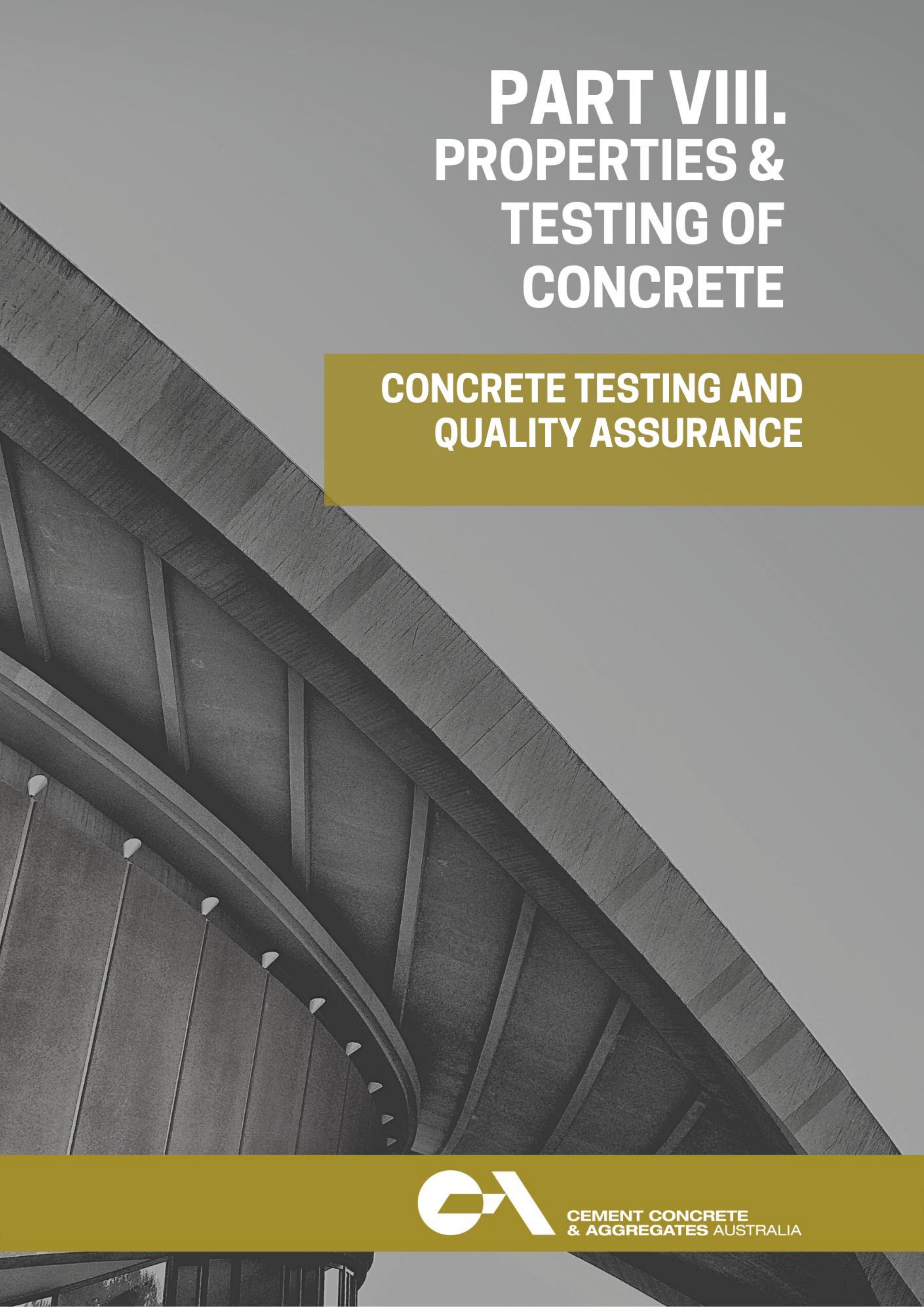

PART VIII. PROPERTIES & TESTING OF CONCRETE

CONCRETE TESTING AND QUALITY ASSURANCE

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

Tests are carried out on concrete, either in the laboratory or in the field, to determine its properties. This information may then be used in a number of ways: to determine whether the concrete complies with the requirements of a specification; to forecast how it will perform in service; to determine the effect of different materials; or simply to determine whether some change is necessary in the mix proportions, e.g. the water content.

Unless these tests are conducted strictly according to standardised procedures, the results will be of little value because they will not be comparable with results generated within a given laboratory at a different time or between different laboratories.

Whatever the purpose of the testing, it is imperative that concrete testing be conducted in accordance with standard or otherwise agreed procedures so that there can be confidence that the material meets the specified requirements, and that the results are not affected by (a) variable testing equipment performance, (b) variable testing procedures, (c) capability of testers and/or (d) chance or random factors which would make results meaningless.

This section describes the common methods used to sample and test concrete, highlighting the principal precautions which should be taken to ensure comparable (i.e. repeatable) results. It also describes the more common tests used to determine the properties of concrete and highlights the more important precautions which need to be taken in carrying them out. Full details of the various test methods are to be found in the relevant Australian Standards listed in the references to this section.

2. SAMPLING OF CONCRETE

2.1 GENERAL

It is essential that the test results (whatever use is to be made of them) are representative of the concrete being tested. Hence, it is essential that the test sample be representative of the concrete from which it is taken. AS 1012.1 sets out procedures for obtaining representative samples from freshly mixed concrete for either consistency (slump) tests or the moulding of specimens for other tests.

AS 1379 also imposes a number of requirements on the sampling of concrete. Where the sample is being taken to check the quality of the concrete being supplied to a project, it requires that samples be taken after completion of mixing but prior to site handling. Generally, this means that the concrete is sampled at the job site from the delivery truck, although sampling at the concrete plant after mixing is permitted.

Sampling at the point of placement in the forms may also be specified on occasions, generally to check on-site delivery methods, e.g. where concrete is being pumped long distances. Whilst sampling at this point is perfectly proper, the information obtained from such samples cannot be used to determine the quality of the concrete delivered to the site. The point at which concrete is sampled is an important factor in determining the use to which test information may be put.

To ensure that samples are representative of the concrete being delivered to the site, it is first necessary to ensure that they are collected in a random manner, i.e. the batches of concrete or delivery units from which the individual samples are taken must be selected randomly, e.g. by using a list of random numbers to select batches. Selection should never be made on what the concrete looks like as it is being discharged.

Secondly, the actual sampling must be done in the prescribed manner. When a consistency or slump test only is to be performed, the test sample will normally be taken from the delivery or mixer truck immediately after the first 0.2 m^3 of concrete has been discharged.

For other tests, including consistency tests on concrete sampled from non-agitator delivery units or from other locations on the site, composite samples are used. These are samples obtained by taking three or more approximately equal increments during the whole of the discharge. (Increments are not taken during the first nor the last 0.2 m^3 of the batch.) The increments are then mixed together to form a composite whole from which the sub-samples are taken for (consistency) testing and/or moulding of test specimens.

AS 1012.1 should be consulted for details of a number of other specific precautions which must be taken to ensure that composite samples are representative of the batch.

3 TESTS ON FRESH CONCRETE

3.1 GENERAL

A number of tests are carried out, more or less routinely, on fresh concrete. These are tests for its consistency, its air content, its mass per unit volume and, perhaps less routinely, its bleeding characteristics. Consistency does not refer, as might be supposed, to the uniformity of concrete, but rather to the ability of the concrete to hold its shape when unsupported and to do so without segregating or falling apart. The most commonly used test for this is the slump test.

The consistency of concrete is closely related to its workability, i.e. the ease with which it can be moulded and compacted. Since it is really the workability in which we are interested a range of tests have been devised to measure this property – but they are generally more difficult to carry out than the slump test. The latter has therefore retained its popularity although it measures only indirectly the workability of concrete.

Because the various test procedures used to determine the consistency and/or workability of concrete actually measure different parameters, it is not advisable to compare directly the results of one procedure with another. Certainly, the results obtained by one test procedure cannot be used to determine compliance with a specification requirement based on another test procedure.

3.2 THE SLUMP TEST

The slump test is described in Section 25 *'Properties of Concrete'* and detailed in AS 1012.3.1. The test is carried out by filling a mould, in the shape of a truncated cone, with concrete and then withdrawing the mould. The amount by which the concrete subsides or 'slumps' is then measured (**Figure 26.1** and **Figure 26.2**).

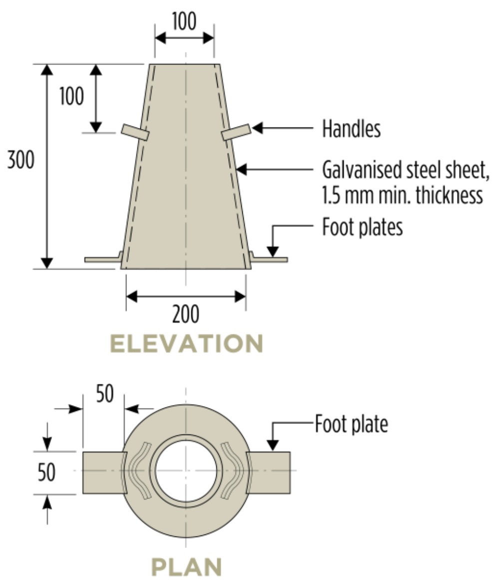

Figure 26.1 – Typical Mould for Slump Test

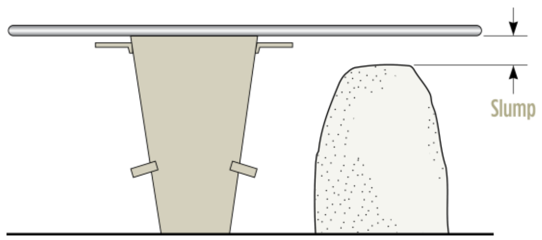

Figure 26.2 – Measuring the Slump

After the slump has been measured, the concrete is tapped gently on the side to obtain an indication of the cohesion of the mix. Mixes which are well proportioned and cohesive tend to subside a little further. Poorly proportioned, harsh mixes tend to fall apart.

The test does not work well for concrete with either very high or very low workability. Very workable concretes may simply lose their shape completely by subsiding and flowing, while concretes of very low workability may not subside (slump) at all.

Some mixes may lack sufficient cohesion for the test to be carried out properly. The cone of concrete may shear or otherwise collapse as the mould is withdrawn. If this occurs, the test must be repeated with another part of the sample. If the concrete shears or collapses, the slump is not measured but a shear or lateral collapse is recorded (see **Figure 26.3**).

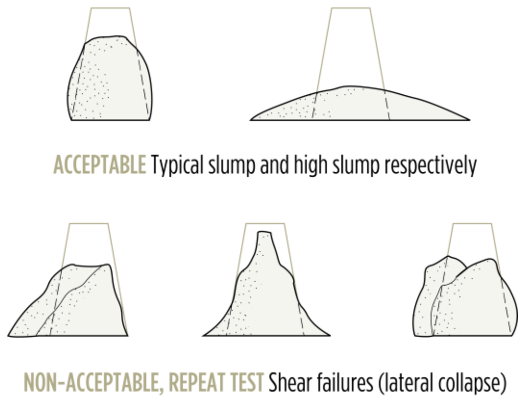

Figure 26.3 – Examples of Slump

3.3 THE COMPACTING FACTOR TEST

The compacting-factor test is generally regarded as a more direct indicator of the workability of concrete than the slump test. Moreover, it can be used on concretes for which the slump test is not suitable, e.g. concretes with very little or no slump. It is, however, quite sensitive to the early stiffening of concrete as hydration of the cement commences. In the laboratory it is normally carried out within four minutes of water being added to the mix. Obviously, this is not practical on site, but the sensitivity of the test to this factor should be recognised in interpreting the results.

The test is described in AS 1012.3.2 and is carried out by measuring the compaction achieved in a sample of concrete by performing a fixed amount of work on it. The apparatus is illustrated in **Figure 26.4**. The upper hopper is filled with concrete and then the trapdoor in the hopper opened, allowing the concrete to fall freely into the second or lower hopper. The trapdoor in this hopper is then opened, allowing the concrete to fall into the cylinder. Excess concrete is struck off and the mass of concrete in the cylinder is determined. The cylinder is then emptied and refilled with a fresh portion of the sample under test, rodding or vibrating each layer of the concrete as it is placed in the cylinder to ensure that it is fully compacted. The mass of fully compacted concrete in the cylinder is then determined and the compacting factor calculated as the mass of concrete in the cylinder (when filled by falling from the hopper above) divided by the mass of concrete in the cylinder (when fully compacted). The higher this ratio then the more workable the concrete is.

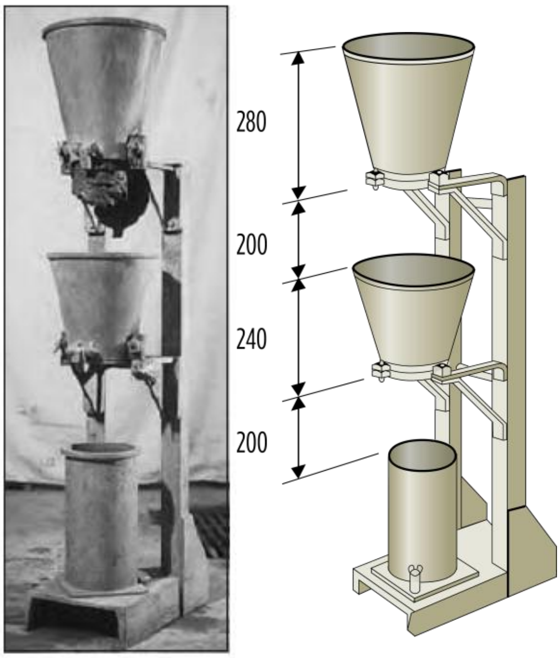

Figure 26.4 – Compacting Factor Test Apparatus

As was noted above, the test is quite sensitive, not only to early stiffening of the concrete but to the method of compaction used to fill the cylinder. This should be kept in mind when comparing results.

3.4 THE VEBE TEST

The ‘Vebe’ test is described in AS 1012.3.3. The equipment consists of a vibrating plate or table on which is mounted a metal cylinder inside which a conical mould or slump cone is placed (**Figure 26.5**).

Figure 26.5 – Vebe Consistometer

The test is carried out by determining the time taken for a cone of concrete (moulded with the slump cone) to subside completely inside the cylindrical mould when subjected to vibration. Whilst the test is sensitive to changes in materials, early stiffening of concrete and other factors which affect its workability, it is not easy to carry out with consistent results. Its application in the field is therefore limited but it has been used quite widely in the laboratory to investigate materials and their impact on workability. It works well for concrete having either very high or very low workability.

3.5 AIR CONTENT OF PLASTIC CONCRETE

Determination of the air content of plastic concrete may be necessary when the purposeful entrainment of air has been specified to enhance the durability of concrete or when it is desired to check the amount of air being entrained by admixtures used for other reasons, e.g. to improve workability.

Three methods of determining the air content of plastic concrete are described in AS 1012.4.1, AS 1012.4.2 and AS 1012.4.3. Two of these, based on determining the change in volume of a given quantity of concrete when subjected to an increase in air pressure, are suitable for normal-weight, relatively dense aggregates. The third method, based on displacing the entrained air with water, is suitable when using lightweight and porous aggregates.

The two methods that apply pressure to the concrete, measure the reduction in the volume of air entrained within the concrete. From this figure and the pressure applied, the actual air content can be calculated. However, the equipment must be calibrated for the height above sea level at which it is being used and a correction may have to be applied for air contained within the aggregates. For this reason, it is not suitable for mixes containing porous aggregates **Figure 26.6**.

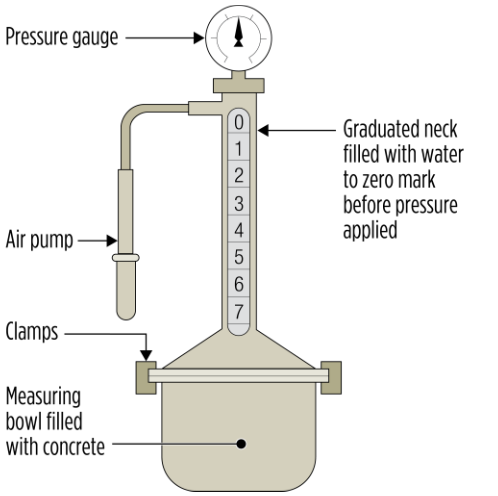

Figure 26.6 – Typical Arrangement of Apparatus for Determining Air Content of Concrete by Applied Air

The volumetric method entails the displacement of the entrained air with water. It is not necessary to calibrate the equipment for height above sea level or to correct for the air content of the aggregate. The test does, however, take longer to perform than the pressure methods (see **Figure 26.7**).

3.6 MASS PER UNIT VOLUME OF CONCRETE

The mass per unit volume (also called 'plastic density'), of freshly mixed concrete is determined by a simple test in which the mass of concrete in a container of known volume is measured. The standard procedure for conducting this test is described in AS 1012.5.

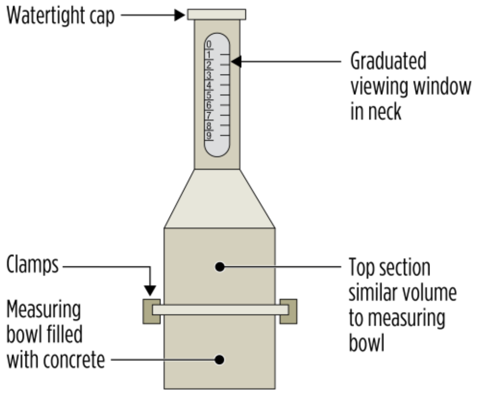

Figure 26.7 – Apparatus for Measuring Air Content of Fresh Concrete by Volumetric Method

Its principal application is the determination of the volume of plastic concrete produced from a given mass of constituent materials. The method for determining the volume of plastic concrete from the mass per unit volume of batches of a concrete mix is provided in AS 1379.

3.7 BLEEDING OF CONCRETE

Tests for the bleeding characteristics of concrete are normally carried out in the laboratory to evaluate trial mixes or to evaluate the influence of different materials, e.g. for the evaluation of admixtures under AS 1478.1. The actual procedure is described in AS 1012.6. A sample of the concrete to be tested is placed in a cylindrical container and compacted, either by rodding it or by vibration. The container is then covered and placed on a level surface. Bleed water is drawn off with a pipette at regular intervals until the amount collected during a 30-minute period is less than 5 mL.

The results may be expressed either as the volume of bleed water collected in a given time per unit surface area of the container, or as a percentage of bleed water to total mixing water if the latter is known.

3.8 SETTING TIME OF CONCRETE

Tests for the setting time characteristics of concrete are normally carried out in the laboratory to evaluate trial mixes or to evaluate the influence of different admixtures or binders on hardening rate.

4 TESTS ON HARDENED CONCRETE

4.1 GENERAL

A variety of tests may be carried out on hardened concrete to determine its properties or to measure its performance under different service conditions. They range from relatively simple tests to determine (say) the strength of the concrete to more-sophisticated and more expensive tests to determine (say) its fire resistance; and from tests which can be carried out quickly and without damage to the concrete, e.g. the Schmidt Rebound Hammer test, to those which may take months or even years to complete, e.g. long-term creep tests.

Viewed in another way, tests on hardened concrete fall into four groups, viz:

- Tests on specimens moulded for the purpose;
- Tests on cores taken from hardened concrete;
- Tests on concrete in situ;
- Tests on concrete elements.

Only tests in the first two categories are considered in any detail in this Guide. Tests in the other two categories usually require special equipment and special skills not normally found on a construction site. Three forms of concrete strength tests are described in AS 1012 Parts 9, 10 and 11 (the compressive strength test, the indirect tensile strength test, and the flexural strength test).

The first two are carried out on concrete cylinders and the last on concrete beams. Casting and curing of test specimens for these tests are described in AS 1012.8.1 (first two) and AS 1012.8.2 (for flexural test beams).

Also included are methods for determining the drying shrinkage and creep of concrete as well as a number of other tests.

4.2 TEST SPECIMENS

The need to standardise procedures for testing hardened concrete is every bit as important as that for testing plastic concrete. Thus, in addition to the care which must be taken in sampling concrete, care must also be taken in the preparation of test specimens. AS 1012.8.1 and AS 1012.8.2 describe the necessary procedures for moulding and curing compression, indirect tensile and flexural test specimens made from plastic concrete, respectively.

There is a common view that the making of test specimens is a simple procedure which can be entrusted to any site personnel. This is not so. Proper preparation requires proper training. It is therefore not unusual to find in concrete specifications a requirement that all site testing be carried out by a laboratory registered for the purpose by the National Association of Testing Authorities (NATA). Whilst it is not a mandatory requirement of the Standard, it helps to ensure that personnel making test specimens are trained for the task. NATA also manages a scheme for certifying personnel properly trained in sampling and testing concrete.

4.3 COMPRESSIVE STRENGTH TESTING

The determination of the compressive strength of concrete is described in AS 1012.9. It makes provision for two sizes of concrete cylinder to be used – either 150 mm-diameter × 300 mm-high, or 100 mm-diameter × 200 mm-high (see **Figure 26.8**). The smaller cylinder may be used provided the maximum aggregate size does not exceed 20 mm and the designer's permission is obtained. Whilst the two cylinder sizes tend to give the same average compressive strength, and hence may be used to determine compliance with the concrete specification, the coefficient of variation of the individual results may be different. Hence, results from the two specimen sizes cannot be combined when determining the average strength.

Figure 26.8 – Moulds for the Two Standard Sizes of Concrete Test Cylinders

Cylinder tests are quite sensitive to the planeness of the ends and to the capping material used to ensure plane surfaces (see **Figure 26.9**). AS 1012.9 devotes considerable attention to this, setting quite stringent limits on the condition of the cylinder ends before capping and then on the materials and methods which may be used to cap cylinders. Alternative methods for treating the ends of cylinders are (a) to mill the cylinder ends, or alternatively (b) to use standard rubber caps. Reference should be made to the Standard for full details of each of these methods. The Standard also sets down requirements for testing machines (see **Figure 26.10**) and testing procedures to ensure that test results from a single batch of concrete are as uniform as possible.

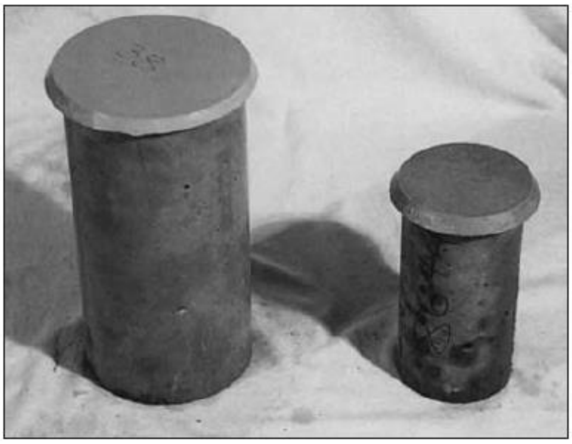

Figure 26.9 – Sulphur Capped Concrete Test Cylinders in the Two Standards Sizes

Figure 26.10 – Test in Compression Machine

4.4 INDIRECT TENSILE STRENGTH TESTING

The indirect tensile strength, the Brazil or splitting test, is conducted on a standard 150 mm × 300 mm concrete cylinder (held in a jig – see **Figure 26.11**) by placing it horizontally in a testing machine and applying a compressive force to it. When tested in this way, the cylinder splits, enabling the tensile strength of the concrete to be determined. AS 1012.10 describes the procedure.

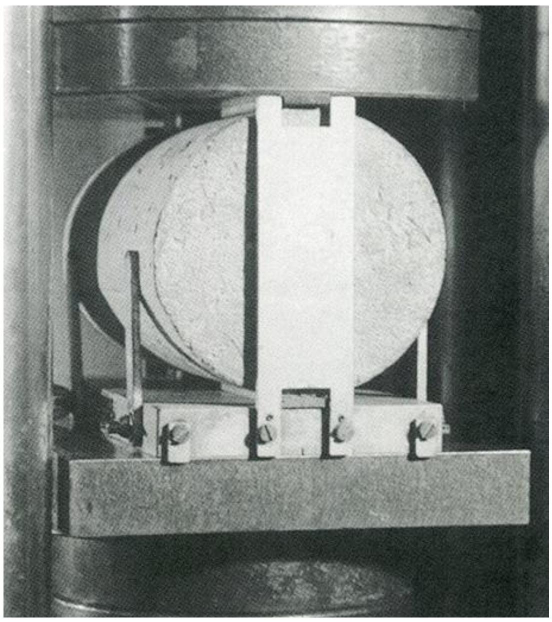

Figure 26.11 – Concrete Cylinder in Jig Ready for Indirect Tensile Strength Testing

4.5 FLEXURAL TENSILE STRENGTH TESTING

The specification of concrete flexural tensile strength is quite commonly used in pavements (aircraft pavements, concrete roads and some industrial pavements) where the strength of concrete in flexure, or bending, is of prime importance.

The most common test method is described in AS 1012.8.2 (for casting and curing) and AS 1012.11 (for flexural testing). The specimens are generally cast on site and the early curing of the specimens is critical to obtaining reliable test information. AS 1379 provides some guidance on the methods of assessing flexural strength data.

Test specimens are in the form of beams. The two common test beam sizes are provided in the Standard. The testing of the beams takes place in a 'four-point' test rig with the beam breaking between the two central loading points (see **Figure 26.12**).

Figure 26.12 – Flexural Testing Beam in Test Rig

For a given concrete, the flexure test gives a higher value for the tensile strength than the indirect tensile strength test and there is not a direct relationship between the two values. In specifying tensile strengths of concrete, care should therefore always be taken to nominate the method by which the value has to be obtained.

Further information on the tensile strength of concrete is provided in Part VIII, Section 25 of this Guide *'Properties of Concrete'*.

4.6 DRYING SHRINKAGE TESTING

Limits on the drying shrinkage of concrete are commonly specified by designers in an attempt to limit both short-term and long-term movements in buildings and other structures and, thereby, the undesirable effects of such movements. For example, drying shrinkage can lead to unsightly cracking and, in extreme cases, loss of structural integrity.

Drying-shrinkage specimens may be prepared in the laboratory but are routinely prepared in the field to check the characteristics of concrete being delivered to the site.

Methods for the preparation and testing of drying shrinkage specimens are set out in AS 1012.8.4 (for casting and curing) and AS 1012.13 (for testing drying shrinkage).

The specimens required for the determination of drying shrinkage are prisms 75 × 75 × 285 mm with gauge studs set in either end (see **Figure 26.13**). The drying shrinkage of the specimen over time is determined by measuring the change in distance between the gauge studs after initial wet curing is complete and the specimens are placed in a standard drying environment (23ºC and 50% relative humidity – similar to that in the interior of an air-conditioned office). Since drying shrinkage is susceptible to the initial curing of the specimens, particularly once they have been demoulded, it is essential that their curing is maintained in accordance with the testing Standard.

Figure 26.13 – Three Drying Shrinkage Specimens Cast in a Mould

4.7 CREEP TESTING

Limits on the creep of concrete may also be specified by designers in an attempt to limit both short- and long-term movements in buildings and other structures.

Whilst most creep specimens are prepared in the laboratory, they can be prepared in the field.

Methods for the determination of concrete creep are set out in AS 1012.16. The test is conducted on standard cylinders prepared in accordance with AS 1012.8.1. After a specified preliminary curing period a constant load is applied to the cylinders, which are stored in a controlled drying environment that is similar to that used in the drying shrinkage test. The change in their length with time is compared with that of companion cylinders which are unloaded (and subject to drying shrinkage). Both sets of specimens shrink. Hence, the difference between the two movements gives an estimate of the extent of creep in the loaded specimens (see **Figure 26.14**).

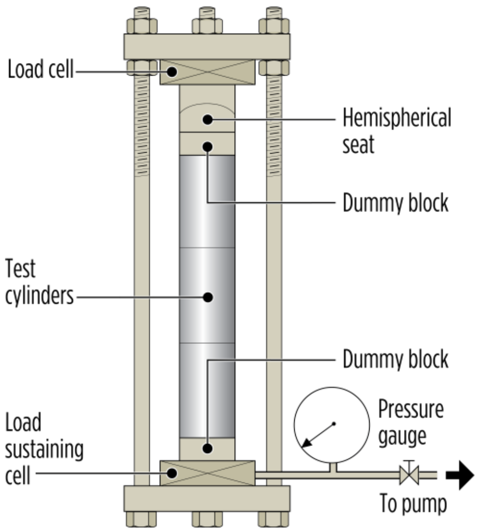

Figure 26.14 – A Typical Arrangement for Loading and Testing the Creep of Concrete Specimens

4.8 OTHER HARDENED CONCRETE TESTS

A number of other tests may be carried out on hardened concrete. These include the determination of its density (mass per unit volume) as a measure of its compaction, and the static-chord modulus of elasticity and Poisson's ratio (see **Figure 26.15**). All these tests are based on the use of standard compression test cylinders, although the Standard does provide a method for determining the density of irregularly shaped specimens.

Figure 26.15 – Test Rig for Modulus of Elasticity

A chemical test, introduced in recent years to provide for requirements given in AS 3600 and AS 1379, is covered in AS 1012.20.1. Where aggregates contain chloride ions that are 'locked up' inside minerals that are part of the aggregate matrix then it is also useful to assess the water-soluble chloride of these aggregates using the method of AS 1012.20.2. This is intended to provide a method to demonstrate compliance with the requirements of AS 3600.

The requirements for the maximum chloride and sulfate content of hardened normal class concrete are detailed in AS 1379. The limits are:

- Sulfate: <50 gm per kilogram of cement;
- Chloride: <0.80 kg/m^3.

In order to calculate these values, the tested mix needs to have a known cement content (kg/m^3) and a tested mass per unit volume (see sub-section 3.6).

As mentioned earlier in this section, concrete may also be tested in-situ by means of a number of non-destructive tests. These range from the Schmidt rebound hammer (a device which measures the surface hardness of concrete and thereby provides an estimate of its strength), to ultrasonic pulse velocity tests (which measure the time taken for an ultrasonic pulse to travel a measured distance through the concrete). An estimate of the strength of the concrete can be obtained given some knowledge of its constituent materials, their proportions and the moisture content of the concrete at the time of test.

Other tests are available to estimate the position of reinforcement in concrete and its potential to corrode.

In general, non-destructive tests are seldom used to ensure compliance with a specification. Nevertheless, they can be useful on occasions to provide information on the behaviour of the member and/or its condition. Further information can be obtained from various sources.

5 QUALITY ASSURANCE OF CONCRETE

5.1 GENERAL

The terms Quality Assurance (QA) and Quality Control (QC) are frequently confused as the activities do overlap. Quality Control is more about inspection and testing of a product. Quality Assurance is more about proving to the customer that adequate systems and processes are in place to ensure a product is fit for purpose, with consistent and predictable properties.

Quality Assurance may be defined as:

All those planned and systematic actions necessary to provide adequate confidence that the customer is supplied a quality product or service.

Quality Control may be defined as:

The operational techniques and activities which achieve and sustain a quality of goods or services that will satisfy a given requirement.

The majority of companies producing concrete have a certified Quality Assurance (QA) system in place and have organised appropriate staff training in that system. As a result, this section will not explore aspects of QA in detail, but will concentrate more on the quality control aspects and briefly touch on the statistical concepts that are used as part of the control of concrete supply in accordance with AS 1379.

5.2 CONCRETE QUALITY CONTROL

Concrete suppliers will typically have two systems used for QA. The general QA system that applies to the majority of supplied concrete that is largely targeted at compliance with the two key Standards, AS 3600 and AS 1379. Contained under the suppliers general Quality Assurance system there may also be 'Quality Plans' that are typically specific plans with details of procedural variations for specific customers or projects. This section will be focused on quality control for the more general QA system.

AS 3600 largely re-directs to AS 1379 for quality control of concrete. AS 1379 provides requirements that must be met for:

- Control of concrete ingredient quality;
- Process control;
- Product acceptance control.

Each of the normal ingredients are controlled through their individual standards such as cementitious material quality standards (AS 3972, AS 3582 Parts 1 to 3), aggregate quality standard (AS 2758.1), admixtures/additives quality standard (AS 1478.1) and mixing water impurities control (AS 1379). (Refer also to this Guide, Part II, Sections 1 to 5).

The requirements for process control are set out in AS 1379 and include – calibration of batching equipment, batching accuracy, uniformity of mixing and delivery time control.

Acceptance control measures are set out in AS 1379 and include plastic concrete properties (slump, air content, workability, temperature, yields etc.), hardened concrete properties (compressive strengths, acid-soluble chloride content, sulfate content, drying shrinkage etc.).

If the control of concrete ingredient quality and the process controls are functioning effectively then action on acceptance control measures should be minimal. This is critical in the case of hardened concrete properties where some testing may not provide results for more than 28 days. Plastic property acceptance control can generally be acted on more immediately (e.g. concrete mix adjustment for unacceptable slump or air content variations).

5.3 STATISTICAL CONTROL MEASURES

Batches of a particular concrete mix are not identical due to variations in testing, the concrete ingredients and the amounts of ingredients measured into a batch. There are inherent variations in any manufacturing operation that must be recognised. Testing variations add to this and for testing, consideration must be given to both equipment and operator variations.

Therefore, it is understood that the results of concrete testing will vary, and the aim of good quality control is to minimise this variation. Analysis of the results statistically assists this process.

Statistical analysis forms the basis of the assessment of the acceptance of concrete compressive strength sample test results to the Australian Standards. Statistical analysis is characterised by two factors:

- Average compressive strength of samples being assessed;
- Standard Deviation of the strength of samples being assessed.

For example, the average (or mean) strength of 15 samples is simply the sum of all the strengths divided by 15. The Standard Deviation is a measure of the variation of the sample strengths from the average strength using a statistical formula provided in AS 1379 and based on formulae derived from use of the 'Normal Distribution'. A larger variability in test results will produce a higher standard deviation.

When carrying out statistical analysis on test data that varies randomly around an average value, it is common to use the principal and formulae associated with the 'Normal Distribution' to estimate the acceptance of that data compared to a minimum or maximum limit. For example, where a large population of tests distributed around an average test result are plotted by graphing the number of tests with equal strength against the strength value, then a plot similar to that shown in **Figure 26.16** is obtained.

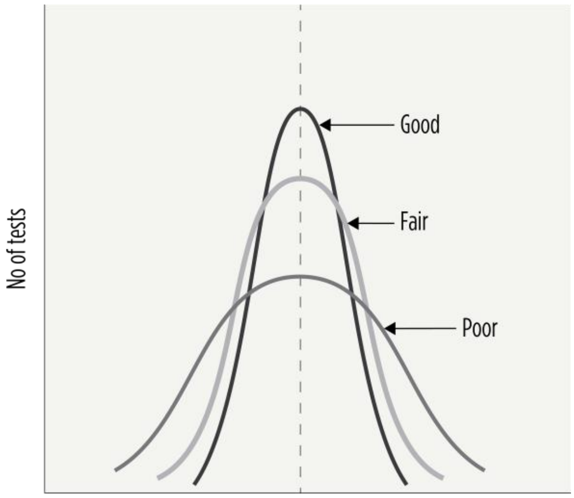

Figure 26.16 – Normal Distribution Related to QC

In **Figure 26.16** the graphs of three different Normal Distributions of test data are shown. The three distributions represent a 'good' (tight distribution around the mean) level of control, a 'fair' (moderate distribution around the mean) level of control and a 'poor' (wide distribution around the mean) level of control. Each of the three curves show a similar trend in that the frequency of occurrence of the same test results falls away as the test value is further away from the average (mean) value (i.e. the vertical line in the middle). The higher proportion of all test data is also closer to the average value in the case of 'good control' than it is for 'poor control'.

The structural designer is unlikely to be interested in the mean strength of concrete, as it is the characteristic strength (f'_c) that is of importance for design. Designers want some assurance that their concrete will not fail and that no more than 5% of compressive strength test results will be below f'_c.

To verify that concrete of a given grade strength meets the requirements of AS 1379, the average compressive strength (F_{cm}) of a set of random samples of the concrete mix must be in excess of that required to achieve a specified characteristic strength – as defined in AS 1379. There is a complex relationship between the number of samples being assessed for a controlled strength grade (see sub-section 5.4), the estimated standard deviation of the sample strengths and the average of the sample strengths. This relationship is defined in AS 1379 and detailed further in the AS 1379 commentary – Supplement 1.

In simple terms the relationship is defined in the following equation:

$$F_{cm} \geq f'_c + k_c \times S \qquad \text{.....}\mathbf{Eq.26.1}$$

Where:

f'_c = Characteristic compressive strength;
F_{cm} = The minimum average compressive strength of the sample;
k_c = The statistical constant (Assessment Factor) based on the number of test samples being assessed for the controlled grade test samples;
S = The standard deviation of the controlled grade sample being assessed.

From **Eq.26.1** it can be seen that a 'target' average strength for a concrete mix can be set by a supplier to ensure that random sets of compressive strength tests can be assessed as complying. This 'target' strength will be higher than the characteristic compressive strength for the grade. It can also be seen that a higher standard deviation will lead to a higher value for the minimum average strength and to a higher 'target' strength.

The values of k_c for differing numbers of controlled strength grade test samples are provided in **Table 26.1**.

The 'Target' compressive strength for a concrete mix is of more interest to the concrete supplier or mix designer. In applying quality control measures to concrete compressive strength at 28 days (or other age) the variation between the average strength of concrete over time is compared to the target strength to assess trends in the mix. The target strength is always greater than the minimum average compressive strength but assumes that 15 or more tests are being assessed for the controlled grade (see sub-section 5.4).

The minimum 'target' compressive strength of a concrete mix is generally based on the following equation:

$$F_{ct} \geq f'_c + 1.65 \times S \qquad \text{.....}\mathbf{Eq.26.2}$$

Where:

f'_c = Characteristic compressive strength;
F_{ct} = The minimum target compressive strength of the sample;
S = The standard deviation of the controlled grade sample being assessed.

Table 26.1 – AS 1379 Assessment Factors for Different Numbers of Test Samples in a Controlled Grade

ASSESSMENT FACTOR k_c	
No. of test samples in controlled grade	**Factor k_c**
4 or less	3.2
5	2.5
6	2.1
7	1.9
8	1.7
9	1.5
10	1.5
11	1.4
12	1.4
13	1.3
14	1.3
15 or more	1.25

The value of '1.65' in **Eq.26.2** is derived from the normal distribution statistical formulae and approximates a value of F_{ct} where 95% of test data in a large population of tests will exceed f'_c.

If less than 15 tests are used to assess the controlled grade average strength and standard deviation, then the target strength of the mix will need to be increased to account for the uncertainty in standard deviation and average strength.

In summary, **Eq.26.1** is used for assessment of concrete compressive strength test data for acceptance and **Eq.26.2** is used by the supplier for setting the target strength for the compressive strength of each mix.

5.4 PRODUCTION ASSESSMENT OF CONCRETE

In AS 1379 there is recognition that a concrete supplier needs to be able to evaluate all strength grade concrete mixes supplied for compliance of compressive strength. Unfortunately, in any production interval, it is likely that very low volumes of some mixes may be produced and so very few test samples can be taken. In order to reduce the impact of this on the consistency of target strengths and mix design more generally, as well as better utilising the test data that is available, several concepts are built into AS 1379 production assessment requirements:

- Controlled grades and Associated grades;
- Grouping of supply plant test data;
- Estimation of Standard Deviation for associated grades;
- Minimum test frequency.

Controlled Grades

Where two or more mixes in a concrete plant or a grouped concrete plant have the same strength grade and are sufficiently similar in terms of ingredient sources, then the test data can be grouped together to calculate the average strength and standard deviation of what is referred to as the 'controlled grade' for a concrete plant or group of plants. The mix selection for this grouping will typically be the most commonly supplied or tested grades for the plant or group of plants. Assessment of controlled grade is made using **Eq.26.2** with S being equal to the controlled grade calculated standard deviation (S_c).

Grouping of Concrete Plants Test Data

Where two or more concrete plants use the same or very similar concrete mix ingredients and are subject to the same quality control procedures then it is possible to combine the data of mixes of the same strength grade to calculate the controlled strength grade standard deviation and various strength grade average strengths. This grouping is allowed provided each supply plant in the group provides a minimum of five test samples for each grade.

Associated Grades

All strength grade mixes in a concrete plant or group of concrete plants, other than the Controlled Grade, become what is referred to in AS 1379 as Associated Grades. The assessment of associated grades is carried out using a standard deviation that is derived from the plant or grouped plants-controlled grade standard deviation using the following equations:

$$F_{cm} \geq f'_c + k_c \times S_a \qquad \text{.....}\textbf{Eq.26.3}$$

$$S_a = R_f\,(\text{Associated grade}) \times S_c \,/\, R_f\,(\text{Controlled grade}) \qquad \text{.....}\textbf{Eq.26.4}$$

Where:

f'_c = Characteristic compressive strength;

F_{cm} = The minimum average compressive strength of the sample;

k_c = The statistical constant (Assessment Factor) based on the number of test samples being assessed for the controlled grade test samples;

S_a = The standard deviation of the associated grade sample being assessed;

S_c = The standard deviation of the controlled grade sample being assessed;

R_f = The 'Relative Factor' derived from AS 1379 and as shown in **Table 26.2** in this section with the R value for the Associated grade strength being divided by the R value for the Controlled strength grade.

Table 26.2 – Relative Factor for Calculation of the Associated Grade Standard Deviation

RELATIVE FACTOR R_f	
Strength Grade (MPa)	**Factor R_f**
20	1.0
25	1.1
32	1.2
40	1.3
50	1.4

Minimum Testing Frequency

AS 1379 requires that production control testing of concrete compressive strength is carried out at a frequency greater than 1 test per 100 m^3 of each strength grade concrete produced over the production interval.

Production Interval

The production interval is the maximum period of time over which a supply plant test results can be assessed. AS 1379 indicates the production interval should be within a range of two weeks to three months and such that at least 10 samples from a plant or group of plants are available in that interval. For plants with production <1,000 m^3 per three months the production interval used may be three months and the assessment based on the number of samples available in that interval.

Where there has been a considerable change in the mix designs or plant performance or upgrade, the supplier needs to start a new production interval from that date.

5.5 PROJECT ASSESSMENT OF CONCRETE

In AS 1379 it is also recognised that a project site owner, specifier, builder or contractor may wish to assess the concrete supplied specifically to that project site. In this case an underlying assumption of AS 1379 is that all strength grade concrete supplied to the site is subject to production assessment of concrete (even though it may not have been sampled on that site).

In this case there are three simple steps for assessment of compliance of project assessment of samples for each strength grade of concrete supplied during the project construction:

- Concrete is tested at a frequency of at least one test per 50 m^3 of each strength grade of concrete;
- For each mix or strength grade of concrete, the average 28-day strength of any three consecutive test samples of concrete is equal to or greater than the characteristic strength of the concrete specified;
- If less than three test samples are available, then each test sample strength is greater than $0.85f'_c$. Where test sample strengths are between $0.85f'_c$ and f'_c the supplier should be contacted for Production Assessment information to ensure that the concrete supplied was assessed as conforming during that period of supply and that there are no reasons for results below f'_c other than random variations.

5.6 CONCRETE SUPPLIER MIX STRENGTH CONTROL

The concrete supplier will normally set up a system of early warnings based on predicted and actual 28-day compressive strength for groups of mixes that are similar and have the same target strength.

Often 1-day (accelerated curing), 3-day or 7-day strengths are used to predict trends in strength grade of these mixes.

Charting of strength results often includes predicted 28-day strength and actual 28-day strength. It gives a visual comparison of the accuracy of the formulae used for prediction as well as overall statistical compliance.

Individual test results are of little value in this process and it is common practice to use systems such as 'Shewhart Charts' or 'Cusum charts' to check that running averages of 5, 10 or 15 data points remain within acceptable ranges of the target strength. Both systems can be set up electronically to verify test data compliance within acceptable limits. A characteristic of Shewhart charts is that running averages of test sample strength can be compared against the target strength as well as a statistically based upper control limit and lower control limit. The control limits vary depending on the number of tests assessed in determining the average value. Programming of the supplier's system can notify the supplier when action is required on the mix design to re-align the mix strength to target (See **Figure 26.17**).

Details of the setup of Shewhart Charts and Cusum charts can be found in AS/NZS 3944 and AS 3940.

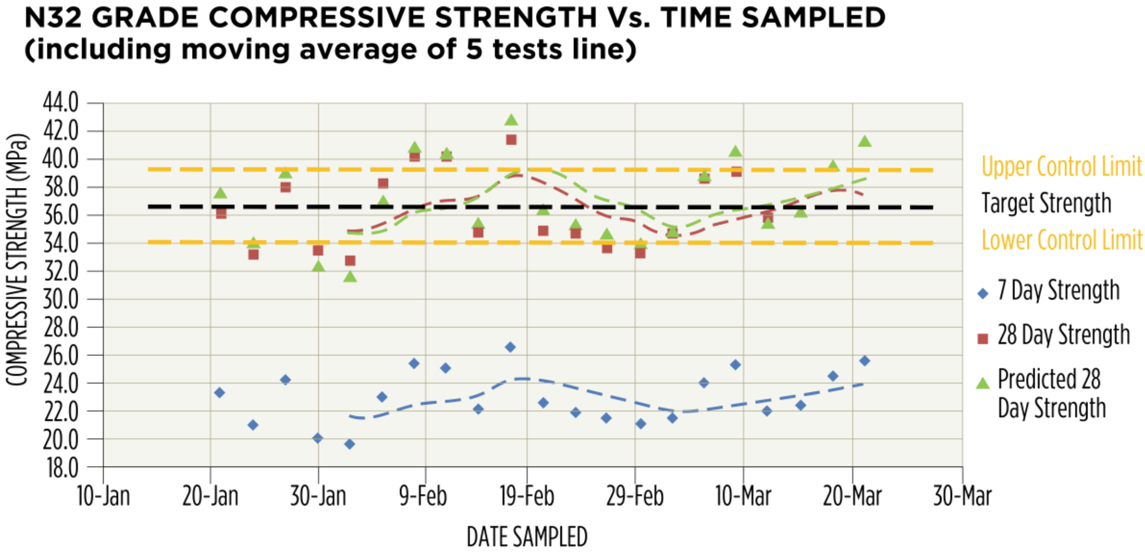

Figure 26.17 – Example of Shewhart Chart Analysis of N32 Grade Mix Test Data

6 QUALITY CONTROL OF TESTING OTHER THAN COMPRESSIVE STRENGTH

6.1 GENERAL

Any testing of concrete for plastic or hardened properties can be part of the quality control program of the concrete supplier. Such tests can include any of those discussed in this section, however AS 1379 refers to the following tests as having defined requirements:

- Slump Test;
- Mass per unit volume;
- Concrete compressive strength (7-day and 28-day);
- Indirect tensile strength;
- Modulus of rupture (Flexural tensile strength test);
- Air content;
- Sulfate and chloride content of concrete;
- Drying Shrinkage.

As noted, there are numerous other tests used to assess properties of concrete including many tests for durability of hardened concrete. The tests other than those specified in AS 1379 should be clearly specified by a designer and include a means of assessing the test results and any additional quality control requirements (such as control of W/C ratio during supply). The supplier will need to provide a quality plan to demonstrate the method of quality control proposed.

AS 3600 and AS 1379 assume a relationship between concrete strength and reinforcement cover in providing adequate durability of the concrete structure in a particular environment and so control of compressive strength is critical for durability performance under these standards.

The following sub sections discuss the specification of each test method provided in AS 1379.

Slump Test Specification

AS 1379 requires 'normal class' concrete to be specified by a 'target slump' or 'specified slump' between 20 mm and 120 mm (in 10 mm increments) as delivered to the customer's site. Slumps outside of this range may be specified but will then cause the concrete mix to be 'special class'.

The acceptable deviation in measured slump and target slump depends on the value of the target slump and the requirements of AS 1379 are shown in **Table 26.3**.

Table 26.3 – Permissible Tolerance on Slump for Ranges of Target or Specified Slump (as per AS 1379)

PERMISSIBLE TOLERANCE ON SLUMP	
Specified Slump, mm	**Tolerance, mm**
<60	±10
≥60 to ≤80	±15
>80 to ≤110	±20
>110 to ≤150	±30
>150	±40

A slump test measurement on site indicating an out-of-tolerance slump may lead to the rejection of the concrete unless re-testing or adjustment to the batch (addition of admixture or water within approved limits) produces a complying slump. Additions of water must be within agreed limits based on the supplier's quality control system and as allowed by the project specification.

Mass per Unit Volume Specification

The mass per unit volume test is called up in AS 1379 in several areas:

- The definition of normal class concrete;
- The assessment of the volume of concrete supplied;
- The mixer uniformity test.

The mass per unit volume of normal class concrete must be assessed and remain within a range of 2,100 kg/m^3 and 2,800 kg/m^3. Concrete with a mass per unit volume exceeding this range will automatically become special class dense weight concrete. Concrete with a mass per unit volume lower than 2,100 kg/ m^3 will be special class light-weight concrete.

The volume of plastic concrete delivered must be as per the supplier's certificate (docket or ticket with each delivered batch). AS 1379 requires that the combined total mass of all ingredients that are contained in a batch of concrete, divided by the supplier's certificate volume, must be more than 98% of the average mass per unit volume of the concrete mix measured using the mass per unit volume of three samples of the same concrete mix. The value of this calculation is often referred to as the 'yield' of the concrete mix. Concrete suppliers are required to carefully monitor yield to ensure compliance with AS 1379. Non-conforming yields are simply remedied by proportionately increasing or decreasing all of the ingredients in an otherwise acceptable mix design.

AS 1379 provides a measure of the performance of a concrete mixer following a standard mixing cycle by comparing two samples of concrete during discharge from the mixer (ideally in the first 10% and last 10% of a discharge stream). A number of factors are assessed including slump, air content, coarse aggregate content and plastic concrete mass per unit volume. The acceptable range in mass per unit volume between the two samples is 'not greater than 50 kg/m^3.

Compressive Strength at 7-Days

The assessment of 28-day strength of concrete has been covered in clause 5 of this section. AS 1379 does have requirements for minimum strength at 7 days as well as requirements for compressive strength compliance at 28 days.

The early strength requirements of AS 1379 were introduced to ensure that minimum early strength was achieved for a given characteristic 28-day strength so as to support minimum curing and stripping requirements of AS 3600. In previous standards the alternative method used was to limit the use of SCM's as they have an impact on early strength growth.

The requirements of AS 1379 are based on a limit to the average (or 'mean') 7-day compressive strength of a normal class strength grade. These limits are repeated in **Table 26.4**. This approach allowed concrete producers to better optimise the use of SCM's in their mix design.

Table 26.4 – Minimum Average 7-Day Strength for f'_c Required by AS 1379

MINIMUM MEAN 7-DAY COMPRESSIVE STRENGTH FOR NORMAL CLASS CONCRETE	
Grade Designation	**Mean 7-day strength (MPa)**
N20	9
N25	12
N32	16
N40	20
N50	25

Flexural and Indirect Tensile Strength

The assessment of both of the tensile strength tests are discussed in AS 1379. The recommended method in the Standard is to carry out an assessment of the tensile and compressive strengths on a range of concrete compressive strength mixes to capture the specified characteristic tensile strength of the required concrete. At least three different mixes using the same types of binder, coarse aggregate, sand and admixtures as proposed to be supplied in the final concrete mix are required for this test program. A 'best fit' relationship is determined between the tensile strength and compressive strength from this testing. From this relationship an equivalent 'characteristic' compressive strength for the specified characteristic tensile strength is estimated. Using this method allows for the compressive strength to be monitored on the mix so as to assure that the specific tensile strength has been achieved.

For example, the relationship between average compressive strength (f_{cm}) and average flexural tensile strength (f_{tm}) has been determined from tests on a set of materials to be as shown in **Eq.26.5**:

$$(f_{tm}) = 0.665 \times (f_{cm})^{0.5} \qquad \text{.....Eq.26.5}$$

If the specified characteristic flexural strength was specified as 4.0 MPa, then the equivalent characteristic compressive strength can be calculated as 36.2 MPa from **Eq.26.5**.

Alternative methods of assessing the compliance of a set of tensile strength testing data need to be carefully considered as determining the correct balance between supplier and consumer risk need to be taken account of and tensile strength testing is notoriously imprecise. (The typical coefficient of variation for tensile strength testing ranges from 50% to 100% greater than for compressive strength testing, and pair differences can be as high as 15-20% of the average tensile strength with no obvious reason for the difference. For compressive strength testing, pair differences are typically less than 5-10% of the average strength).

Air Content of Concrete

The air content of normal class concrete is required to have air content less than 5.0%. When air content is specified the concrete mix is automatically a special class. The measured value of air content must be within ±1.5% of the specified value.

In cases where an entrained air content of the concrete is critical (e.g. slip-form concrete) it is not abnormal for a specifier to limit the air content variation from the target value to ±1.0%.

Air content of concrete is significantly impacted by ultra-fines in the concrete mix and particularly some organic materials in sand, active carbon in fly ash or silica fume and some clays present in aggregates (coarse and fine). Ensuring a high level of control on mix air content requires careful selection, monitoring and control of mix ingredients.

Correction to air content of a batch of concrete on site may be possible by increasing air entraining agent dose rate to increase air content or using an air de-training admixture to decrease excessive air content (e.g. tri butyl phosphate or similar but note that material safety issues and safe handling requirements are critical for this chemical). Where air content of a concrete mix is critical the testing frequency may need to increase until stable air content is achieved. AS 1379 recommends a test frequency of at least 1 test per 100 m^3 but in some cases testing may need to be more frequent, particularly in the first batches supplied to a site.

Sulfate and Chloride Content of Concrete

AS 1379 and AS 3600 set limits on the maximum chloride and sulfate content of concrete. Testing of hardened concrete is generally carried out to AS 1012.20.1 or AS 1012.20.2 (see sub-section 4.8).

AS 1379 requires the concrete supplier to assess the sulfate and chloride content of concrete on the controlled grade concrete mix in a supply plant at least once every six months.

Drying Shrinkage of Concrete

AS 1379 requires that testing drying shrinkage at 56 days is carried out on the controlled grade concrete mix in a supply plant at least once every six months. The maximum individual test sample drying shrinkage at 56 days is 1,000 microstrain. In order to guarantee this the average or target drying shrinkage will need to be much less than 1,000 microstrain.

AS 3600 predicts that the average drying shrinkage value at 56 days (when tested to AS 1012.13) will range from 750 microstrain to 800 microstrain depending on the strength grade. These values are not out of step with those of AS 1379 as the standard deviation of drying shrinkage testing at 56 days may range from 80 microstrain to 150 microstrain. In view of this a maximum individual test sample having a probability of exceeding 1,000 microstrain at 56-day drying is less than 5%.

More information on drying shrinkage is provided in Part VIII, Section 25 of this Guide.

7. REFERENCES

1) AS 3600 – *Concrete structures*
2) AS 1379 – *Specification and supply of concrete*
3) AS 1012, Parts 1 to 20 – *Methods of testing concrete*:
   - Part 1 – *Sampling of concrete*
   - Part 3.1 – *Slump test*
   - Part 3.2 – *Compacting factor test*
   - Part 3.3 – *Vebe test*
   - Part 4.1 – *Determination of air content of freshly mixed concrete – Measuring reduction in concrete volume with increased air pressure*
   - Part 4.2 – *Determination of air content of freshly mixed concrete – Measuring reduction in air pressure in chamber above concrete*
   - Part 4.3 – *Determination of air content of freshly mixed concrete – Measuring air volume when concrete dispersed in water*
   - Part 5 – *Method for the determination of mass per unit volume of freshly mixed concrete*
   - Part 6 – *Method for the determination of bleeding of concrete*
   - Part 8.1 – *Method for making and curing concrete – Compression and indirect tensile test specimens*
   - Part 8.2 – *Method for making and curing concrete – Flexure test specimens in the laboratory or in the field*
   - Part 8.4 – *Drying shrinkage specimens prepared in the field or in the laboratory*

- Part 9 – *Compressive strength tests – Concrete, mortar and grout specimens*
- Part 10 – *Determination of indirect tensile strength of concrete cylinders*
- Part 11 – *Determination of the modulus of rupture*
- Part 13 – *Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory*
- Part 16 – *Determination of creep of concrete cylinders in compression*
- Part 20.1 – *Determination of chloride and sulfate in hardened concrete and aggregates – Nitric acid extraction method*
- Part 20.2 – *Determination of water-soluble chloride in aggregates and hardened concrete*

4) AS 1478.1 – *Chemical admixtures for concrete, mortar and grout – Admixtures for concrete*
5) AS 3972 – *General purpose and blended cements*
6) AS 3582, Parts 1 to 3 – *Supplementary cementitious materials for use with Portland and blended cement*
7) AS 2758.1 – *Aggregates and rock for engineering purposes – Concrete aggregate*
8) AS/NZS 3944 – *Shewhart control charts*
9) AS 3940 – *Quality control – Guide to the use of control chart methods including Cusum techniques*

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