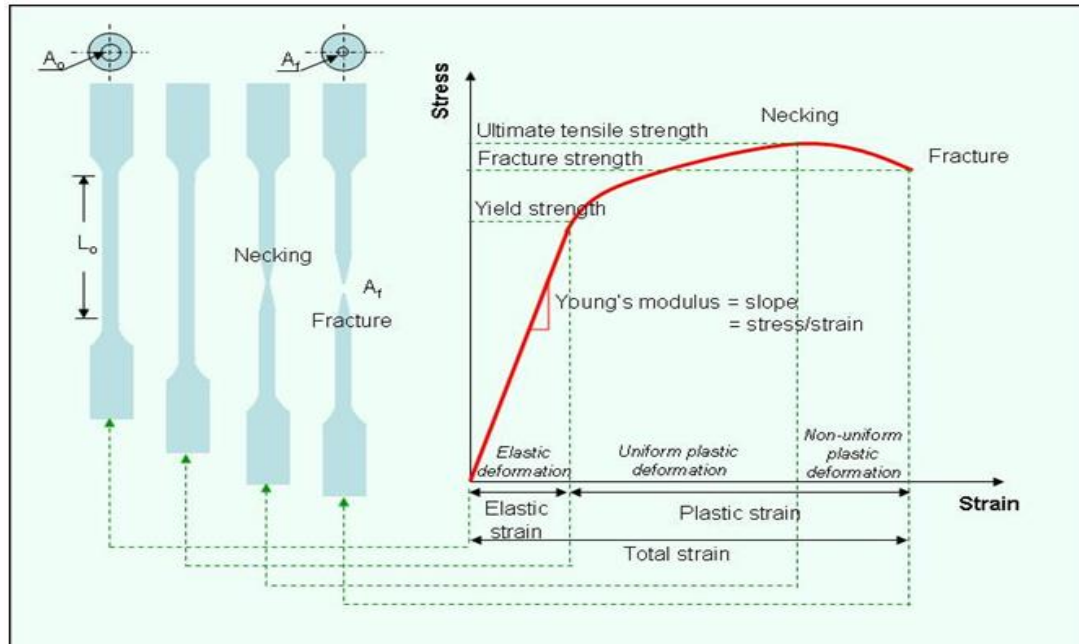


Figure 18.6: Stress-strain relationship under uniaxial tensile loading. Adapted from *Correlation between Engineering Stress-Strain and True Stress-Strain Curve*, by Science and Education Publishing, 2014, Retrieved from <http://pubs.sciepub.com/ajcea/2/1/6/index.html>. Copyright 2013 by Science and Education Publishing.

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