THINK BRICK AUSTRALIA

Manual 10

Construction Guidelines for Clay Masonry

This publication updates and supercedes the publication of the same name issued by the Clay Brick and Paver Institute and first published April 2001.

Cover: The brickwork in Valencia, a mixed use development overlooking Sydney's Homebush Bay, is supported on concealed shelf angles, eliminating unsightly exposed slab edges. Raked mortar joints add detail to the large walling expanses. Designed by Allen Jack + Cottier Architects for Payce Properties, and built by Southern Cross Constructions. Photograph courtesy Boral Bricks.

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1. Introduction

This manual provides guidance for the construction of clay masonry in buildings. The guidance is of a general nature and represents industry recommendations for good practice. Alternative methods exist in many cases, and might be preferred in some situations for architectural, geographical or other reasons.

In conjunction with this manual, appropriate reference should be made to the Building Code of Australia (BCA)[1] and the various relevant Australian standards, including Masonry Structures (AS 3700)[2] with its Commentary[3] and Masonry in Small Buildings (Construction) AS 4773.2[4].

Because masonry is assembled on site, correct construction practices are probably more critical for performance than is the case with some other materials. This manual discusses the important requirements for materials (as they relate to construction), workmanship, tolerances, temporary bracing, site control testing, and compliance assessment.

Typical details for clay masonry are presented in Manual 9[5] of this series. Guidance on cleaning and removal of stains is given in the code of practice Cleaning of Clay Masonry[6].

2. Construction requirements in Australian Standards

The Masonry Structures Standard AS 3700 contains requirements for construction, including materials, workmanship, tolerances, site control, grouting and testing of in situ masonry. Because of the performance nature of the standard, these are mostly expressed in non-prescriptive terms. For example, the masonry must be constructed in such a way that the requirements of the standard for strength, durability etc are satisfied. Similarly, the standards for design and construction of masonry in small buildings AS 4773.1[7] and AS 4773.2 contain requirements for masonry that are often expressed in performance terms. The purpose of this manual is to recommend ways in which these requirements of the standards can be fulfilled. In this manual, 'the standards' is used to refer to any or all of AS 3700, AS 4773.1 and AS 4773.2.

In using AS 3700, masonry can be nominated as Special Masonry as a part of the design; this brings with it certain requirements for construction and testing. Masonry nominated in this way is assumed to have higher than usual strength, and this must be verified by site control testing. To date, there has been no attempt in Australia to base capacity reduction factors on the level of on-site supervision, as is done in some parts of the world, but the code might incorporate this in future. If it does, designers will be able to benefit from the specification and execution of a higher level of site supervision and control, leading to greater efficiency in the design.

The main purpose of the construction provisions in AS 3700 and AS 4773.2 is to ensure that the masonry is built in accordance with the design, as specified in the job documents. So, for example, it is necessary to use the bonding pattern as specified, to minimise cutting of units, to only cut holes and chases where specified, and to properly build-in all wall ties and accessories. Specific requirements of the standards are discussed in the following sections.

3. Materials

3.1 General

It is important to ensure that the materials used in construction meet the specification in every respect. This requires that all relevant properties must be checked, if necessary by obtaining the appropriate test certificates or assurance of compliance from the manufacturer or supplier. This checking process should encompass the masonry units, cement, lime, sand, wall ties and accessories.

The job documents should show the following information:

- Category (for example solid), type (for example clay) and work size (for example 230 x 110 x 76 mm) of the masonry units.
- Characteristic unconfined compressive strength (for example 10 MPa) of the masonry units.
- Proportions or classification of the mortar (for example 1:1:6 or M3).
- Joint finish, depth of raking (if any) and bond pattern.
- Salt attack resistance grade or durability class for the units.
- Wall tie grade and strength and stiffness of accessories (when used).
- Any special properties or requirements, such as site control testing.
- Other necessary properties such as lateral modulus of rupture of the units, grout strength, reinforcement grade etc.

Correct attention to the specification both prior to and during construction will ensure that the masonry is properly constructed to meet the design requirements and remains serviceable and free of faults during its lifetime.

All materials must be properly stored on site. Cement and lime must be adequately protected against water damage and masonry units should be kept dry until laying.

3.2 Units

Units should be blended from the packs during laying to eliminate banding by distributing units with colour variations somewhat evenly throughout the wall, thus ensuring a satisfactory appearance in the finished masonry. Especially in the case of two-storey construction, all units should be delivered at the start of the job and stacked on site to facilitate blending from the packs.

Second-hand units should be used only when specified. After they have been bedded in mortar, even soft lime mortar, units will have a mortar residue clogging the pores on their bedding surfaces, which makes it difficult to bond properly with mortar if they are to be re-used.

Masonry units of all types must be protected on site from moisture and contaminants from the ground, which can cause problems with efflorescence and salt attack in the completed masonry. Entry of salts from the ground into the units will lead to unsightly efflorescence later, as the salts are mobilised by moisture from rain and the atmosphere. High moisture content at the time of laying can cause problems such as poor bond strength and efflorescence. It is strongly recommended that the masonry units should be stacked clear of the ground, for example on pallets, and covered to give protection from the rain. Figure 1 is an example of bad practice, where ground water is allowed to contact the units, with the possibility of staining and take-up of salts.

Figure 1. Staining from ground water

Units should not be wetted prior to laying except in the rare circumstance, as a last resort, when it is known to be necessary to ensure satisfactory bond. It is far preferable to adjust compatibility of mortar and units by the appropriate use of sands and mortar admixtures (see Section 3.3) than to indiscriminately wet the units to lower their suction. For bricks containing manganese, laying wet bricks may lead to the development of manganese staining.

Cutting of units should be minimised as far as possible. While it is permissible to cut units with a bolster, the preferred method is with a masonry saw. Roughly cut or broken ends should never be allowed to protrude into the wall cavity. For loadbearing masonry that is classified as *Special Masonry*, any horizontal cutting of units must be done with a masonry saw.

3.3 Mortar

3.3.1 General

The standards contain performance statements for mortar, supported where possible by deemed-to-satisfy clauses. AS 3700 requires that mortar provide adequate workability, appropriate durability and the ability to impart to the masonry the required compressive and tensile strengths. It is written in this way to free specifiers and bricklayers from the rigidity of past traditional mortar mix proportions, and to facilitate the development and use of new mortar types that will better match particular types of masonry units.

The standards are based on an expectation that all masonry will have a characteristic flexural tensile strength of not less than 0.2 MPa. This is to encourage the proper matching of mortar to the characteristics of the masonry units in each particular case. With some care this can be achieved, but if this matching is not carried out, the appropriate level of strength might not be reached, even with high standards of workmanship.

Mortar determines the overall soundness of masonry. It bonds the units together in such a way that the applied loads can be resisted, while providing a construction method that makes possible the wide variety of shapes characteristic of masonry. It performs the following functions:

- Accommodates variations in unit size and shape – a nominal joint thickness of 10 mm is usually adequate for this purpose.

- Provides adhesive bond strength sufficient to resist lateral loads and to provide overall robustness.
- Allows for even bedding of the units and sufficient strength to resist compressive loads.
- Provides a weather-tight and durable wall by sealing the joints between units.
- Provides aesthetic effects by various joint treatments, pigmentation, bonding patterns and so on.

The most important functional properties of mortar are its consistency, its durability and its ability to bond with the masonry units. All of these can be significantly affected by workmanship and site practices.

It is important that the mortar ingredients and mix composition should be exactly as specified. Correct matching of mortar to masonry units involves many factors and departures from the specification during construction can lead to serious problems. For example, if the specification calls for Type GP or Type GB cement, then this should be used and not substituted with masonry cement.

There are no clear guidelines for consistency of mortar. Consistency can be defined as the ability of the mortar to be spread to form a joint, without undue segregation of the ingredients. A flow table is the traditional laboratory method for measurement of this property but in recent years a cone penetrometer has become the preferred method. However, testing of fresh mortar in this way is usually only useful for research purposes and experience shows that the amount of water to be added for workability is best left to the bricklayer. It is difficult to use a mortar that is too wet or too dry and, apart from the possible adverse effects of admixtures (see Section 3.3.8) the most suitable mortar for the bricklayer will usually impart the best properties to the masonry.

When wet mortar and masonry units come into contact, a certain amount of water is absorbed into the units. This movement is beneficial to bond, but should not be so great as to leave the mortar with insufficient moisture for proper setting. The ability of the mortar to retain sufficient water against the suction of the unit is called water retentivity and is thus one of the important factors in promoting tensile bond strength. It is defined as the ability of the mortar to retain moisture against a standard suction applied for one minute (to simulate the suction effect produced by the masonry unit). Water retentivity is particularly important for mortars used with high-suction bricks. Good water retentivity provides three benefits:

- Limiting the bleeding of water from the mortar.
- Preventing rapid stiffening of the mortar bed before units are laid for the next course.
- Retaining sufficient water in the joint for hydration of the cement.

Water retentivity can be controlled by the choice of an appropriate sand grading (see Section 3.3.4) and to some extent by the choice of mortar composition. Mixes with a higher proportion of lime (such as 1:2:9) will usually exhibit a higher water retentivity than others (such as 1:¼:3).

Durability of masonry mortar is as important as strength and is governed by a mortar classification system (see Section 3.3.3). While it is also strongly influenced by joint finishing, it has been found that durability of mortar increases markedly as the cement content increases. Durability can be measured by a scratch test (see Section 8.2).

There are no requirements for routine testing of masonry mortar for site control purposes. Only in exceptional circumstances, if problems are evident and investigation is required, should testing of the mortar be contemplated. Even then, the best course of action is to test the assembled masonry whenever possible. Testing procedures for strength of masonry are described in Section 7.

3.3.2 Bond between mortar and units

Bond strength between mortar and masonry units is often a more important property than compressive strength because it determines the strength of a wall against wind and earthquake, as well as its general serviceability. In masonry buildings, failure is more likely to occur from lateral loads, particularly wind, than from vertical loads. Tensile bond strength is strongly affected by mortar type; it is usually enhanced by the presence of lime and may be markedly reduced by workability admixtures. It is not always the case that tensile bond strength increases with cement content.

The formation of bond involves complex mechanisms and depends primarily on the interaction between the suction of the unit and the water retentivity of the mortar. There are two major factors that are known to affect bond strength adversely:

- Sand grading – an excessive amount of particles passing the 75-micron sieve will reduce bond strength. It is common for bricklayers to use a 'brickies sand' with high clay content, which improves the workability. This type of sand may be satisfactory with some clay units but is certainly not the best choice for all. If the clay content is too high, the bond strength will be reduced as a consequence.
- AS 3700 permits the use of plasticisers and workability agents. However, the use of admixtures such as air entraining chemicals, many of which are virtually indistinguishable from soaps or detergents, always has the effect of reducing the bond strength. When accurately batched, the improvement in workability can offset the reduction in strength, but over-dosing or over-mixing produces large reductions in strength.

3.3.3 Composition

Mortar has traditionally been specified in a prescriptive way by giving the proportions of cement, lime and sand. More recently, durability and strength of mortar are controlled by a classification system, comprising grades M1, M2, M3 and M4. Typical mix proportions to achieve these grades are given in the standards. The masonry designer should choose an appropriate grade for the mortar and specify this grade or, where specifically needed, the proportions.

The conventional notation for mortars is cement, lime and sand in that order, with proportions (by volume) indicated by C, L and S respectively, each followed by a number. The main cementing agent is always given as unity and the traditional proportion of cementitious agent to sand is one to three. Common mixes are C1:L½:S4½ and C1:L1:S6. The letters are often omitted and only the numbers are shown, for example 1:1:6. Only cement and sand are shown if there is no lime.

The standards (AS 3700, AS 4773.1 and AS 4773.2) give the mortar grades required in order to ensure satisfactory durability in various exposure environments. By far the commonest mortar grades are M2 and M3. Most masonry in housing and small-scale structures, where the environment is interior or mild exposure, uses an M2 mortar, while for general work and loadbearing walls an M3 mortar is more suitable. M4 mortar is used for applications where high compressive strength or high durability is required. M1 mortar can only be used in heritage or restoration work.

In the deemed-to-satisfy provisions, the mixes classified as M3 include the following:

- 1:1:6
- 1:5 with water thickener
- 1:4 with masonry cement

The tables also show for which type of units each mortar is suitable.

The requirements of the standards are all expressed by reference to the mortar grade rather than the precise mix composition. It is therefore preferable, at least for major jobs, for the documents to specify the mortar grade and leave the actual mix proportions to be determined on site, based on the available cement and sand types.

One of the most common misconceptions about masonry is that increasing the cement content in the mortar will increase the tensile bond strength. While an increase in cement content will generally cause an increase in durability and compressive strength of mortar (and therefore the masonry made with it) the same is not necessarily true for tensile bond strength. The formation of bond between masonry units and mortar relies on complex mechanisms. These are partly dependent on cement hydration, but they also depend on the transport of moisture and fine particles in the interfacial zone and on the degree of matching between the properties of the fluid mortar and the suction and surface characteristics of the unit. In this context, simply increasing the cement content in the mix will not guarantee an increase in tensile strength.

In addition to the main ingredients, a range of mortar admixtures is available, including those for workability, bond enhancement, colouring and retardation of setting (see Section 3.3.8). Thin-bed mortars are specially formulated and should be used only in accordance with the manufacturer's instructions.

The following general points should be noted and are discussed in detail later:

- Sand should be free of salts and organic matter. The particle size grading and clay content are the most important properties.
- Cement type is important because not all cements are equal. Type GP and Type GB cements are used in the same proportions but masonry cements are used in different proportions, as required by the standards.
- Lime is beneficial to masonry mortar. It adds workability, increases water retentivity and enhances bond strength and durability.
- Water should be clean and free of impurities.
- Admixtures should be used with care as over-dosing can cause severe problems.

The following sections discuss the constituents in turn, along with various other aspects of masonry mortars.

3.3.4 Sand

As well as the need for sand to be clean and free of salts and organic matter it must have a suitable grading and should not contain too much clay. The grading of sand has an influence on the properties of mortar in both the plastic and hardened conditions; however, quantifying this influence is difficult. Sand grading is given in terms of percentage passing a standard set of sieves. However, specifying a grading envelope is not recommended, because satisfactory mortar performance can also be achieved with sands whose grading curves fall outside the generally accepted envelopes.

Figure 2 shows a set of grading limits that was previously recommended in the commentary to AS 3700. The curves are similar to grading limits that have been recommended in other parts of the world. However, they should be taken as a guide only and should not be used in a specification for building works.

A generally accepted limit for good mortar to be used with clay units is that the sand should not contain more than 10% passing the 75-micron sieve and not more than 1% retained on the 2.36 mm sieve. However, sands outside these limits can give quite adequate strength and durability performance. The most important requirement is that the sand should produce a mortar compatible with the units and the best guide for this is experience. In difficult situations, it can be useful to carry out a trial mix and test the required properties with the units to be used on the job.

Excessive material below 75 microns in size usually indicates high clay content and can produce the following problems:

- Smears and stains on the finished surface of the masonry caused by the clay particles. These smears can be difficult to remove.
- Reduction in mortar strength and particularly tensile bond strength of the masonry.

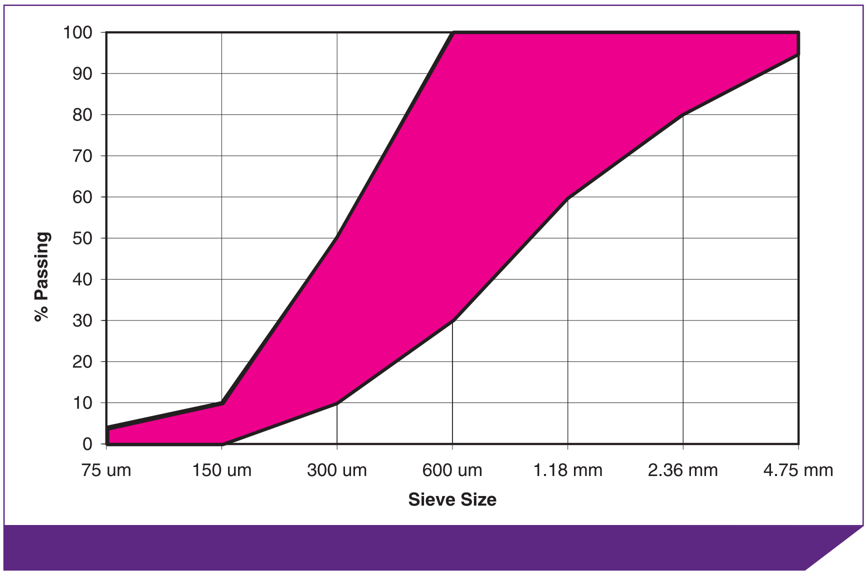

Figure 2. Typical sand grading envelope for mortar

- A 'sticky' mortar mix, which encourages the bricklayer to overdose with air entraining admixtures.
- Durability problems caused by the breaking down of clay particles under cycles of wetting and drying.
- Shrinkage cracks within the mortar joints.
- The mortar will have good workability without the addition of lime, tempting the bricklayer to omit lime from the mix and thereby invite adverse effects.

On the other hand, small amounts of clay can be quite useful as a plasticiser and can produce a workable mix without the need for proprietary plasticisers, which are so susceptible to overdosing. When problems arise, they are not because of the presence of clay, but the presence of too much. In many cases, the best course of action is to blend sand from equal parts of 'fatty' sand and washed sand to give a mix that provides a suitable workability and adequate strength. Good sand suppliers will do this at the source of supply.

When sand for use with clay units contains very fine material that is silica rather than clay, experience suggests that the use of a cellulose-type water thickener can improve tensile bond strength.

3.3.5 Cement

Three types of cement are commonly used for masonry in Australia. General-purpose Portland cements (Type GP) are probably the most common. General purpose blended cements (Type GB), sometimes known as 'Builders' cements, are very common, and consist of Portland cement mixed with fly ash or blast furnace slag. Portland and blended cements must comply with AS 3972[8]. The third type is masonry cement, which is available in some parts of Australia and consists of blends of Portland cement with various ingredients such as fly ash, blast furnace slag, finely ground limestone, building lime, plasticisers and air entrainer. Masonry cements must comply with AS 1316[9] but their constituents and quality can vary widely between different regions. The onus is on the manufacturer of such cements to demonstrate that their use will result in masonry meeting the requirements of the standards.

It is important to realise that masonry cement cannot replace Type GP or Type GB cement in the same proportions. The deemed-to-satisfy mix compositions given in the standards (AS 3700, AS 4773.1 and AS 4773.2) allow for this fact, as discussed in Section 3.3.3. It follows that the type of cement required for a job should be specified along with the mortar grade; otherwise it should be assumed that Type GP or Type GB cement is intended.

Special purpose cements are rarely specified for mortars. Many types of cement that meet the special purpose requirements of AS 3972 also meet the general purpose requirements and may be used in mortar. One special purpose cement, sulfate resisting cement (Type SR), may be specified for use where sulphate containing waters may contact the masonry, as in the case of building on acid sulphate soils.

3.3.6 Lime

Lime is an important ingredient in masonry mortar and confers many benefits, including plasticity during setting, self-healing of minor cracks throughout the life of the masonry and promotion of good bond with clay units. For at least 2000 years, extending into the 20th century, lime was the primary cementitious material in mortar and our cities contain many functional buildings constructed with L1:S3 mortars. Now that Portland cement is the main agent, the benefits of lime can easily be overlooked. The self-healing property of lime repairs micro-cracks that can form because of atmospheric conditions, long-term expansion or shrinkage. Lime also reduces the speed of hardening, allowing masonry to take up minor movement incidental to construction.

Some work done in recent years on the conditions at the brick/mortar interface has improved our understanding of the mechanism of bonding and in particular has provided evidence in support of the benefits of using lime. As well as imparting plasticity to the mix during setting, the presence of lime can produce an initial coating on the surface of clay bricks, which appears to promote bonding as the cement hydrates.

Lime can be used as dry hydrated lime or as lime putty. The latter has the advantage of imparting to the mix a higher plasticity, with attendant advantages for workability, tensile bond strength and water permeability. However, the use of lime putty requires care to ensure that mixes are consistent and that the desired mix proportions are achieved. Lime putty can be prepared by mixing dry hydrated lime with water to a creamy consistency and letting it stand for 16 hours or more to 'fatten up' before use.

Because of the potential benefits, the use of lime is widely encouraged for clay masonry. Admixtures should never be used to replace lime without test data to show that strength and other properties will not be adversely affected.

3.3.7 Water

Water is the lubricant that allows the other constituents to be brought to a workable consistency. It must be free from harmful quantities of anything deleterious to the masonry, the reinforcement or any embedded items. In particular, it should be free of suspended fine particles and dissolved salts or other compounds. The usual test for satisfactory water is that it be potable (drinkable).

Water also brings about hydration of the cement, which is ultimately responsible for the tensile and compressive strengths and the durability of the mortar. With masonry, there is not the same relationship between water/cement ratio and strength as there is with concrete. This is because, in the case of masonry, large amounts of water are removed from the wet mortar by the suction of the units. It is then possible that there will not be sufficient water remaining to ensure full hydration of the cement. In addition, masonry is not given the benefits of good curing that are often available with concrete.

Experience has shown that it is best not to control the amount of water added to a mortar – it should usually be mixed as wet as possible to allow it to flow into the surface irregularities of the units, while remaining stiff enough for the bricklayer to use it. The bricklayer will generally add sufficient water for good workability, and this will result in the best strength under the circumstances.

3.3.8 Admixtures

Inappropriate use of admixtures in masonry mortar is a very common source of problems. The standards restrict mortar admixtures to certain types and these must satisfy the relevant standards. The following are permitted:

- Plasticisers and air entraining agents – designed to improve mortar workability.
- Methylcellulose water thickeners – designed to enhance water retentivity, especially for use with concrete and calcium silicate units.
- Colouring pigments.
- Set-retarding agents – usually added at the batching plant and designed to provide up to three days setting time.
- Bonding polymers – designed to enhance bond strength (these are little used in Australia).

The admixtures should only be of a type specifically designed for use with masonry mortars and must be used strictly in accordance with the manufacturer's instructions. Any admixture not of the types listed above must have its performance verified by testing with the masonry units to be used on the job, and these tests must show that the strength and durability properties are not adversely affected by the use of the admixture.

Chemical admixtures such as plasticisers and workability agents should never be used as substitutes for lime. Most proprietary air entraining agents are chemically similar to detergents and they always reduce the strength of the mortar. This reduction might not be serious but it should be recognised that the use of these agents is prone to overdosing and excessive mixing time, both of which have a marked effect in reducing strength, especially tensile bond. Under no circumstances should household detergent be used as a substitute for air entraining agent in mortar.

It is well established that optimum tensile bond strength with concrete and calcium silicate units is achieved by using a cellulose-type water thickener and appropriate sand. The effect of this admixture is to provide workability to the mix while reducing the rate at which water can be removed by the relatively high long-term suction of the units. There is also some evidence that this type of additive can be beneficial with high-suction clay units and sand that has a very narrow particle size grading. When a water thickener is used, it should be one that is specifically designed for masonry mortars and must only be used at the dosage and in a manner recommended by the manufacturer. Some bricklayers find these mixes a little too sticky and adding a small quantity of lime (up to one-quarter of the volume of cement) in addition to the water thickener can alleviate this.

The most common admixtures for colouring mortar are synthetic metal oxides. These mix with the cement to form pigmented slurry that coats the sand grains. It is generally recommended that no more than 10% of pigment (by weight of cement) should be added, because there will be no further increase in colouring. However, carbon black should not be added in proportions greater than 3% by weight of cement. It should be borne in mind that the pigment adds to the total fines content of the mix and will therefore affect the workability and water retention properties (and hence the bond strength). Liquid suspensions are the most convenient but care should be taken if the liquid medium is an air-entraining agent. Apparent fading of pigmented mortars can be caused by too little cement in the mix, over-use of air entraining agents, degradation due to aggressive atmosphere or moisture, and light coloured staining due to efflorescence or chemical deposits.

Set-retarding admixtures should only ever be used in pre-mixed mortars batched in a factory and must be used within their retardation period or discarded. They are usually only practical for large construction jobs and can offer the advantage of improved quality control. However, it is essential that the adequate performance of masonry built with these mortars is demonstrated and it is advisable to carry out routine site testing to confirm adequate strength. Experience has shown the possibility of drastic reductions in tensile bond strength and durability when retarded mortars are used with high suction units.

In addition to the admixtures referred to above, there are various proprietary permeability-reducing ('waterproofing') additives. It is recommended they should not be relied upon as a substitute for membrane damp-proof courses unless there is strong local evidence that foundation movements are very small and that the admixtures have a proven history of reliable performance in that locality. Any crack in a mortar course containing one of these admixtures will destroy the water-resisting effect and the use of excessive quantities of admixture will seriously weaken the mortar. Where these admixtures are employed (for example in copings) this should only be in conjunction with C1:S3 mortar.

Finely powdered clay, which can be referred to as fire clay, builders' clay, brickies' clay or plasterers' clay, is sometimes marketed as an admixture for masonry mortars, to enhance workability. While bricklayers find it produces a readily workable mix, this type of admixture can have severe effects on bond strength. As the dose of clay increases, the bond strength reduces markedly (see Figure 3). Hence, the use of fire clay is not permitted as a mortar additive under Clause 12.2.3.5 of AS 3700-2001. Lime as a plasticiser does not suffer from these adverse effects and, as explained above, brings positive benefits.

AS 3700 Clause 12.2.3.5 also specifically prohibits the use of detergent, sugar and sweetened beverages as mortar additives.

Probably the most common construction error in masonry is over-dosing of air entrainer, leading to extremely low bond strength. When air is entrained in masonry mortar the air bubbles behave like ball bearings and increase the workability. However, the entrained air reduces the contact area between the masonry unit and the mortar and lowers the efficiency of the cement paste in the mortar. The results can be a drastic

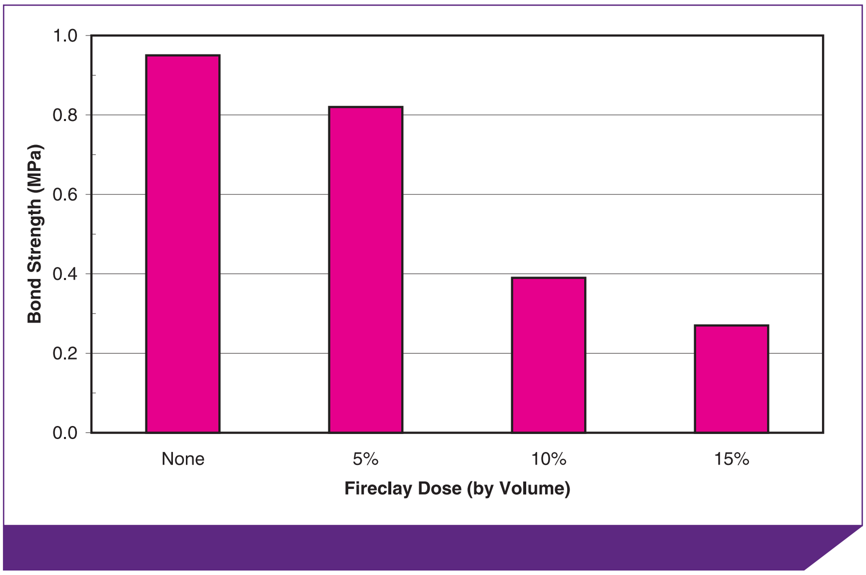

Figure 3. Typical effect on bond strength of using clay as a plasticiser

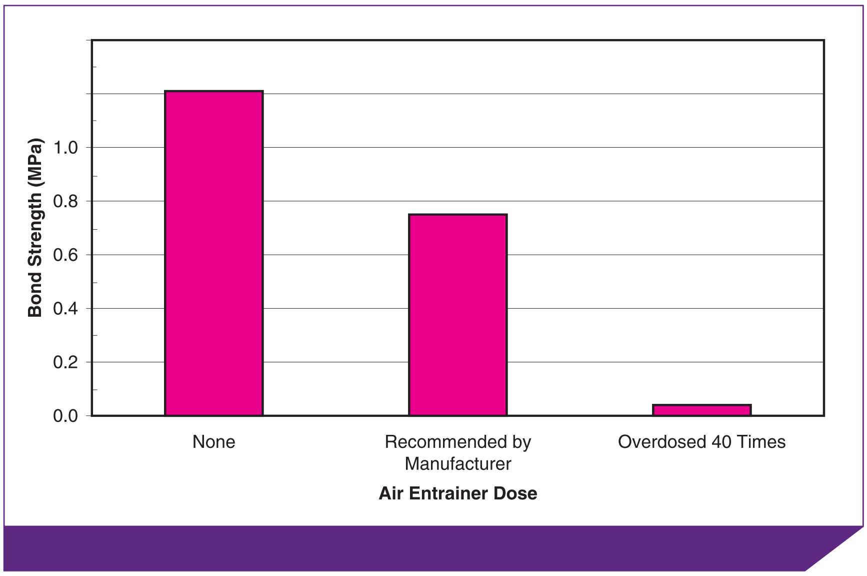

Figure 4. Typical effect of overdosing air entrainer

reduction in bond strength, particularly if the air entrainer is used at more than the recommended dose. The standards do not have prescribed limits on entrained air, such as exist in some countries, and it is therefore imperative that builders exercise caution in the use of these admixtures. Figure 4 illustrates the typical effect on bond strength of increasing the dosage of air entrainer. Much too often on site the dose used is up to 40 times the recommended dose, leading to a drastic reduction in strength.

It is well established that the strength of hardened mortar in masonry joints is considerably greater than would be obtained by testing moulded specimens such as cubes. This results from the removal of water from the mortar by the suction of the bricks, lowering the water/cement ratio from its initial very high value. However, if all the water that passes into the units evaporates, the cement in the mortar will not achieve full hydration. Curing of the masonry will permit some of the moisture to return to the joints over time and enhance cement hydration, leading to higher compressive and tensile strengths, and greater durability.

Unlike the case with reinforced concrete construction, curing of masonry is not common on site. At the very least, masonry should be protected from drying out too rapidly in hot conditions. The strength values used in design are based on an age of seven days, assuming normal rates of strength development. If drying out interrupts this development, the required strength might not be achieved.

For masonry constructed in a wall, the mass of construction, combined with the effect of the cavity (if present), is sufficient to ensure a degree of curing except in very dry conditions. By contrast, site control and laboratory specimens are more exposed to drying effects. This, together with the fact that they are intended to indicate the full potential strength of the masonry, explains the requirement in AS 3700 for these specimens to be wrapped in a vapour-proof sheet for curing.

3.3.10 Mixing

Specification of an appropriate mortar composition is only half the story; achieving it on site is the other half. It is essential that batching methods should be such as to ensure that the specified composition is achieved. While shovel batching is the most convenient (and common) it is usually the least accurate and is often the cause of durability problems resulting from the cement content being lower than intended. Mortars with too low a cement content can be soft and susceptible to damage by abrasion and salt crystallisation.

The lack of accuracy with shovel batching arises mainly from the different bulking properties of sand, cement and lime. Figure 5 illustrates the large difference that can occur in the volume of a shovel of cement and a shovel of sand. Because of the natural bulking of moist sand, the volume will be much greater, leading to a mortar with cement content much less than intended. Volume batching with buckets or gauge boxes will avoid this problem.

The best method of batching is to add bagged cement and lime in the correct quantities to a mixer of known volume and then to fill the mixer with sand. The volume calculations are straightforward

Figure 5. The effects of bulking on shovels of cement (left) and sand (right)

and once they are carried out for a particular mixer they will not change. For example, most mixes have a volume of cementitious material (cement and lime) equal to one third the volume of sand. Since the cementitious material fills the interstices between the sand grains it does not add to the overall volume. The volume of cement and lime combined should therefore be one-third of the volume of the mixer. In the case of a 1:1:6 mix this cementitious component would be made up of half cement and half lime. Once this is added, the mixer can be completely filled with sand (and the required amount of water for good workability) and the resulting mix will have the correct proportions.

Mixing time for masonry mortar should be controlled. A minimum of six minutes is recommended because shorter times can produce strength and colour variations in the mortar. While there is no recommended maximum time, it is particularly important that mortars with air-entraining admixtures should not be over-mixed. Extended mixing of these mortars will entrain too much air and lead to very low bond strength.

Mortar must not be used once setting has commenced but it can be re-tempered to replace water lost by evaporation up to this time. This re-tempering should not extend beyond the time of initial set of the mortar, which is usually from one to two hours after mixing, depending on the conditions.

3.4 Grout

In reinforced clay masonry, whether constructed with steel bars in pockets or in cores through the blocks, grout must be incorporated to protect the steel reinforcement from corrosion and to bond it to the masonry. To achieve this, grout must completely surround the bars and must contain sufficient cement to provide a protective alkaline environment.

To ensure that the bars are fully surrounded, the grout must be mixed to a pouring consistency so that all pockets, cores and cavities within the masonry units are filled. Traditional concrete technology would suggest that a high water/cement ratio would give a lower strength for the grout. However three factors should be borne in mind:

- Complete filling of the cores is more important than having a higher strength grout.
- The units absorb much of the water out of the grout, reducing the water:cement ratio and at the same time improving the bond between the grout and the unit.
- An increase in the strength of the grout beyond the strength of the blocks gives a relatively smaller increase in the strength of the masonry. Because of this, even if a high strength grout is used, the Standard places an upper limit on the strength that can be assumed for design.

The ideal mix design for grout depends on the strength requirement and on the size of the cores to be filled. AS 4773.2 recommends a mix of 1 cement : 2 sand : 4 aggregate. The aggregate should ideally be 5 mm to 10 mm rounded river gravel or pea aggregate and should never exceed 20 mm in size. Additives such as fly ash, silica fume and chemical admixtures can be used, provided they comply with the relevant standards. However, the most important requirement concerning the grout is for corrosion protection to the reinforcement, and the standards require the cement content to be at least 300 kg/m^3 to ensure adequate durability.

4. Workmanship

4.1 General

It is important that the type of bedding (full or face-shell) specified in the documents should be followed in the construction. This is because the strength of masonry depends on the type of bedding. Joint thickness influences strength as well as appearance and must therefore be constructed as specified. Tolerances (see Section 5) are prescribed for any variations in joint thickness. The vertical joints (perpends) must be filled with mortar unless the documents indicate otherwise; filling of these joints has an effect on horizontal bending strength, water penetration resistance, and other properties such as sound transmission. The base course should always be laid on a freshly prepared, horizontal bed of mortar, applied to a clean surface.

Various general construction details also require attention. The bonding of the masonry units, in particular the unit overlap and the use of header units, must be as specified by the designer. Toothing must not be used where one wall intersects another and they are built at different times. Figure 6 shows an example of bad practice in toothing a wall before connecting it to return walls. It is preferable for the wall built first to be racked back or metal ties to be embedded during construction of the first wall and incorporated into the second wall when it is built. In general, the use of cut units and the cutting of holes and chases should be minimised as far as possible. Chases can have serious adverse effects on strength, fire resistance and sound transmission and should only be used within the limits permitted by the design.

Figure 6. Bad practice in toothing a wall junction

The rate of construction of masonry should match the conditions. Construction that is too rapid can lead to slumping of the work, and excessively hot and dry or freezing conditions should be avoided. Once constructed, the masonry should be allowed to set without disturbance. Initial bond between a masonry unit and mortar is formed quite rapidly by transport of water from the mortar into the unit, and it is most important that the unit should not be moved after being tapped into position.

During wet weather, the tops of walls should be covered to prevent rainwater entering the units, which could lead to damage, excessive shrinkage and efflorescence.

Weep-holes and cavities between masonry leaves should be kept free of mortar and other materials. Cavities can be kept clean by using a cavity batten that is pulled up as the work proceeds. It is also good practice to hose out cavities at the end of each days work. Weep holes can be formed by inserting a duct or other insert, or by using a rod that is removed once the mortar has stiffened sufficiently.

4.2 Joints

4.2.1 Mortar joints

Mortar joints (both bed and perpend) are usually specified as nominally 10 mm in thickness. Any raking, if specified, should not exceed 10 mm depth and should not penetrate closer than 5 mm to any core or perforation in cored units or to within 20 mm of the cores in hollow units. Tooling of joints is particularly beneficial in improving durability and must always be carried out as specified. Various types of joint finishes are illustrated in Figure 7.

4.2.2 Control joints

Control joints are used in clay masonry to accommodate movements within the masonry or between the masonry and other parts of the building. Such movements can arise from various sources including foundation movements, expansion of the clay masonry units, thermal movements and shrinkage of concrete elements. When foundation movement is the cause, the joints are referred to as articulation joints.

Control joints must be kept clear of mortar droppings and other materials and properly back-filled with sealant as specified. A temporary gap-filling material can be inserted in a control joint to ensure that it is kept free of mortar. However, it is essential that this temporary filler is removed and the joint properly filled when construction of the wall is complete. To ensure proper functioning, it is particularly important that expansion joints in clay masonry should be filled only with specified compressible material. Figure 8 shows two methods of filling control joints.

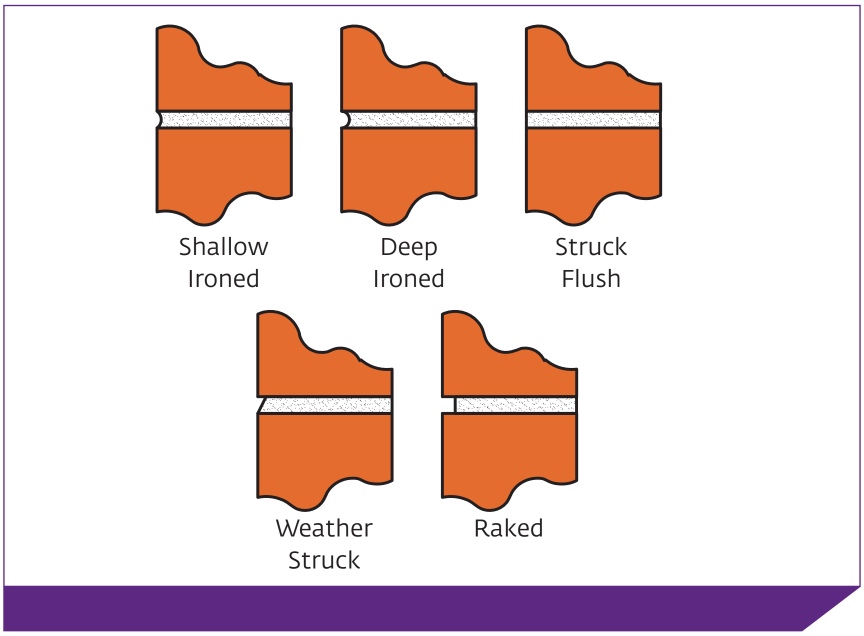

Figure 7. Varieties of joint finishes

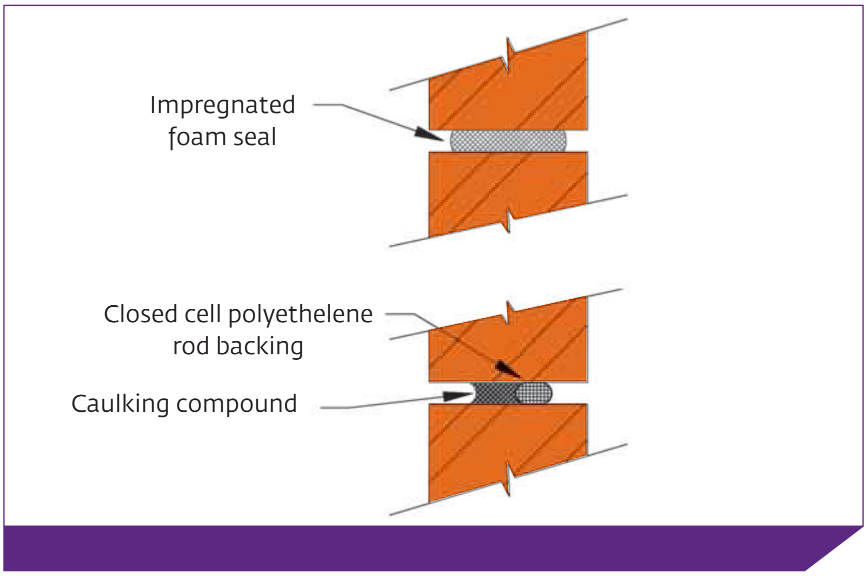

Figure 8. Methods of sealing control joints

Figure 9. Control gap sealant squeezed out by joint closure

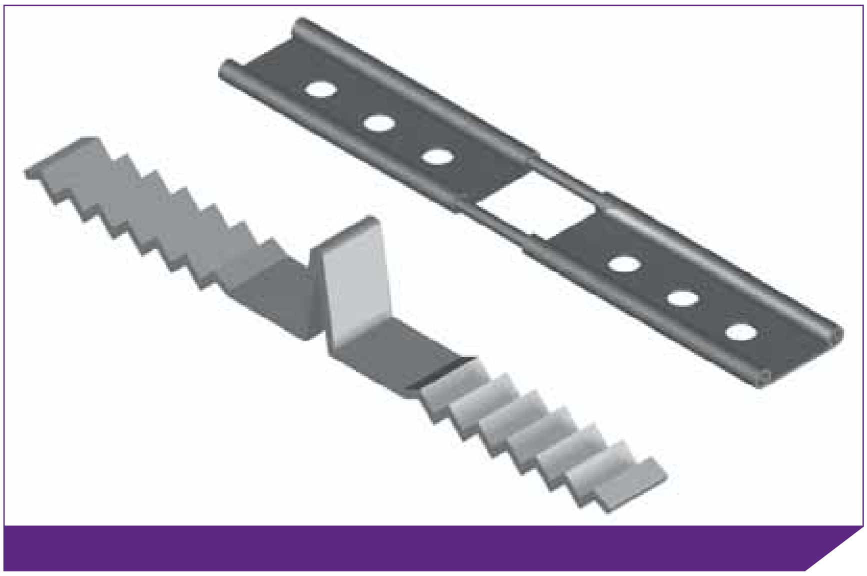

Figure 10. Two types of connectors suitable for control joints

Flexible sealant should be left well back from the surface to avoid unsightly squeezing out as the joint closes (see Figure 9). If the flexible sealant has squeezed out, it may be trimmed with a sharp knife.

Control joints should have appropriate flexible ties (not cavity ties) installed across the joint. Figure 10 shows two types of connectors suitable for control joints.

4.3 Flashings and damp-proof courses

Correct installation of damp-proof courses and flashings is one of the most important construction considerations for masonry. The standards require damp-proof courses and flashings to be provided for the following purposes:

- To prevent moisture from moving upward or downward through the masonry.
- To prevent moisture passing from the exterior to the interior of a building, including passing across a cavity.
- To shed moisture from a cavity to the outer face of a masonry wall.

While chemical parging of damp-proof courses has proven successful in some areas (for example Western Australia) the use of membrane damp-proof course materials is by far the most common. Recommended locations for flashings and damp-proof courses are given in TBA Manual 9.

Traditionally, membrane damp-proof courses (DPC) and flashings have been embedded in joints with mortar above and below, not directly laid on the units. However, there is evidence to suggest that slip joints, which are often implemented with two layers of DPC material, are more effective if they are laid directly on the units. The specification should be carefully followed in this regard. The bed joint on which the DPC is laid should be flushed up with mortar, but this does not mean that core holes should be filled or that the DPC should necessarily be sandwiched within the mortar joint.

Joints at the ends of DPC and flashing material should be lapped to a length at least as great as the thickness of the masonry leaf, to guard against moisture migrating along the lap and penetrating the wall. Care should be taken in storage and handling to avoid puncturing DPC and flashing materials, thereby allowing moisture to pass through.

The materials for damp-proof courses, copings, flashings and weatherings must comply with AS/NZS 2904[10] and must be corrosion resistant and compatible with all materials they will contact in service. The following are common materials used for this purpose:

- Aluminium
- Copper and copper alloys
- Lead
- Zinc
- Zinc-coated steel
- Bituminous-coated metal
- Bituminous materials without metal centres
- Polyethylene sheet

It is essential that the membrane DPC should be visible at the front surface of the wall after construction. This is best achieved by allowing the material to project while the masonry is under construction, followed by cutting it off flush or turning the edge down when construction is complete. The most common cause of dampness in masonry buildings is bridging of the DPC, either because of insufficient projection from the surface of the joint or by the application of a render coating after construction of the wall. Any external landscaping or rendering of the wall must not be allowed to bridge the DPC and form a path for moisture to pass above the DPC level.

Where the wall is to be rendered to below the DPC, the DPC should not be cut off until after the rendering is complete. The most common reason for render failing is saline ground water wicking up through the render, drying and depositing salt, which builds up between the render and the brick, eventually popping the render off.

4.4 Wall ties and connectors

4.4.1 General

Wall ties that interconnect the leaves of a cavity wall or connect a masonry wall to a backup frame of timber or steel stud are essential structural components of the building. If their integrity fails, there is a significant risk of the masonry skin falling off the building in high wind or earthquake. This was one of the most significant causes of failure in the Newcastle earthquake of 1989. The wall tie standard AS/NZS 2699.1[11] specifies the required characteristics of ties, while AS 700, AS 4773.1 and AS 4773.2 specify how they should be designed and installed. It is essential that these standards should be complied with.

An important feature of AS/NZS 2699.1 is the labelling requirements. These require each package of ties to show the strength rating (light, medium or heavy duty), the rated cavity width, the durability category (R1 to R5) and the fastening requirements (for veneer ties). The individual ties must be colour coded or stamped to indicate the durability rating. If colour coding is used it should be as follows (in order of increasing durability):

- Green R0 or R1
- Yellow R2
- Red R3
- Blue R4

The builder must ensure that the ties installed into the building comply with the specification in all these respects. It is particularly important that ties should not be used at cavity widths greater than

Figure 11. Incorrect installation of ties at more than the rated cavity width

the rated width shown on the packaging, because the strength rating no longer applies at any greater width. Figure 11 shows an example of incorrect installation of a tie at greater than its rated cavity width of 50 mm.

Connectors used in masonry, for example across control joints and to tie the tops of walls must comply with the appropriate standard AS/NZS 2699.2[12]. These connectors must also have a durability rating (R1 to R5) and must be selected and installed in accordance with the specification. The same colour-coding scheme used for wall ties (see above) or another form of stamping or labelling must be used to indicate the durability rating of connectors. Manufacturers test these products and provide strength values, which are used for the design of critical connections such as the tops of walls. It is therefore essential that the appropriate types, at the specified spacings, should be used in the construction.

4.4.2 Installation

All ties and connectors must be built into the masonry as the work proceeds, to ensure that they are properly embedded in fresh mortar.

AS/NZS 2699.1 requires the tie manufacturer to supply the fastener for use with veneer ties. This is an important requirement, necessary to guard against the risk of electrolytic corrosion caused by dissimilar metals being in contact. Any such corrosion, leading to disintegration of the fastening, would quickly render the ties useless. For this reason, veneer ties must always be installed using the fastener supplied with them. While veneer ties have traditionally been attached to timber framing with nails, recent research has shown that this can lead to a loss of strength under cycles of reversing load. Consequently, there is a trend in Australia to require screw fixings and this is already the common practice in New Zealand.

All ties must be installed to prevent water transfer across the cavity from the outer masonry leaf to the inside of the building. Ties are tested to ensure that they will not permit water transfer if installed level, but an additional safeguard is provided by giving them a slight slope towards the outside of the wall. However, this slope should not be too great, or the strength of the tie connection will be affected. Careful planning and setting out should be used to avoid excessive coursing differences between the leaves of a cavity wall.

The strength of embedment of the ties in the masonry affects their ability to transfer forces. The standards require all ties to be embedded at least 50 mm into the mortar joint and to have at least 15 mm remaining cover to the outer surface of the mortar joint. In the case of hollow masonry units, laid in face shell bedding, the cores should be filled with grout or mortar (at least where the ties are located) to provide sufficient embedment for the ties.

Particular care must be taken if the ties are bent up or down during construction of a masonry leaf, to ensure that they are properly embedded when the second leaf is constructed and that they have the correct alignment. Two-part ties can be useful to avoid the tendency to bend ties during construction.

As the wall construction proceeds, it is important to keep mortar droppings out of the cavity (or clean them out at the end of each day) because an accumulation of droppings adhered to the ties is likely to cause problems of water penetration during the life of the building.

Whereas bolts and anchors for attachment of roof trusses can be added later in accordance with the specification, tie-down straps must be built in as the wall is constructed.

4.4.3 Spacing

Ties must be installed at the correct spacing, as specified on the documents for the job. It is important to remember that this spacing can vary from one job to the next and even for different areas within the same building. The spacing should never exceed 600 mm in either the vertical or the horizontal direction. There will generally be an overall spacing of ties for the wall, for example 450 mm by 450 mm and a requirement for additional ties to be installed in some locations.

Alongside openings, control joints and edges of a wall, the first row of ties should be within 300 mm of the edge of the masonry. This is to ensure that all parts of the masonry are adequately supported. This requirement also applies opposite intersecting walls and at other points of support for the wall. Where a two-storey masonry veneer is continuous past a floor level, there should be a row of ties within 300 mm below the floor and a separate row within 300 mm above the level of the floor. This is to ensure that the masonry in both the upper and lower storeys is adequately supported, considering that the floor membrane acts as a very stiff point of support. These rows are also each required to contain additional ties (see below).

Double the usual number of ties must be installed in rows in the following locations:

- At the top of a single storey veneer.
- Opposite vertical lateral supports (for example intersecting walls) in both veneer and cavity walls.
- For a continuous multistorey veneer, in the row immediately above and the row immediately below the intermediate floor level.

As an alternative to using double the number of ties, ties of a higher strength rating could be used but this will not usually be practicable. The standards no longer require additional ties around the edges of door and window openings or at control joints. In general, the requirements should be specified on the drawings.

4.4.4 Common abuses

There are some common abuses in the use of wall ties, which came to light in the 1989 Newcastle earthquake and have also been observed at other times. These all detract from the performance of the masonry in terms of either its integrity or its durability. The more common ones are:

- Not engaging the ties (bending down). This can be avoided by using two-part ties or polymer ties.
- Not embedding the ties for a sufficient distance (often due to an inappropriate cavity width).
- Not embedding the ties properly in mortar, resulting in low pullout strength.
- Use of sub-standard ties (in terms of strength or corrosion resistance).
- Misalignments of ties across the cavity, resulting in water transfer into the building and reduced strength.

- Mortar dags in the cavity, leading to water penetration.
- The cavity cluttered with cables, debris and so on, leading to water penetration.

The proper performance of a masonry structure depends on the ties being properly designed, specified and installed. The standards provide the rules for achieving this but lack of compliance is a recurring problem.

4.5 Lintels

Lintels are used to support masonry over openings such as doors and windows. A lintel should have sufficient strength and stiffness and be made of a material that is compatible with the masonry it supports. Lintels are commonly made from the following materials:

- Galvanised or stainless steel
- Reinforced or prestressed concrete (precast or in situ)
- Reinforced or prestressed masonry
- Stone

All lintels must comply with the durability requirements in AS/NZS 2699.3[13]. This standard provides for durability ratings using the same classification system (R0 to R5) as that used for ties and connectors. The standard requires lintels to have identifying markings and, in particular, to be colour coded to indicate the durability class, using the same scheme as for wall ties and connectors (see Section 4.4.1). This colour coding and the identifying marks should be visible when the lintel is embedded in the wall.

Lintels, especially those of steel with galvanized or duplex coatings, must be handled carefully to prevent damage before they are installed. Any damage to the coating arising from dropping the lintel, or other impact, will compromise the corrosion protection and shorten the life of the lintel.

Correct installation is also vital if lintels are to perform satisfactorily. The specified bearing distances at each end of the lintel must be complied with and any specified propping procedure must be followed. To ensure proper composite action with the supported masonry, some lintels should be propped during construction. Where they are used, the props should not be removed until the masonry has hardened sufficiently, usually seven days after the masonry is built above the lintel. Steel angle lintels should be installed with the longer leg vertical and should always have any space between the vertical leg and the masonry packed with mortar to prevent twisting.

4.6 Grouting

When masonry is grouted, it is most important that the grout should flow into all cavities and fully surround all reinforcement. Vibration or rodding should always be used to ensure complete filling. Before commencement of grouting, the cores and cavities should be free of any debris and excessive mortar dags. During the grouting process, care must be taken to keep the reinforcement in its specified position; AS 3700 provides tolerances on the reinforcement position that must be maintained at all times.

The height of individual grout lifts depends on the type of units and the strength of the mortar joints. If too high a lift is attempted or the joints have not hardened sufficiently, there is a risk of joints blowing out under pressure of the fluid grout. This will be less of a risk if the units are of high suction so that the grout stiffens quickly as a result of water being drawn into the units.

After the cores are filled with grout they must be topped up to compensate for shrinkage. This is usually best done approximately 30 minutes after initial filling. This top-up should be rodded to ensure that it merges with the previous grout filling.

The most important requirement for the grout is that it should have at least 300 kg of cement per cubic metre, to ensure adequate corrosion protection for the reinforcement. It is only necessary to sample and test the strength of grout if this is called for in the specification. (Additional information on grout is given in Section 3.4.)

4.7 Cleaning

The final stage of construction of clay masonry is cleaning and removal of mortar residue from the units. Guidance on appropriate techniques for this cleaning and for the removal of stains is given in the guide on Cleaning of Clay Masonry. It is essential that cleaning be carried out with care, especially if it involves the use of high pressure water sprays. Figure 12 shows the disfiguring effect that high pressure cleaning can have on mortar joints if not used correctly.

Figure 12. Damage to mortar joints by high-pressure cleaning

5. Tolerances

5.1 General

Tolerances are necessary to allow for inevitable variations in the size of masonry units and inaccuracies in construction techniques. Masonry must generally be built to the specified dimensions within the tolerances provided by the standards. Tolerances for face-work or aesthetic reasons should ideally be a contractual matter agreed between the parties; tolerances for structural reasons must be complied with to ensure that the structure performs in the manner assumed by the designer and implicit in the standards. The latter are tighter than the former.

Tolerances are given in the standards to cover all aspects of construction:

- Location of elements in plan and elevation
- Deviation from plumb
- Deviation from horizontal
- Thickness of bed and perpend joints
- Width of cavities
- Location of reinforcing bars during grouting
- Bow of surfaces

Bow refers to the curvature of the plane of the masonry and does not refer to depressions or raised areas on individual bricks departing from the plane.

5.2 Structural tolerances

The limits on position in plan and relative displacement between storeys are necessary to ensure proper load transfer through the building. Limitation of the bow in any wall is necessary to ensure that the wall has its correct vertical load capacity as designed. The method of measuring bow is specified in AS 3700.

The deviation from plumb, for structural considerations, is not to exceed plus or minus 10 mm per 3 m height or 0.05 times the thickness of the leaf, within any storey. The latter limit will usually govern. The limit of 0.05 times the thickness of the leaf corresponds to the nominal eccentricity that is always assumed by the vertical loading design rules. These limits on deviation from plumb are illustrated in Figure 13 for the common wall thicknesses and a range of storey heights. It can be seen that the limit of 0.05 times the thickness governs in all cases except the 230 mm leaf. The maximum deviation within the height of the building is limited to plus or minus 25 mm.

Limits on joint thickness and alignment are to ensure correct flexural and compressive load capacity and the limit on deviation from the specified cavity width is primarily to ensure proper performance of the ties.

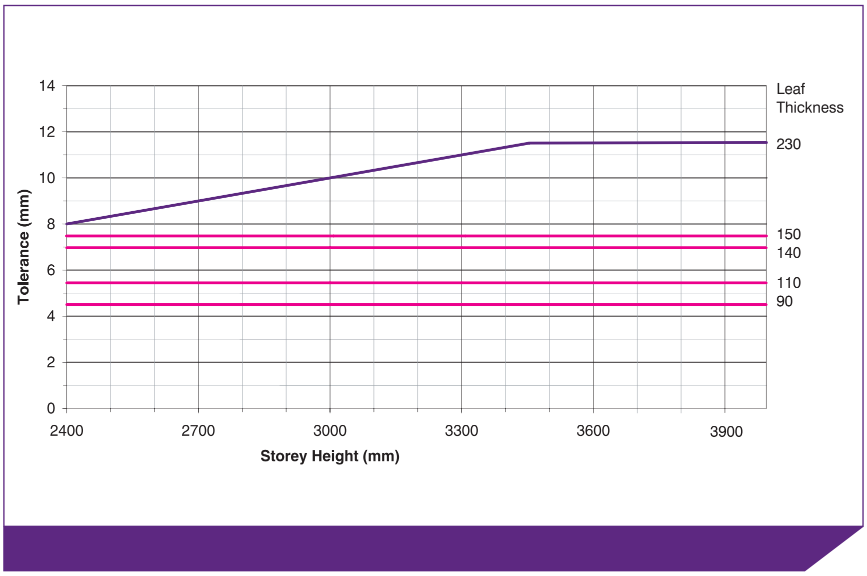

Figure 13. Structural tolerances for out of plumb (within each storey)

5.3 Appearance

Unless otherwise agreed between the builder and the client, the following tolerances are recommended, over and above the structural tolerances, for the purpose of ensuring a generally satisfactory appearance.

- 10 mm maximum deviation from plumb in any member.
- 3 mm maximum bow in the plane surface of any member.
- 2 mm maximum step between any two masonry surfaces that are both visible.
- 5 mm maximum deviation of the average perpend thickness from that specified.
- 8 mm maximum difference between the thicknesses of any two perpends in a wall.

These tolerances are currently given in AS 3700 for non-structural facework tolerances. However, consideration should be given to the dimensional class of the masonry units when applying these tolerances. For example, bricks having a dimensional class of DW0 are often intended to provide a rugged appearance and the strict application of these non-structural tolerances would be difficult, if not impossible, to satisfy. Figure 14 shows an example of poor control over perpend joint thickness.

Figure 14. Poor control over perpend joint thickness

6. Temporary bracing

The standards give no rules for temporary bracing during construction and there is no generally accepted guidance available. AS 3700 imposes the overall requirement that masonry under construction must be braced or otherwise stabilized as necessary to resist wind and other lateral forces, without impairing the structural integrity. It is left to the builder or designer to determine how this should be done in each particular case.

Once mortar joints have hardened, masonry develops a certain level of bond strength quite quickly and the standards assume it has reached full strength in seven days. It is probably reasonable (and conservative) to assume that masonry has no bond strength for the first three days, then 50% of its full strength up to an age of seven days. On this basis it is possible to calculate safe working heights for unbraced masonry, taking into account wind loading for the height of building, region, topography etc.

Wind loadings differ widely depending on the circumstances, and it is therefore not possible to give figures applicable to all situations. As a guide, the limiting heights in Table 1 have been calculated using f'_{mt} equal to 0.1 MPa (half the code requirement), for various wall thicknesses and the wind classes of the wind loads for housing code AS 4055[14]. This indicates typical figures that might be derived for walls with vertical supports at four metre centres and no top support (for example, prior to installation of a top plate and roof trusses). Walls of any greater height should be propped with temporary braces until the masonry has gained sufficient strength to be self-supporting.

The wind loading code AS 1170.2[15] requires freestanding walls to be designed to resist a pressure of 1.8 kPa. Freestanding walls will usually have a membrane or non-masonry material at their base, requiring an assumption of zero tensile strength at this point. Using these values, Table 2 shows height limits calculated for a sheltered suburban environment with building heights up to 4 metres. These heights are for freestanding walls with no means of support.

It should be emphasized that both Table 1 and Table 2 are intended as guidance. No reliance should be placed on these figures without independent engineering advice to suit the particular circumstances. It should also be noted that these figures are based on wind loading only and no account is taken of other possible loads arising either accidentally or from construction activities.

Table 1. Limiting heights for masonry under construction (walls with vertical supports at 4 m centres, age 3 to 7 days)

	Wind class N2		Wind class N3	
Wall thickness (mm)	Single leaf height (mm)	Cavity wall height (mm)	Single leaf height (mm)	Cavity wall height (mm)
90	880	2050	525	1360
110	1050	2600	620	1580
140	2400	N/A	1580	N/A
150	2700	N/A	1700	N/A
190	3050	N/A	1840	N/A
230	8000	N/A	2600	N/A

Table 2. Limiting heights for freestanding masonry walls (sheltered suburban environments, building height up to 4 m)

Wall thickness (mm)	Limiting height (mm)
90	124
110	186
140	301
150	345
190	554
230	812

The limiting heights shown in Table 2 are impractical for most construction situations but are quoted here to highlight the need for walls under construction to be supported against wind loading. Any masonry wall built to greater heights than those shown in Table 2, with no support from returns, intersecting walls or other means, should be propped with temporary braces until it is connected to the supporting structure as required by the design. The values shown in Table 1 can be used as a guide for props at 4 m centres.

During periods of high winds, to ensure safety for all masonry less than seven days of age, the vicinity of any unsupported wall should be evacuated on either side for a distance of the height of the wall plus 1.2 m.

7. Strength testing of masonry

7.1 General

AS 3700 provides two methods of assessing the strength of masonry – compressive strength and flexural strength. Their use depends on the type of masonry structure and the circumstances surrounding the testing. Apart from research applications, strength tests may be carried out to:

- Assess the quality or compliance of masonry during construction. This is only required when design strengths higher than the default are used and the masonry is declared as *Special Masonry*.
- Determine design characteristic strengths for masonry constructed with new or unfamiliar components. This application is rare and is outside the scope of this manual.
- Assess the adequacy of a structure that has failed or where there is some doubt about its strength. This situation is outside the scope of the standards, although the procedures given there can be used if appropriate.

When specimens are prepared for testing, the materials and bricklayers should be the same as those used on the job, so that in every respect the test specimens represent the masonry actually being constructed on site. AS 3700 defines the laying procedure for test specimens in order to simulate the normal laying of masonry. The bricklayer should pause for a time between stringing out the mortar and bedding the units on it because the run of mortar strung out in normal work would be longer than that required for a typical sample of test specimens. The timing of the operation is important, to allow water transfer from the mortar to the lower course of units before the upper course is bedded down. It is also important (particularly for flexural tensile tests) that the joint treatment for the test specimens should be the same as that used for the masonry in the job.

For both compressive and tensile tests, the testing is carried out at an age of seven days. When specimens are constructed specifically for testing, wrapping them in polythene sheeting immediately after construction promotes curing and is required by AS 3700.

7.2 Quality control testing of special masonry

Whenever a designer uses a higher design strength than the default value given in AS 3700, the corresponding masonry is classified as Special Masonry. This means that site testing for quality control becomes mandatory for that masonry and must be carried out at the prescribed rate. This testing is usually for either flexural tensile bond strength or compressive strength and would rarely be required for both on the same job. The number of specimens in a sample is at least three for compressive strength and at least six for flexural tensile strength. The procedures for testing are described in Sections 7.3 and 7.4. All assessment of test results is based on the average strength of the test sample.

The sampling rate is the minimum of:

- One sample per storey height
- One sample per 400m^2
- Two samples

Target strengths are given in AS 3700 for compression and tension as follows:

- Compression 1.4 f'_m
- Tension 1.7 f'_{mt}

Where f'_m and f'_{mt} are the design characteristic compressive and flexural strengths respectively. The multiplier for tension is higher than for compression because the inherent variability of tensile strength is higher than for compressive strength.

The test strength is the average strength of the specimens in a sample. For control of Special Masonry the test strength for each sample is calculated and if the average of the last four samples falls below 90% of the target, then action must be taken to correct the problem. Clearly, while normal variation is expected, if successive sample strengths fall below the target it would be prudent then to check the construction practices for compliance with the specification, rather than waiting for the code criterion to be violated.

The best way to monitor test results is to maintain a control chart on site and, as each test strength becomes available, to plot it on the chart, along with the average of that test result and the three preceding ones. Lines representing the target strength and 90% of the target should also be drawn on the chart.

The sample chart in Figure 15 shows six separate test sample results (A to F) from a hypothetical job. The design characteristic tensile strength (f'_{mt}) is 0.4 MPa, giving a target strength of 0.68 MPa. Each sample average is shown, as well as the running average of four samples (or less in the case of the first three samples). Although sample B has strength well below the target, the average of A and B is still above 90% so there is no immediate cause for concern. However, when sample C comes in even lower, and brings the average of A, B and C below the 90% line, then the causes should be investigated and remedial action taken. Sample D gives a higher result, trending in the right direction, but with an average (now of four samples) still below the 90% line. In this hypothetical case, the improvements are sustained, resulting in a high strength for sample E and leading to the running average being restored to an acceptable level at sample F.

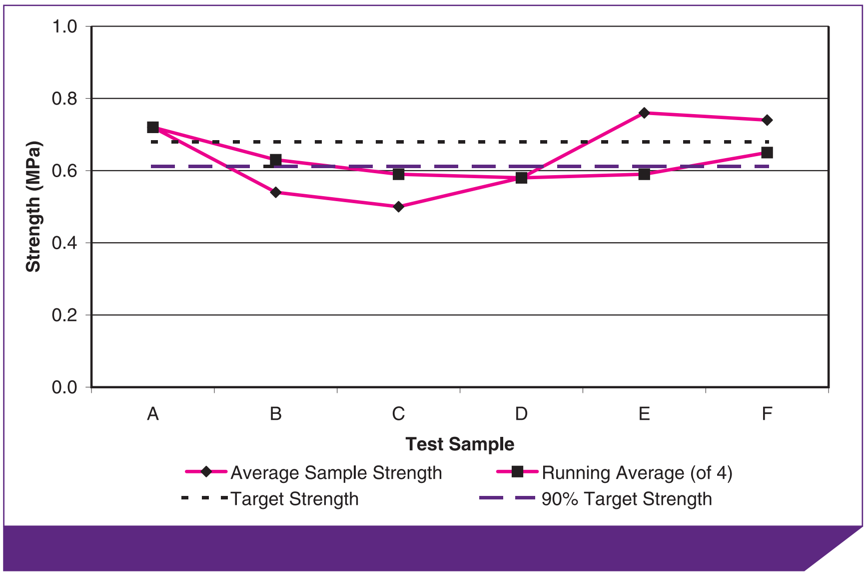

Figure 15. Example quality control chart

Note that every individual sample average is above f'_{mt} and therefore none of these samples fails the criteria for compliance (see Section 7.5). This is the purpose of quality control testing – to correct adverse trends such as that displayed by samples A, B and C in this example before they cause a situation where masonry is liable to rejection.

7.3 Compressive strength testing

For compressive strength testing the specimens are stack-bonded prisms and are required to have a height-to-width ratio between two and five, with at least three courses in the specimen. This latter requirement is to ensure that there are at least two mortar joints in the specimen because of the significant effect that joints have on compressive strength. It is also possible to derive compressive test specimens from undamaged portions of beams that have been tested for flexural strength or by cutting pieces from a wall. The last option would be used if the strength of constructed masonry were to be assessed and there were no test specimens made at the time of construction with the same materials.

Laboratory specimens must be cured by wrapping in plastic sheeting for seven days before testing. Testing is carried out in a compression test machine with plywood end caps on the specimen to minimise platen restraint and even out any irregularities in the surface. An aspect ratio factor is applied to the measured strength to eliminate the effects of platen restraint. AS 3700 permits the rejection of abnormal results, if they meet certain criteria, before calculation of the sample strength.

7.4 Flexural strength testing

For flexural tensile strength the specimens are stack-bonded prisms with between three and seven courses. The same specimen type can be used for both compressive strength and tensile strength tests, which simplifies the task of specifying construction of test specimens.

The bond wrench method of testing has almost completely superseded the bond beam test method, although the latter is still permitted by AS 3700. Using the bond wrench, the strength of each joint in the specimen is individually determined. The sample strength is then the average of the individual joint strengths. Again, it is permitted to reject abnormal test results and a characteristic strength is only calculated when the aim is to derive a design strength, not for compliance or site control test purposes. Whereas it is possible to test beam specimens and then use the remaining pieces for bond wrench tests this is rarely done.

In principle, the bond wrench applies a uniform moment to a bed joint, with negligible superimposed compression. It therefore measures the modulus of rupture of the joint. This moment is converted to a flexural tensile stress at the extreme fibre, using the section modulus based on the manufacturing dimensions of the units. This stress is equivalent to the flexural tensile strength property used in design.

It is also possible, and useful when the strength of constructed masonry is to be assessed, to use a bond wrench to measure the strength of joints directly in a wall. Access to the top of the wall is required and the perpend joints at both ends of the bed joint to be tested are cut through. The bond wrench is then attached and used to 'peel' off the brick. Subsequent tests can be applied to adjacent joints, followed by those in the courses below.

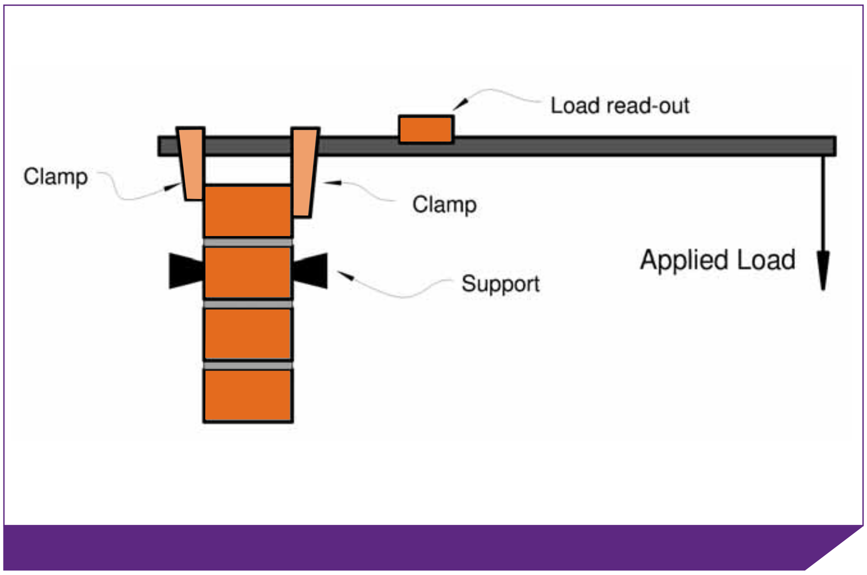

Figure 16. Schematic arrangement of bond wrench test

The specification of the bond wrench apparatus is more closely defined in the 2001 edition of AS 3700 than in earlier editions. It is important to check that any bond wrench used for testing actually conforms to the specification.

7.5 Assessment of compliance

The results of site tests can be used for the assessment of compliance of Special Masonry, as well as for quality control. Each individual test sample represents a segment of masonry on the job and this relationship should be tracked and recorded on site. Then if the result of any sample falls below a specified strength level the whole of the masonry represented by that sample is deemed not to comply with AS 3700.

If the test strength of any sample is below the design characteristic value (f'_m or f'_{mt} as appropriate) then the masonry represented by that sample is deemed not to comply with the standard. What happens then is a contractual matter, and various options are discussed in Section 7.6. At first sight it might appear strange (even generous) that the requirement is to compare an average strength with a characteristic value but the method is based on an assessment of the risks involved and is designed to minimise the chances of adequate masonry being rejected and forcibly demolished.

The sample chart in Figure 17 shows six separate test sample results (A to F) from a hypothetical job. The design characteristic strength (f'_{mt}) for this job is 0.4 MPa. Each sample average is shown, and also the target strength (0.68 MPa) for quality control.

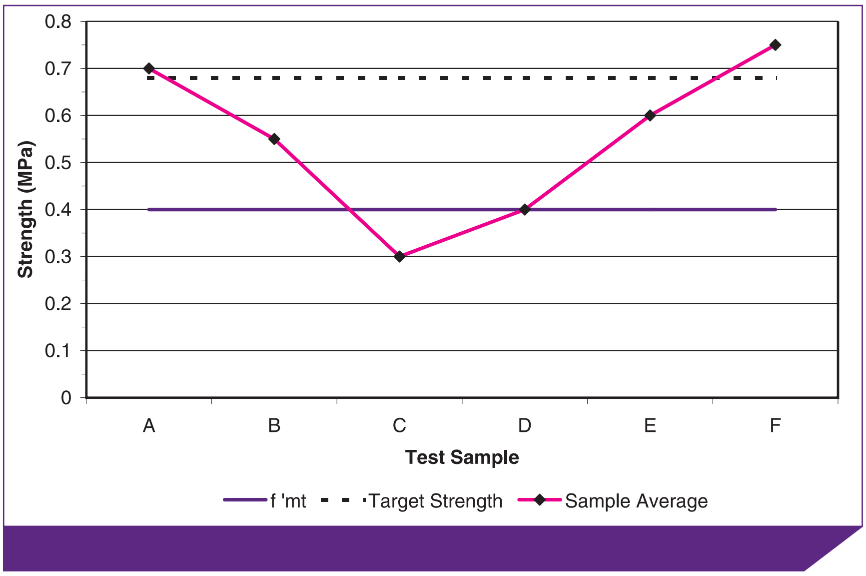

Figure 17. Example compliance assessment chart

Both samples A and B pass the criterion for compliance but, whereas A meets the target for quality control, B falls below and should be a cause for concern. The downward trend continues and sample C fails the compliance criterion because its strength is below *f 'mt*.

Improvements are made and sample D satisfies the compliance criterion but is still well below the target strength, indicating that further improvement in site practices or materials is necessary. The upward trend continues and sample E complies but is still below target. Further improvements in this hypothetical case bring sample F above the target strength.

As a result of this series of tests, only sample C fails the compliance test. However, all the masonry associated with this sample is deemed not to comply with AS 3700. The appropriate actions to deal with this failure are described in the next section.

7.6 When masonry does not comply

When a test sample fails the compliance assessment, the whole of the masonry represented by the sample is deemed not to comply.

What happens when masonry does not comply with the standard is a contractual matter between the builder and his client and is therefore not specified by AS 3700.

Options to be considered include the following:

- A design check to see if the particular masonry element (with reduced strength) still has sufficient resistance to withstand the design loads. Many masonry elements are over-designed because a uniform specification of wall thickness and materials is used throughout the job.
- Carrying out further tests on specimens constructed on site to assess their strength and identify reasons for failure of the initial test sample.
- Carrying out tests of the masonry strength within the wall (by in situ bond wrench or by cutting specimens from the work) – see below.
- Strengthening the construction by retrofitting.
- Demolishing and rebuilding the masonry.

Where problems arise in masonry construction or where doubt exists that the masonry strengths meet those required by the design, guidance is given in AS 3700 (Appendix I) for carrying out tests on the constructed masonry. This will usually involve obtaining test specimens directly from the wall, which can be for flexural or compressive strength testing. Use of the bond wrench for testing in situ was discussed in Section 7.4.

8. Mortar testing

8.1 General

AS 3700 also provides a test method for durability of mortar joints. This can be used to assess the durability potential of mortar mixes not deemed-to-satisfy the requirements of the standards or to assess compliance of new construction. The use of this test is described in Section 8.2.

When a mortar is to be used that is not included in the deemed-to-satisfy specifications of the standards, a durability grade (M2, M3 or M4) must be obtained by the scratch test, using the criteria in AS 3700 Table 10.2.

When the mortar used in construction is one of the mixes included in the deemed-to-satisfy specifications of the standards, but there is doubt about compliance with the mix proportions, AS 3700 Clause 11.3.3.5 requires a chemical test to be carried out for cement content (see Section 8.3). If the mortar fails this test, then there would be reasonable doubt that the required properties of the mortar would be reached, and AS 3700 Clause 11.6 would require strength tests. These strength tests would be carried out as described in Section 7 and a course of "reasonable action" would be necessary if these tests did not show the required strength properties. In a case where the required strength of the masonry was not high and the strength tests showed it to be adequate, but durability was a potential concern, then a scratch test to assess the durability potential would be a reasonable course of action. If the mortar failed the scratch test, the durability could be increased by the application of a hardening solution or by re-pointing the mortar joints.

8.2 Scratch test

The scratch test was introduced to AS 3700 in Amendment 1, published in 2002. The operation of the test is described in AS 3700 Appendix FA. The test measures the indentation of a spring-mounted probe into the joint under a controlled scratching action. The appendix provides an in-principle description of the scratch test tool and a procedure for sampling and testing to derive a 'scratch index'. Because of the natural point to point variability in mortar surface properties, the scratch index is derived as the average of five separate measurements of penetration. A higher index indicates lower surface hardness and therefore lower potential durability of the mortar. The scratch index has been shown to correlate well with the cement content of the mortar, but is also strongly affected by joint tooling and the quantity of fine material (lime or clay) in the mortar.

The performance of a scratch test on a mortar joint in situ is shown in Figure 18.

Figure 18. Scratch test performed on a mortar joint

8.3 Cement content

This test is, strictly speaking, a test for the content of calcium oxide and soluble silica and is done in accordance with AS 3700 Clause 11.11. This clause provides an acceptance level of 80% of the required mass of ingredients for the specified mix proportions. Testing for cement content should be used with care because, while it can be a good indicator of compressive strength, it often bears little relationship to the flexural tensile strength of the masonry. It is much more relevant to durability, but for this there are no established performance criteria that relate to cement content. In many cases, it is preferable to test the required property of the masonry (such as tensile strength) rather than the cement content.

9. References

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14 *Wind Loads for Housing*, AS 4055, Standards Australia, Sydney, 2006.

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