PART A

Chapter 5

Properties

This chapter describes the typical properties of concrete masonry units.

Contents

5.1 INTRODUCTION

QUALITY CONTROL AND QUALITY ASSURANCE

In concrete masonry manufacture, the selection of raw materials and the design and proportioning of mixes are equally as important as for structural concrete.

For the finished concrete masonry to possess the required properties of strength, density, resistance to water penetration, colour, texture, acoustics, thermal insulation and fire resistance, the concrete masonry units must have consistent mix proportions and aggregate grading. Proper curing conditions and techniques play a vital part in product properties.

Good control of curing methods and raw materials grading, quality and proportioning ensure that variations in the finished product are kept within acceptable limits. Automatically controlled proportioning, mixing, moulding and handling equipment and curing controls eliminate human error from these processes.

Most concrete masonry manufacturers adopt sound management techniques and some have quality systems complying with AS/NZS ISO 9001[Ref 1], which set out internationally-recognised quality assurance requirements.

AUSTRALIAN STANDARDS

The use of concrete masonry in buildings is governed by the National Construction Code (NCC) – National Building Code of Australia[Ref 2] (BCA), which is adopted into legislation in each of the state Building Regulations. NCC–BCA in turn calls up AS 3700[Ref 3], which sets out rules governing the use of unreinforced, reinforced and prestressed masonry.

The NCC–BCA Volume Two also calls up AS 4773.1 and AS 4773.2 for masonry in small buildings (design and construction respectively).

From the perspective of a structural designer, it is particularly useful that AS 3700 has combined design rules for both reinforced, unreinforced masonry into a single document.

Concrete masonry units must comply with AS/NZS 4455.1[Ref 4]. This standard combines the requirements for all masonry units of concrete, clay, calcium silicate and stone, together with the requirements for paving units of these materials.

The tests relevant to masonry units and pavers are specified in AS/NZS 4456[Ref 5]. This standard consists of eighteen parts, but only some of the parts are applicable to concrete masonry wall units and only a few are relevant for commonly-available products. The testing standards that are relevant to the supply of concrete masonry walling units to most projects are as follows.

Designers are required to specify the dimensional tolerances, compressive strength and resistance to salt attack using the following standards:

AS/NZS 4456.3	*Determining dimensions*
AS/NZS 4456.4	*Determining compressive strength of masonry units*
AS/NZS 4456.10	*Determining resistance to salt attack*

For face masonry, which does not have an applied finish, designers may also wish to specify limits for efflorescence potential and permeability to water using the following standards:

AS/NZS 4456.6	*Determining potential to effloresce*
AS/NZS 4456.16	*Determining permeability to water*

The following standards are also available for use by manufacturers and in abnormal circumstances (such as research or product development), and should not be routinely called up by specifiers or designers.

AS/NZS 4456.1	*Sampling for compliance testing*
AS/NZS 4456.2	*Assessment of mean and standard deviation*
AS/NZS 4456.7	*Determining core percentage and material thickness*
AS/NZS 4456.8	*Determining moisture content and dry density*
AS/NZS 4456.12	*Determining coefficients of contraction*
AS/NZS 4456.14	*Determining water absorption properties*
AS/NZS 4456.15	*Determining lateral modulus of rupture*
AS/NZS 4456.17	*Determining initial rate of absorption (suction)*

5.2 PROPERTIES

DIMENSIONS AND TOLERANCES

The work sizes of a masonry unit are the principal dimensions from which any deviations are measured and are nominated by the manufacturer. For example, overall lengths, heights and widths of prismatic units are work sizes. So too are the principal dimensions of the cores and face shell in hollow units, since they influence strength and weight.

AS/NZS 4455 Clause 2.1 requires manufacturers to make available the work sizes, face shell width of hollow units and the characteristic unconfined compressive strength (f'_{uc}), discussed in detail below.

AS/NZS 4456.3 provides two methods of determining dimensions, one based on averaging the dimensions over 20 units and the other based on measuring the dimensions of individual units.

AS/NZS 4455 Table 2.1 sets out dimensional deviation categories from DW0 (no requirements) to DW4 (the tightest requirements) for masonry wall units. It requires that, unless specified and agreed otherwise, masonry wall units (including concrete units) should comply with category DW1.

Category DW1 requires that, when 20 walling units are placed in a line (end to end or side to side) the cumulative dimension should not deviate from 20 times the particular work size (the dimension being checked) by the following limits. The corresponding average tolerance per unit based on 20 units is also tabulated.

Work size	AS/NZS 4455, permissible DW1 deviation	Corresponding average/unit deviation
Under 150 mm	± 50 mm	± 2.5 mm
150 to 250 mm	± 90 mm	± 4.5 mm
Over 250 mm	± 100 mm	± 5.0 mm

Thus, dimensional deviation category DW1 permits the average length of units to be outside specification by up to ± 5 mm, with no controls on the lengths of individual units at all.

Because of the method of manufacture, concrete masonry units can be manufactured to much tighter tolerances than other masonry units and they generally meet category DW4. Category DW4 requires not only the average dimension of units to be within ± 3 mm of the work size, but also that the dimensions of individual units be controlled by requiring that the standard deviation of dimensions be not more than 2 mm. This limits the potential for big variations in the size of concrete masonry units, which is common for other types of masonry units.

SHELL THICKNESS AND WEB THICKNESS OF HOLLOW BLOCKS

Minimum thicknesses of face end shells and webs of hollow concrete blocks can be calculated from AS/NZS 4455, which states:

Masonry units and segmental pavers shall be able to be handled, transported to the purchaser and laid.

NOTE: Integrity does not include aesthetic characteristics of masonry or paving units.

For hollow masonry units, this requirement is deemed to be satisfied if the characteristic unconfined strength is at least 3 MPa for cored units and 2.5 MPa for solid units …

… For solid and cored masonry units, this requirement is deemed to be satisfied if the average measurements of each part of five random-sampled units (measured at the same positions on each unit) are not less than the values given in Table 2.4-

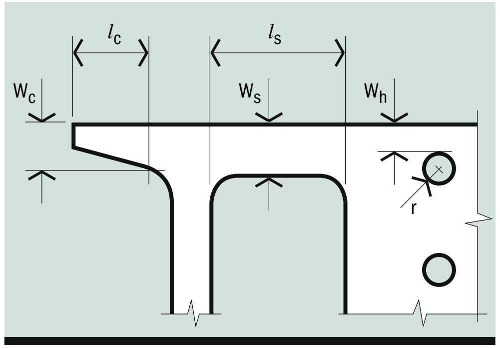

Figure 5.1 *Proportions of Units*
[Based on AS/NZS 4455 Figure 2.1]

Table 5.1 *Minimum Average Width of Section of Hollow Units*
[Based on AS/NZS 4455 Table 2.4]

Identification of section	Minimum average width of section, W, for characteristic unconfined compressive strength of: under 10 MPa	10 MPa or over
Width of section supported at one end only (W_c)	0.3 l_c	0.2 l_c
Width of sections supported at both ends (W_s)	0.15 l_s	0.1 l_s
Edge distance of core holes (W_h)	0.3 r	0.2 r

NOTE: Symbols in the above table are defined in Figure 5.1, above

The most commonly applied minimum face-shell dimensions and web dimensions for hollow concrete blocks, complying with AS/NZS 4455 Table 2.4, are given in **Table 5.2**.

Table 5.2 *Typical Face-shell and Web Dimensions for Hollow Concrete Blocks, Complying with AS/NZS 4455, Table 2.4*

Hollow block width (mm)	**Minimum face shell thickness** (mm)	**Minimum thickness of any web** (mm)	**Minimum total web thickness per course in any 200 mm length** (mm)
90 or less	25	25	25
over 90 to 140	25	25	30
over 140 to 190	30	25	30
over 190	35	30	38

These minimums apply for structural reasons. They are frequently exceeded for production purposes, or where acoustics or fire resistance requirements govern. When dimensions or mass of units are critical, information should be obtained from the manufacturer.

CORE PERCENTAGES AND MATERIAL THICKNESS

The core percentage of cored units and the material thickness of hollow units are required when determining a masonry wall's fire resistance level for insulation.

The material thickness of units with a core percentage of greater than 30% is the net volume of material in a unit, divided by its face area. In other words, it is the volume of material compressed solid without cores.

The material thickness of units with a core percentage of less than 30% is the gross volume of the unit (neglecting any cores) divided by its face area. This is numerically equal to the external thickness of the unit.

Testing for core percentage and material thickness does not need to be carried out as part of routine quality control. If a test is required, it should be carried out in accordance with AS/NZS 4456.7.

MASS AND DENSITY

The mass of masonry units depends on:

- the external dimensions;
- the core dimensions, and hence the material thickness (effective thickness if all cores were compressed); and
- the density of the material.

The external dimensions are dictated by structural considerations and the economics of manufacture and construction.

The core dimensions are commonly dictated by fire and sound requirements and, if required, the ability to include grout and reinforcement.

Dense-weight concrete masonry units have a density of approximately 2100 to 2250 kg/m³. Units for fire resistance, thermal performance or lightweight concrete masonry units are often produced down to 1600 kg/m³. These densities are the 'stockyard' densities (ie the weight of units as sampled divided by their net volume) and are the sum of the dry density and the ambient moisture content. AS/NZS 4456.8 provides the test method for determining these parameters.

Table 5.3 gives the mass of various masonry units.

Table 5.3 *Mass of Various Masonry Blocks*

Length of unit (mm)	Height of unit (mm)	Width of unit (mm)	Percentage solid[1] (%)	Material thickness (mm)	Mass of unit, (kg), based on density[2] of 2180 (kg/m³)	2000 (kg/m³)	1800 (kg/m³)	1600 (kg/m³)
390	190	90	70	90	10.2	9.3	8.4	7.4
		110	100	110	17.8	16.3	14.7	13.0
		140	55	77	12.4	11.4	10.3	9.1
		190	51	97	15.7	14.4	12.9	11.5
390	140	90	70	90	7.5	6.9	6.2	5.5
		110	100	110	13.1	12.0	10.8	9.6
		140	55	77	9.2	8.4	7.6	6.7
		190	51	97	11.5	10.6	9.5	8.5
390	90	90	70	90	4.7	4.3	3.9	3.4
		110	100	110	8.4	7.7	6.9	6.2
		140	55	77	5.9	5.4	4.9	4.3
		190	51	97	7.4	6.8	6.1	5.4
290	162	90	70	90	6.5	6.0	5.4	4.8
		110	100	110	11.3	10.3	9.3	8.3
		140	55	77	7.9	7.2	6.5	5.8
		190	51	97	9.9	9.1	8.2	7.3
290	119	90	70	90	4.8	4.4	4.0	3.6
		110	100	110	8.3	7.6	6.8	6.1
		140	55	77	5.8	5.3	4.8	4.3
		190	51	97	7.3	6.7	6.0	5.4
290	90	90	70	90	3.7	3.4	3.1	2.8
		110	100	110	6.3	5.7	5.2	4.6
		140	55	77	4.4	4.0	3.6	3.2
		190	51	97	5.5	5.1	4.6	4.0
290	76	90	70	90	3.1	2.9	2.6	2.4
		110	100	110	5.3	4.8	4.4	3.9
		140	55	77	3.7	3.4	3.1	2.7
		190	51	97	4.7	4.3	3.8	3.4
230	76	90	70	90	2.5	2.3	2.1	1.9
		110	100	110	4.2	3.8	3.5	3.1
		140	55	77	2.9	2.7	2.4	2.2
		190	51	97	3.7	3.4	3.0	2.7

NOTES:
1 Percentage solid will vary, depending on the manufacturer
2 Some low densities may not be available in various locations

COMPRESSIVE STRENGTH

AS/NZS 4455 specifies a characteristic unconfined compressive strength (f'_{uc}) of at least 5 MPa for hollow units, 3 MPa for solid or vertically covered units and 2.5 MPa for horizontally cored units. These values are in the standard to ensure that the units have a basic level of resistance to breakage during handling and transport. However, AS 3700 requires the designer to nominate the required strength on the drawings, and it is recommended that this be done in consultation with the manufacturer.

Compressive strength tests should be carried out in accordance with AS/NZS 4456.4. A masonry unit is placed in a compression testing machine and subjected to increasing load until it fails. From the maximum load, the unconfined compressive strength may be calculated. Solid or cored units must be fully bedded in the test and the compressive strength calculated using the full-bed area. On the other hand, hollow units must be bedded only on the face shells, and the compressive strength calculated using the face-shell area. An aspect ratio factor is applied to account for the confining effect of the machine platens on short, wide units, such as bricks.

A common characteristic unconfined compressive strength specification, set out in **Part C:Chapter 2**, is as follows:

- 10 MPa for cored or solid loadbearing masonry (determined using full-bed area)
- 15 MPa for reinforced hollow masonry or loadbearing hollow masonry (determined using face-shell area).

LATERAL MODULUS OF RUPTURE

Lateral Modulus of Rupture is a measure of the 'sideways' bending strength of masonry units. If the lateral modulus of rupture of units is too low, a wall could crack vertically when subjected to horizontal out-of-plane loads such as wind or earthquake. AS 3700 uses a default value of 0.8 MPa for characteristic lateral modulus of rupture.

It is not common, nor is it a requirement of AS/NZS 4455, to test for lateral modulus of rupture. If a test is required, it should be carried out in accordance with AS/NZS 4456.15. This test requires three units to be glued together end-to-end, the resulting beam to be supported on its side and subjected to a breaking load, see **Figure 5.2**.

Unless required otherwise, it is a reasonable expectation that hollow concrete masonry units have a characteristic lateral modulus of rupture in excess of the AS 3700 value of 0.8 MPa, probably in the range 1.0 to 2.0 MPa.

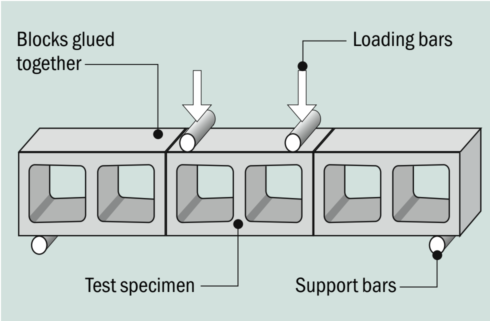

Figure 5.2 *Lateral Modulus Of Rupture Test*

SALT ATTACK RESISTANCE

The Salt Attack Resistance Grade is a measure of the resistance of the masonry unit to deterioration under the action of various salts resulting from sea spray or ground water. AS 3700 Table 5.1 sets out the requirements for various applications, the most common being **General Purpose Grade**.

Protected Grade units may only be used in mild environments, in the interior of buildings above the damp course, or above the damp course as exterior walls that are coated with a waterproof coating and are properly flashed.

Exposure Grade units should be used in severe marine environments, interior environments subject to saline wetting and drying, in contact with aggressive soils, in saline or contaminated water and within 1 kilometre of industry producing chemical pollutants.

It is not common, nor is it a requirement of AS/NZS 4455, to routinely test for salt attack. If a test is required, it should be carried out in accordance with AS/NZS 4456.10 Method B. Specimens are cut from masonry units and are subjected to cycles of soaking in salt solution, oven drying and cooling. When particle loss occurs, the total mass of the particles lost is determined by weighing.

PERMEABILITY

Permeability is a measure of the amount of water that will pass through a masonry unit, or the face shell of a hollow masonry unit, when a 200 mm hydraulic head is applied.

Hollow blocks with thin face shells exhibit a higher permeability than hollow blocks with thick face shells or solid blocks of the same mix, because the water traverses a thinner section of concrete to escape from the test apparatus. Thin face shells are more difficult to fill with concrete and are therefore of lower average density than thick face shells or solid blocks of the same mix. They are therefore more permeable.

Low permeability (high impermeability) is gained by good mix design to achieve minimum voids and high density, and is aided by proper curing. The quantity and quality of the cement binder is a primary determinant of low permeability and low total absorption. These properties improve with improvements in the binder.

The common method of lowering the permeability is to increase the fines content of the mix and, if necessary increase the cement content to compensate. This provides more paste, which not only fills the voids within in the body of the block, but also provides a slick on the block surface as it is extruded from the mould. The slick tends to cover the face, making it more impermeable than the body of the unit. However, three common specification requirements combine to increase the difficulty in achieving impermeability:

- The requirement for uniformity of colour and texture effectively precludes a use of a slick.
- The splitting of units to create a 'split face' removes any slicked surface.
- The specification of a particularly high lateral modulus of rupture and transverse strength places a requirement for the mix to include sharp angular aggregates, thus increasing its coarseness, lowering the density and increasing the permeability.

It is not common, nor is it a requirement of AS/NZS 4455, to test for permeability. If a test is required, it should be carried out in accordance with AS/NZS 4456.16. A masonry unit is subjected to a measured head of water in a cylinder sealed to the face of the unit. The passage of water through the unit over time is used to determine permeability, see **Figure 5.3**.

Unless required otherwise, it is a reasonable expectation that dense weight concrete masonry units have a maximum permeability of 2 mm/minute.

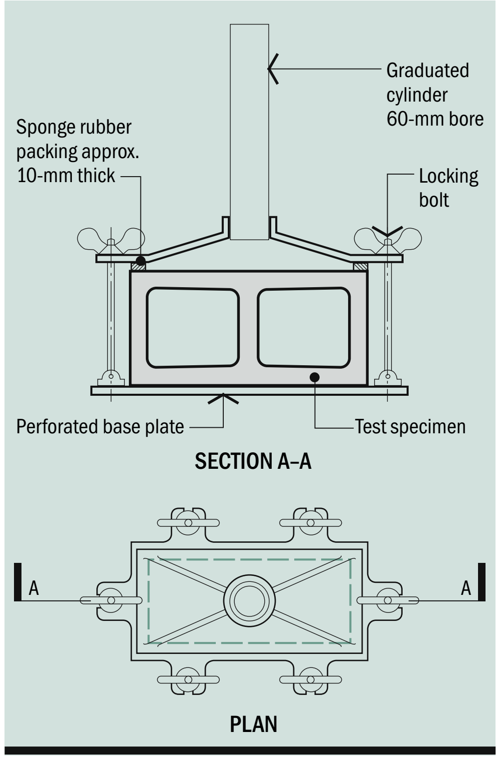

Figure 5.3 *Permeability Test*

EFFLORESCENCE POTENTIAL

Efflorescence is the white encrustation of salts, which may occasionally appear on the surface of masonry walls. It occurs when soluble salts, usually of sodium or potassium, or calcium hydroxide are borne to the exposed surface of the wall by moisture in the units. Sometimes, the salts are present in the masonry units from manufacture, but often they are leached into the units from the mortar binding them together in the wall.

Soluble salts can be readily washed off, but the calcium hydroxide reacts with the carbon dioxide in the atmosphere to form insoluble calcium carbonate, which is extremely difficult to remove.

Reduced risk of efflorescence deposits on a wall can be achieved by:

- minimising moisture entering the wall by using correct flashings;
- inhibiting the migration of moisture to the exposed surfaces by venting cavities and cores;
- ensuring that mortars are impermeable to moisture and manufactured only from clean materials; and
- ensuring that the concrete units are manufactured from materials free from soluble salts and that they are correctly cured.

It is not common, nor is it a requirement of AS/NZS 4455, to test for efflorescence potential. If a test is required, it should be carried out in accordance with AS/NZS 4456.6. A number of units are placed in a dish of water, allowed to soak for seven days, followed by air curing for two days. These units are then compared and assessed with respect to a matching unit, which has not undergone the soaking, for the development of efflorescence above the waterline on each external face.

Unless required otherwise, it is a reasonable expectation that concrete masonry units have an efflorescence potential of nil or slight.

CONTRACTION

Concrete masonry units shrink as the cement cures. To ensure that this does not contribute to cracking of the completed masonry, units should be properly cured before delivery to the site. Saturated units should not be laid as they could lead to subsequent drying shrinkage as the moisture evaporates from the wall.

AS/NZS 4456.12 provides two tests, Coefficient of Residual Curing Contraction and *Coefficient of Drying Contraction*, for contraction of concrete masonry units. These tests are not routinely performed, and are specified only when dealing with specific problems related to shrinkage and cracking.

Coefficient of Residual Curing Contraction is the shrinkage which takes place in newly manufactured concrete units (at constant saturated moisture content). It is an indication of the likelihood of shrinkage-related cracking as a result of cement hydration in the units. It is indicative of the lower bound of shrinkage in the wall.

For example:

0.1 mm/m represents at least 0.8 mm in an 8 metre length of wall.

0.3 mm/m represents at least 2.4 mm in an 8 metre length of wall.

Although there are no limits set in AS/NZS 4455 or AS/NZS 4456, a value over 0.1 mm/m would probably be relatively high.

Coefficient of Drying Contraction is the change in length which takes place in concrete units (when dried from a fully-saturated condition to a stable dry condition). It is an indication of the likelihood of shrinkage-related cracking as a result of expelling all of the moisture from the units. When combined with the shrinkage caused by the mortar, it gives an indication of the upper bound of the possible shrinkage in the wall.

For example:

0.6 mm/m represents at least 4.8 mm in an 8 metre length of wall.

0.8 mm/m represents at least 6.4 mm in an 8 metre length of wall.

No limits are set in AS/NZS 4455 or AS/NZS 4456. A value over 0.6 mm/m would probably be considered to be quite high.

MOISTURE CONTENT

Moisture content is the quantity of free moisture present in the unit expressed as the mass of moisture per unit volume (kg/m^3). Moisture content must be distinguished from total absorption and initial rate of absorption, which will be dealt with in the following sections.

It is not common, nor is it a requirement of AS/NZS 4455, to test for moisture content. However, if it is required, the test should be carried out in accordance with AS/NZS 4456.8. A reasonable expectation is that concrete masonry units have a maximum moisture content before laying of 80 kg/m^3. This is to ensure that units are constructed in reasonably dry condition, so that the tendency to drying shrinkage of units after placing in the structure is reduced.

INITIAL RATE OF ABSORPTION

Initial Rate of Absorption (IRA) is not necessarily related directly to the properties of total absorption or permeability. Initial rate of absorption is the property of masonry units commonly known in the building industry as 'suction'. It is a measure of the quantity of water absorbed in one minute per unit area of the bedding face of a unit under standard conditions, and may be used to compare the 'suction' of different units.

A test method for initial rate of absorption is given in AS/NZS 4456.17. A masonry unit is oven-dried, then cooled and placed with its bed face in contact with water for a period of a minute. From the increase in weight from water absorption, the initial rate of absorption is calculated, see **Figure 5.4**.

Bond developed between masonry units and mortar depends to a great extent on the initial rate of absorption of the unit, the water retention properties of the mortar, and the balance achieved between them.

If units with low initial rate of absorption are combined with mortars of high water-retentivity, the mortar will take too long to set and good bond will not occur. If units with a high initial rate of absorption are combined with mortar of extremely low water-retentivity, the mortar will stiffen too quickly and bond again will be lost. The ideal solution in this case is a compromise mortar design. Careful matching of the water retentivity of mortar to the initial rate of absorption of the units is important.

Generally, it is found that concrete masonry units have considerably lower suction than most clay masonry, and so require mortar with lower water retentivity. An experienced mason, familiar with bond strength requirements should be able to adjust the mortar appropriately. Typical values of initial rate of absorption for concrete masonry units are:

Top of concrete hollow block	2.7 kg/m^2/min
Bottom of concrete hollow block	1.8 kg/m^2/min
Bedding surface of concrete brick	0.9 kg/m^2/min.

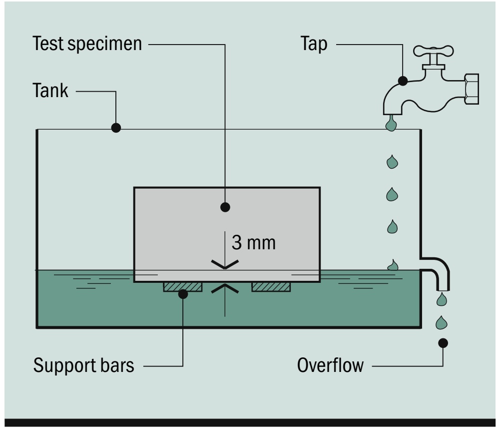

Figure 5.4 *Initial Rate of Absorption Test*

TOTAL ABSORPTION

The total absorption of a masonry unit measures its total capacity to absorb moisture. It is, in effect, a measurement of the voids content of the units, but not necessarily of the permeability, which is the unit's resistance to passage of water under pressure.

AS/NZS 4456.14 provides a standard test method for assessing this property. No limits are given in the standard. **Table 5.4** gives the levels of total absorption common in concrete masonry.

Table 5.4 *Typical Levels of Total Absorption in Concrete Masonry Units*

Type of unit	Oven-dry density of concrete (kg/m^3)	Maximum water absorption (kg/m^3)
Ultra-lightweight	<1400	320
Lightweight	1400–1700	290
Medium-weight	1700–2000	240
Normal-weight	>2000	210

5.3 REFERENCES

1 AS/NZS ISO 9001 *Quality management systems – Requirements*, Standards Australia.

2 National Construction Code (NCC) – BCA – *Building Code of Australia* – Volumes One and Two

3 AS 3700 *Masonry structures*, Standards Australia.

4 AS 4773.1 Masonry in small buildings – Part 1 Design, Standards Australia.

5 AS 4773.2 Masonry in small buildings – Part 2 Construction, Standards Australia.

6 AS/NZS 4455.1 *Masonry units, pavers, flags and segmental retaining wall units* Part 1 *Masonry units*, Standards Australia.

7 AS/NZS 4456 [Set] *Masonry units, pavers and flags – Methods of test*, Standards Australia.