

MOISTURE EXPANSION OF CLAY BRICKS: AN APPRAISAL OF PAST EXPERIENCE AND CURRENT KNOWLEDGE

TOM McNEILLY

Research Director
Brick Development Research Institute,
Melbourne, Australia.

ABSTRACT

An understanding of the amount of moisture expansion in clay bricks and the rate at which it occurs are of paramount importance when dealing with bricks in construction. Techniques for predicting the amount of expansion that will take place in particular bricks are discussed in this paper. It is suggested that the method developed by the Brick Development Research Institute (BDRI) and now written into the Australian Standard Method for Testing Clay Bricks (31) provides answers of sufficient accuracy for building purposes. It is however acknowledged that some refinements are possible in aspects of the test and in the reporting of results.

The two principal directions of brickwork movement - horizontally in the length of the wall and vertically in its height - are discussed and proposals are put forward for control measures aimed at preventing the damage which results from such movements. The possibility that movement might be eliminated or reduced if bricks can be set aside for a time after they are made and before they are built into structures is discussed and found to be of minor importance. The paper concludes with a proposal for control of the consequences of moisture expansion in construction.

1. INTRODUCTION

This paper considers the phenomenon of moisture expansion in clay bricks as it affects the buildings from which they constructed. It attempts to discuss the topic on an international basis, but it will have an Australian bias. This is inevitable given that it was the high level of expansion in bricks manufactured in Australia during the 1950s and 1960s that brought the matter into the bright light of investigation and controversy, and it has been in this country that much of the important experimental work has been carried out.

In covering various aspects of the topic, brief mention is made of some historical detail. But the paper is not primarily concerned with history. For the Australian historical picture, readers are referred to the relevant publication by BDRI (6) and, for the UK story, to FOSTER and JOHNSON (17). Similarly, the mechanism of moisture expansion is not discussed in any detail, it being a matter for ceramic scientists rather than for those involved in the end use of the products. The important work of Dr W.F. Cole at the CSIRO Division of Building Research has provided a basis for effecting significant reductions in the amount of expansion. However, current understanding of the mechanism is incomplete and more could be done.

2. THE MAGNITUDE AND RATE OF EXPANSION

In discussing the phenomenon of the moisture expansion of fired clay bricks, it seems necessary first to emphasise the great variation in the magnitudes of expansions that occur in different parts of the world and the rates at which those expansions take place. In some parts of the world, brick growth is of only negligible importance, but such is not the case in Australia. Although the situation is now much better than it was, a common reaction among local architects, builders and structural engineers is still one of resentment and anger that the phenomenon has caused them great

trouble. In Figure 1, the range of the time-expansion curves for some Australian bricks - those quoted by GOLDFINCH (19) in his paper at this conference - are compared with data extrapolated from those quoted in 1980 by SCHELLBACH and SCHMIDT (28) for bricks from the Federal Republic of Germany. The magnitude of ultimate expansion of German bricks is shown to vary from 0.05 mm/m up to a maximum of 0.62 mm/m. By comparison, the Australian bricks have ultimate expansions varying from 0.6 mm/m to at least 2.2 mm/m. Although it is now known that 0.6 mm/m is close to the Australian average and Goldfinch's figures are no longer typical of either his own company's products or those of most other local manufacturers, it has to be acknowledged that there is a substantial difference in the magnitudes of growth that must be accommodated in these two countries. However, more important is the rate at which the expansion takes place. For the majority of German bricks, Schellbach and Schmidt show that growth close to the ultimate is usually achieved in five to ten days from the kiln-fresh state, although there are some cases where up to 90 days must elapse before this occurs. By contrast, it takes at least 5 years before most Australian bricks approach their ultimate growth.

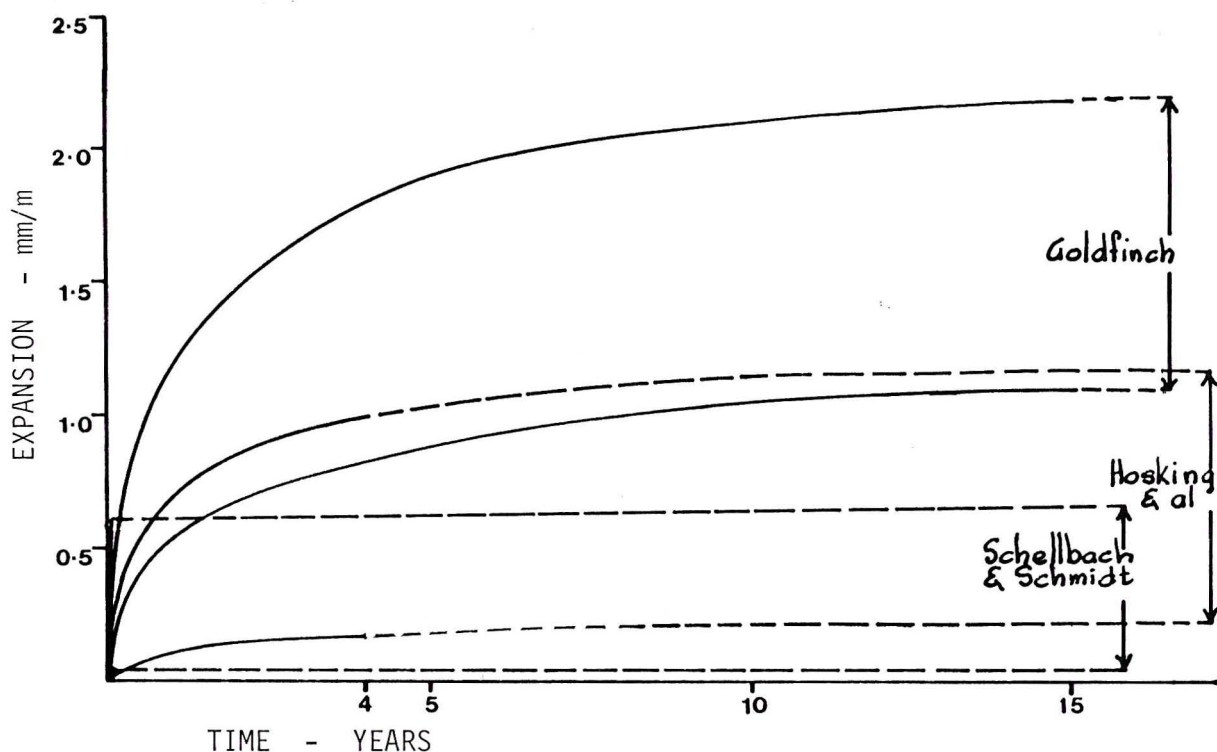


FIGURE 1. TIME-EXPANSION CURVES FOR SOME BRICKS OF AUSTRALIAN, GERMAN AND USA ORIGIN

All Australian expansion measurements are taken on the length of the brick specimens. Those of Schellbach and Schmidt were taken on the height of their extruded specimens because they believed that growth in the height of a brick should be greater than in its length as a result of the method of manufacture. If this is so, some details of the comparisons drawn above may change, but it is unlikely that these differences will detract from the general pattern of differences.

On the site where construction is taking place or in the the drawing office where construction is being planned, differences between the magnitudes and rates at which expansion takes place would cause operatives in the two countries to doubt if they were dealing with the same phenomenon.

Schellbach and Schmidt correctly described brick moisture expansion as being "...of little or no importance...in most of the types of bricks used..." in Germany. Such is not the case in Australia even though the situation has improved considerably from that represented by the growth patterns of the 15-year-old bricks quoted by Goldfinch.

It seems reasonable to suppose that the German and Australian moisture expansions values represent something close to the extremes of world patterns in this property. Some evidence favouring this conclusion is given by HOSKING, WHITE and PARHAM (21) who, in 1966, examined the moisture expansion of bricks and laboratory specimens in Illinois, USA. The expansion magnitudes they reported were slightly higher than those given for Germany, but the diminution in the rate of growth is much closer to that slower change found to apply to Australian bricks. Their four-year results, extrapolated to 15 years, are also shown in Figure 1.

In 1983, COLE (12) summarised part of some of his earlier writings (10) (11) when he said "It was shown that Australian brick-making clays are high in $K_2O + Na_2O$ and low in $CaO + MgO$, and consequently have high expansions. British and American brick clays were the reverse." Differences of this sort between the mineralogical and chemical compositions of different clays are shown by him to account for differences in expansion magnitudes. A number of Australian manufacturers have used this information and added lime or crushed basalt to their clay mixes as part of the procedures employed to bring about substantial reductions in the total growth of their products. Still to be explained is the high early growth rates of some bricks and the lower early growth rates of others, perhaps particularly those made in Australia. If all bricks could be induced to substantially complete their expansion in five to ten days, problems associated with moist expansion could simply be eliminated by ensuring that all bricks are at least ten days out of the kiln when they are built in.

In Britain, there are some clays that follow the very fast early growth of German bricks and some that follow the much slower early growth of Australian and some USA bricks. THOMAS (33), for example, examined two UK brick types, both made by extrusion. The first type was made from a blue boulder clay fired at $980^{\circ}C$ and the second from carboniferous shale fired at $1050^{\circ}C$. The clay brick grew a total of 0.72 mm/m in 517 days, but managed 32% of that total in the first two days. By contrast, the shale brick grew 0.27 mm/m in the same period but only 3.5% occurred in the first two days. These results serve to show that variation within one country can be considerable and possibly account for different past perceptions of the need to take the phenomenon seriously.

3. PREDICTING THE MAGNITUDE OF EXPANSION

In 1928, SCHURECHT (30) was developing autoclaving techniques under a pressure of around 1 MPa (150 psi) for one hour to induce moisture expansion in the expectation that he was accelerating a natural occurrence and thus speeding the study of its effects on ceramic bodies - in this case, the the development of crazing in ceramic glazes. Others, including MILLS (27), TREISCHEL (34) and MCBURNEY (23), subjected other ceramic materials, including structural clay tiles, to similar treatments with pressures varying up to around 1.7 MPa (250 psi) and treatment times up to seven hours. By 1952, the American Society for Testing and Materials proposed a standard test procedure (32) which involved subjecting specimens to a one-hour treatment at 150 psi. Except for the work of McBurney, all autoclaving work related to the crazing of glazes.

When the Australian work on the topic of moisture expansion of clay bricks began, the autoclaving technique was chosen as the basis for experiment. By 1958, HOSKING and HUEBER (20) were reporting their belief that, by repeated autoclaving for 24-hour periods at a pressure of 1.55 MPa (225 psi), they were able to induce the total possible expansion in a variety of ceramic products. For bricks, the average expansion induced by this method was the seemingly high value of 3.5 mm/m, but some specimens ranged as high as 8.5 mm/m. Subsequent work by the same group, reported by WATERS, HOSKING and HUEBER in 1960 (35), lead to the conclusion that autoclaving produced an unsatisfactory relationship with natural expansion "...apparently due to the autoclave expansion being not simply an acceleration of the natural expansion but, in part at least, an expansion produced by reactions other than those that occur at ordinary temperatures." The authors went on to conclude that autoclaving specimens "is not a satisfactory means of determining what allowance should be made...in the design of the structures and the way in which the bricks are used."

By 1964, CULLEN, KLUCIS and McDOWALL (13) had adopted a milder steam treatment at atmospheric pressure and reported "that the ratios of 30-day and 90-day natural expansions to 4-hour steam expansion were fairly constant". In 1967, FREEMAN and SMITH (18) reported a good correlation between natural expansion for 128 days and steaming at 100°C for six hours and, in 1970, McDOWALL and BIRTWISTLE (24) reported a mathematical relationship between the expansion induced by four hours in a steam bath at 100°C and the natural expansion over time.

The McDowall-Birtwistle relationship has been used in the method developed by BDRI to accelerate moisture expansion and determine what is called the "characteristic expansion" of a particular brick type. Characteristic expansion is a value approximating the five-year natural expansion and is a version of the "expansion index" advocated for use by DE VEKEY (14). The method was further developed by BDRI (3) (5) and is now incorporated in the Australian Standard for determining the characteristic expansion of bricks (31).

A view seems to be developing that bricks should be separated into groups with low, medium and high characteristic expansions or expansion indices. FOSTER and JOHNSON (17) have made a suggestion for grouping UK bricks, and a similar Australian proposal has been developed by the Association of Consulting Structural Engineers of New South Wales and published in the Masonry Code of Practice (26). It also appears in the Australian Building Specification (2) where it is accompanied by a requirement that a certificate be obtained prior to the delivery of bricks to a building site stating the characteristic expansion of the bricks. The certificate must not be more than six months old and must have been produced by a laboratory registered with the National Association of Testing Authorities to carry out the standard accelerated test.

Both the UK and the Australian proposals are set out as part of the information given in Table 1 (see below). As might be expected, the Australian categorisation covers bricks with higher expansion values than those proposed by Foster and Johnson. Since many Australian brick manufacturers have successfully reduced the expansion of their products, it seems possible that the UK values and categories may come to be suitable for Australian bricks. On the other hand, the measurement of expansion values of bricks made in parts of the world other than Australia has not been particularly extensive or systematic and a complete survey of the property may disclose the fact that, in many places, there are some products that can have characteristic expansions as high as 2.4 mm/m.

4. HORIZONTAL EXPANSION

In 1966, SCHUBERT (29) conducted an examination of 104 structures in the Sydney area constructed with semi-dry pressed bricks and, among other things, noted significant differences in movement between brickwork in the outside leaves of external cavity walls and the brickwork in parapets and garden walls. This work influenced further thinking at BDRI and at the Experimental Building Station (EBS), particularly in relation to the effects of restraint on brickwork growth. Working in collaboration, the two organisations developed similar proposals for the design of the spacing and size of control gaps (joints) to accommodate brick expansion. A BDRI publication, "The Design of Brickwork for Differential Movement" (4), was published late in 1973 and, by early 1975, EBS had published NSB 135 (15) to provide similar information. The control measures in these publications are broadly similar to those advocated by FOSTER and JOHNSON (17) in 1982 and this paper will, at a later stage, compare the two methods for calculating control gap spacing.

The method for calculating control gap spacing for a given brick type uses the characteristic expansion value obtained from the accelerated test and the following assumptions:

- In most walls, there are conditions of restraint which reduce the actual long-term expansion of the brickwork to half that indicated by the long-term (5-year) unrestrained expansion of the bricks themselves. In parapets, however, such restraint appears not to exist and the full amount of long-term unrestrained brick expansion is assumed to occur. On the other hand, in base brickwork which is not more than about 600 mm high between ground level and a sheet damp-proof course, experience shows that the risk of damage is slight if expansion gaps are omitted.
- Vertical expansion gaps are spaced so that the maximum movement at each gap is limited to 7 to 8 mm from the wall section on each side of the gap - that is, a total movement at the gap of 15 mm.
- Since corners and offsets are the places most vulnerable to damage, the first gap shall be located at a distance from each such corner or offset of not more than half the calculated gap spacing for walls in general. Hence, any wall or section of wall whose length between corners or offsets is more than half the calculated gap spacing shall be protected by the inclusion of a vertical control gap at approximately the centre of its length.
- The gap width shall be not less than 15 mm plus the compressed thickness of the joint filler plus a small margin for safety - say 5 mm - which gives an overall gap width of at least 20 mm.
- Gaps shall be cleaned to ensure that no hard materials such as mortar droppings remain in the gaps to prevent their proper functioning.
- Any joint filler used shall be of a highly compressible type. Rigid foam polystyrene and impregnated softboards are both too rigid to be suitable fillers for a closing gap.

Most of these assumptions seem likely to prove uncontroversial. A possible exception is the decision to assume that, in the ordinary run of walling, the restraint offered by surrounding brickwork and other elements of the structure would reduce brickwork growth to 50% of the actual brick growth. British work by DE VEKEY (14) and others such as FOSTER and JOHNSON (17)

suggests 60% and the Australian proposal will thus be seen by them to be to that extent unconservative.

If the above assumptions are satisfied, it can be shown that, in restrained walls with vertical gap spacings at S_v , the total closure at each gap would be:

$$S_v (0.5e_m + 0.35) \text{ mm}$$

where e_m is the residual unrestrained expansion of the brick at the time when it is built in, and 0.35 mm/m is an allowance for a temperature change within the wall of about 45°C. If the closure of the gap is to be restricted to 15 mm, then:

$$S_v = \frac{15}{0.5e_m + 0.35} \text{ m}$$

A similar approach to unrestrained brickwork in parapets gives:

$$S_{vp} = \frac{15}{e_m + 0.35} \text{ m}$$

where S_{vp} is the gap spacing in a parapet.

The most comprehensive non-Australian proposal known to have been made for the design of control measures to accommodate brickwork growth was made by FOSTER and JOHNSON (17). Table 1 compares the results using their suggested global expansion rates (60% of $e_m + 0.3$ mm/m for thermal expansion) with those resulting from the application of the BDRI method (50% of $e_m + 0.35$ mm/m for thermal expansion). The table uses the earlier discussed notion of categorising bricks into expansion groups. In using this grouping to simplify the description of control measures, it is necessary to assume that all members of the category have expansion properties at the upper end of the category.

Characteristic Expansion	Brickwork Expansion (mm/m)		Maximum Gap Spacing for 15mm movement (m)	
	UK	BDRI	UK	BDRI
Low (UK and Aust) less than 0.6	0.66	0.65	22.5	23.0
Medium (UK) 0.6 - 1.0 (Aust) 0.6 - 1.2	0.90	0.85	17.0	17.5
	1.02	0.95	14.5	16.0
High (UK) 1.0 - 1.8 (Aust) 1.2 - 2.4	1.35	1.25	11.0	12.0
	1.74	1.55	8.5	9.5

TABLE 1. COMPARATIVE VALUES FOR BRITISH AND AUSTRALIAN METHODS FOR DESIGNING BRICK EXPANSION CONTROL MEASURES.

Eleven years of Australian experience with the BDRI method shows that it provides satisfactory results. The differences between gap spacings determined by the two methods are small. It therefore seems desirable to reach agreement and to adopt one or other of these methods. Even if that agreement proves impossible to achieve and differences remain between the two countries, the practical differences in the locations of gaps will be

nearly undetectable. For the most part, low characteristic expansion values will be used in both places and it is at this level that the differences between the methods are at their smallest. A substantial body of Australian data, some of which are published in Table 6 of BDRI Technical Note No. 7 (7), show that approximately half of Australia's bricks have expansion values of less than 0.6 mm/m, and LOMAX and FORD (22) have estimated that some 80% of UK bricks have comparably low values.

5. VERTICAL MOVEMENT

With hindsight, it became clear that differential vertical movements between shortening structures and expanding brick cladding were likely to cause distress to one or both. In some ways, it is surprising to find that consideration of the problem in the literature is comparatively recent. ANDERSON (1) mentioned the topic in 1961 and FOSTER (16), writing in 1971, made an important distinction between modern reinforced concrete framed structures which are subject to creep, and the older steel framed buildings which are not. In addition, the former have a poorly supported, external single leaf of brickwork sitting on a shelf angle or concrete haunch and restrained only by ties across the cavity to a single inner leaf. In contrast, the external continuous leaf of the latter is bonded without a cavity to two internal leaves of brickwork well supported within the frame.

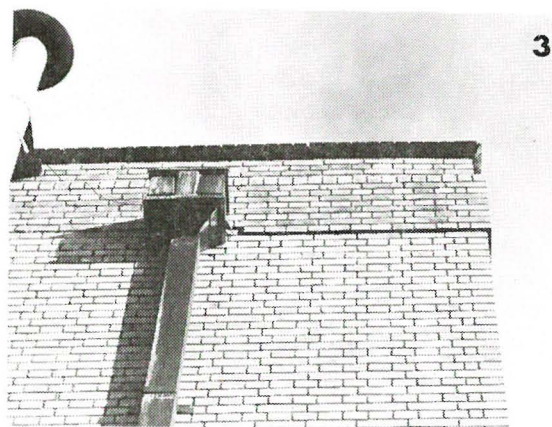
One such steel-framed building - in New York, USA - is shown in Figure 2. The pattern of cracking suggests some horizontal movement, presumably resulting from moisture expansion of the bricks, but the vertical growth and potential elastic shortening of the frame seem to have been contained. It is interesting to speculate on the possibility that this building is no longer supported by its frame. It is probably a loadbearing wall structure partially post-tensioned by the frame that was intended to support it. A second instance - the Chemistry School in the University of Melbourne - is illustrated in Figure 3. Again, the building is steel framed with a three-leaf brick cladding and, again, the vertical differential movements have been contained without damage. Not so the parapet where horizontal expansion has caused a very noticeable movement at the corner. No laboratory estimate has been made of the characteristic expansion of the bricks in this building, but the salt attack damage seen in the parapet brickwork indicates that the bricks are low-fired and it seems probable that its value would be in the order of 1.2 to 1.5 mm/m.

Another Australian building of interest is the Royal Melbourne Hospital. It was completed in 1942 and has had frequent and extensive repair of damage due to horizontal moisture expansion of the bricks with which it is clad, but only one minor instance of vertical differential movement is known to have required repair. This building is of the more modern type having cavity external walls with the outer leaf supported on shelf angles. It would therefore be seen as one having eccentric support of the outer leaf of the type that is commonly associated with troublesome differential vertical movement. The fact that the building has a steel frame with a minimum potential for shortening is seen as the reason for the absence of vertical movement problems.

All Australian examples of substantial vertical movement damage, typified in Figure 4, are associated with reinforced concrete frames, and it seems that creep shortening of such frames is the dominant cause of that damage. The magnitude of the shortening is usually at least as great as the growth of the brickwork. BDRI (4) (8) and FOSTER (16) have emphasised the need to provide compressible joints under the shelf angles or haunches that support the outer leaves of cavity walls, but further consideration suggests that



2



3

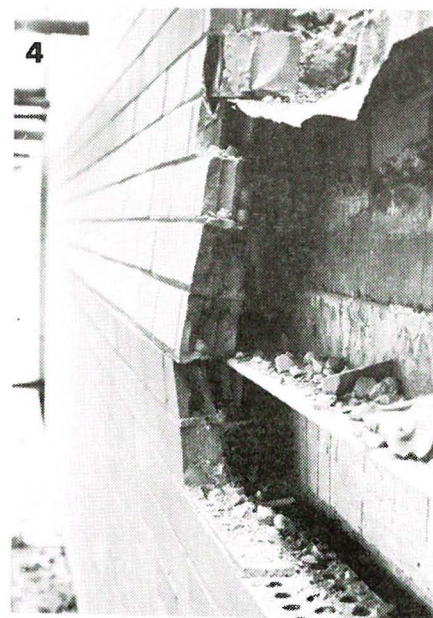


FIGURE 2. STEEL FRAMED BUILDING: NEW YORK

FIGURE 3. CHEMISTRY SCHOOL: UNIVERSITY OF MELBOURNE

FIGURE 4. TYPICAL VERTICAL MOVEMENT DAMAGE

the authors may have placed too much emphasis on brick expansion and too little on frame shortening. In an experiment carried out some years ago by BDRI and briefly mentioned by McNEILLY (25), two walls were built with day-old bricks, one 2 m high and the other 3.7 m. Measurement of their heights, using a chain of 10 inch Demec gauge points in the centre of each wall, showed a shortening in the first few days after they were built. It was six months in the case of the shorter wall and 12 months in the case of the taller before either was as tall again as it was when they were first built. WYATT (36), working on restrained vertical moisture expansion of clay masonry, has also shown that the initial movement is one of shortening. It seems probable that a structure usually has to cope with no more than about half of the potential expansion of the bricks. The BDRI publication on the topic (4) suggests that, in calculating the width of an expansion gap under a shelf angle or haunch, an allowance should be made for the full characteristic expansion of the bricks under consideration but this now seems conservative. Also conservative, but probably not unduly so,

is the suggestion that an allowance of 1.7 mm/m be made for the elastic and creep shortening of a concrete frame. For a steel frame or a loadbearing brick structure giving support to an outer leaf of brickwork, the suggested allowance is 0.5 mm/m. It is also suggested that the total movement at any gap (the gap closure) should be limited to 10 mm to eliminate the risk of damage to wall ties and flashings. The thermal movement required to be accommodated is the difference between inside and outside temperatures and, for Australian conditions, an allowance of 0.2 mm/m is seen as adequate; it may need to be greater in places with colder winters.

If the usual condition of a shelf angle or haunch support at each floor level is assumed and, if the floor-to-floor height in a reinforced concrete framed structure is 3.5 m, a total of $(1.7 + 0.2) \times 3.5 = 6.65$, say 7 mm, is required for frame shortening and differential thermal expansion. If the total movement is to be limited to 10 mm, it follows that a brick with a characteristic expansion as high as $3/3.5 = 0.85$ mm/m can be used if the full expansion is assumed to take place. If however, as seems probable, rather less than half the characteristic expansion is actually reflected in an increase in the height of the supported brickwork, it seems that bricks with characteristic expansion values at least as high as those categorised as medium in Australia (1.2 mm/m) can be comfortably accommodated.

Consideration must also be given to the contribution that inaccuracies in building make to differential vertical movement problems. Every instance of damage observed by the writer has been associated with poorly fixed or aligned shelf angles and haunches that leave the vulnerable external leaf teetering on the verge of being provided with no reliable support. It seems probable that, were these misalignments avoided, the incidence of damage would be much reduced.

6. "GRASSING" OF BRICKS

Literature on the subject of moisture expansion contains many references to the fact that, in the early stages after manufacture, brick growth is high and the rate of that growth diminishes with time. As a result, many authors have advocated that bricks be not used kiln-fresh. In Australia, building specifications commonly call for clay bricks to be kept for various periods after manufacture before they may be built into a structure. In calling up this practice, the term "grassing" has been borrowed from horse racing to describe a period of rest for bricks to enable them to get their early high growth out of their systems before they are used in building.

This requirement usually causes difficulty and it is worth considering the result before insisting upon it. If bricks are of the sort that approach their ultimate expansion in a very short time, such as five to ten days after they are drawn from the kiln, it is clearly worth ensuring that they are not built in until that expansion has occurred. However, many bricks, including those made in Australia, take approximately five years to approach their ultimate growth. Such bricks closely follow the logarithmic relationship between expansion and time first proposed by COLE (9). The version of that relationship given by McDOWALL and BIRTWISTLE (24) is as follows:

$$y = Z \times$$

Where y is the expansion over time t in months and x is the expansion induced by the 4-hour steam treatment. They found that $Z = -0.1929 + 0.6013 \ln(t + 2.2977)$. These equations are used to prepare the information given in Table 2 which is based on bricks with an x value of 0.025%; that is, a characteristic expansion of 0.6 mm/m (following the calculation method given above in connection with horizontal growth).

Elapsed Time Ex-Kiln	Residual Expansion to 5 years		Spacing of Control Gaps (m) [allowing for 15 mm movement]
	% 5-yr exp	mm/m	
24 - 36 hours	100	0.6	23
1 week	83	0.5	25
1 month	78	0.47	26
3 months	67	0.40	27
6 months	57	0.34	29
12 months	42	0.25	32

TABLE 2. RESIDUAL EXPANSIONS AND CONTROL GAP SPACINGS FOR GRASSED BRICKS WITH AN ACCELERATED EXPANSION OF 0.025%.

It can be seen from these results that, compared with using bricks that are as kiln-fresh as cool to the touch, keeping them at grass for a week or a month in a situation where control provisions have been designed on the basis of accommodating the full moisture expansion potential of kiln-fresh bricks does little more than provide a small margin for safety. Grassing for at least three months is needed to make any practical difference to the distance between expansion gaps and it seems probable that the occasions when this is needed will be few.

If a brick at the top of the Australian intermediate range of characteristic expansion values is to be used (i.e. $e_m = 1.2$ mm/m), the appropriate 15 mm control gap spacing is just over 14 metres. Keeping that brick at grass for one week will enable the spacing to be opened out to 17.5 m which may seem worthwhile. One month after manufacture, the appropriate spacing will be a little under 19 m, and six months at grass will be needed to enable the gaps to be opened out to the 23 m that is appropriate for bricks with low characteristic expansion values.

For kiln-fresh bricks with high characteristic expansion values ($e_m = 2.4$ mm/m), the gap spacing is 9.7 m, widening out to 11 m after one week. Even after 12 months storage, the appropriate gap spacing is still as high as just under 18 m and grassing for almost two years would be needed to bring the residual expansion down to the level of kiln-fresh bricks with low characteristic expansion values.

7. PROPOSALS FOR THE MANAGEMENT OF MOISTURE EXPANSION

Because characteristic expansion determined using the accelerated four-hour steam test has provided a satisfactory basis for calculating the spacings of control gaps, it is proposed that the method be adopted more widely in Australia and elsewhere. This would allow a more consistent approach to the management of problems caused by moisture expansion in clay bricks.

For convenience and simplicity, all bricks should be categorised into characteristic expansion groups; low, medium and high.

It is strongly recommended that recent test data be used for all calculations. Australian experience shows that characteristic expansion can change considerably over comparatively short times during the continuing or periodic production of what is visually the same brick. Halvings and doublings in results from tests taken less than one year apart have been observed.

Control gap spacings and gap widths should be calculated using the methods described in Sections 4 and 5 of this paper.

Grassing of bricks before they are built in is most appropriate for bricks that approach their ultimate expansion in five to ten days, but of doubtful value for those taking around five years to approach their ultimate expansions. This is particularly so for bricks with low characteristic expansions (0.6 mm/m or less).

Observation of many Australian buildings suggests that the damaging effects of moisture expansion in clay bricks would be better controlled if, rather than insisting on the supply of grassed bricks, more consideration was given to the location of expansion gaps.

Of great importance is the need to supervise the proper construction of control gaps. Again, observation shows too many instances where gaps have been sealed with an inadequately compressible filler or, more importantly, where substantial accumulations of mortar droppings in the gaps have not been cleaned out before the gaps are caulked. In both instances, movement is inhibited to the stage where the gaps do not function. The building is effectively without gaps and may be damaged as a result.

As part of the process of acceptance of these proposals, it is acknowledged that the current Australian method for determining characteristic expansion should have added to it some estimate of the error inherent in the method. It is also accepted that the time-expansion relationship on which it is based should be re-examined using the data that have accumulated since McDowall and Birtwistle derived their equation about 15 years ago.

The method being advocated is based on the notion that accommodation, by way of the provision of expansion gaps, should anticipate the total movement over the first five years of the life of the building and no more. The adequacy of this approach may be seen to require further examination. Extrapolation from the four-year expansion data of HOSKING, WHITE and PARHAM (21) for Illinois bricks - Figure 1 - suggests that the growth beyond five years for bricks with a modest characteristic expansion of around 0.7 mm/m is unlikely to be more than 0.1 mm/m. Extrapolation from the 15-year results of GOLDFINCH (19) suggests that the difference may be in the order of 0.3 mm/m for very high growing bricks with characteristic expansions around 2.0 mm/m. The generous allowance of 0.35 mm/m for thermal expansion provided in the Australian method of gap design will comfortably accommodate moisture expansion beyond the first five years for products with characteristic expansions of up to 0.7 mm/m. For the higher expanding bricks, a short period at grass to reduce residual brickwork growth after five years by up to 0.2 mm/m will be all that is needed. A period of one week will achieve this objective.

8. DESIGN PROCEDURE

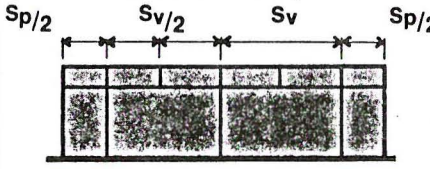
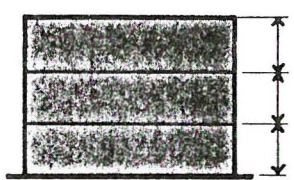
This paper concludes by presenting the design procedure previously proposed in the BDRI publication, "Clay Brickwork Expansion Gaps" (8).

DESIGN PROCEDURE

(External Clay Brickwork)

- (i) Determine the characteristic expansion — the e_m value — of the clay bricks to be used. Information is available from the brick manufacturer or BDRI.
- (ii) Select appropriate vertical gap spacings for walls and parapets from the table noting the maximum distances allowance between salient corners and the first gap in each direction. Provide slip-joints at re-entrant corners.
- (iii) Check that the vertical spacings of horizontal gaps do not exceed the maximum given in the table.
- (iv) Check to ensure that the gaps do not make the walls unstable.
- (v) Select appropriate construction details and use flashings, wall-ties and gap sealants with the correct properties.

MAXIMUM EXPANSION GAP SPACINGS FOR CLAY BRICKWORK (m)

NOTES: 1. Minimum vertical gap width: 15mm movement + gap width = around 25mm 2. Minimum horizontal gap width: 10mm movement + gap width = around 20mm	Maximum Spacings¹ (m) of Vertical Gaps 		Maximum Spacings² (m) of Horizontal Gaps 	
Characteristic Expansion of Bricks ' e_m ' mm/m	Walls S_v	Parapets S_p	Reinforced Concrete Frames	Steel Frames & Loadbearing Brickwork
Low (up to 0.3)	30.0	23.0	4.4	10.0
Medium (0.31 to 0.6)	23.0	16.0	4.0	7.8
High (0.61 to 0.9)	18.8	12.0	3.7	6.3
(0.91 to 1.2)	15.8	9.7	3.2	5.3
(1.21 to 1.8)	12.0	7.0	2.7	4.2
High (1.81 to 2.4)	9.7	5.5	2.3	3.2

9. ACKNOWLEDGEMENTS

The assistance of Julie Marginson and Jean Holzinger is gratefully acknowledged.

10. REFERENCES

- (1) ANDERSON, G.W. "Architectural and Structural Problems Involved in the Prevention of Cracking in Masonry." Paper 1.CB.3, Australian Building Research Congress (1961).
- (2) AUSTRALIAN BUILDING SPECIFICATION. Sect.230 Brickwork Sub-sect.134 Bricks Clause 05 Brick Expansion: Brickwork, p.93. Ed. B. Mortlock, Australian Building Industry Specifications Pty Ltd, Sydney, Australia (1982).
- (3) BRICK DEVELOPMENT RESEARCH INSTITUTE. "A Method for Estimating Long-term Dimensional Changes in Clay Bricks." Test Method No.B01, Melbourne, Australia (1969).
- (4) BRICK DEVELOPMENT RESEARCH INSTITUTE. "The Design of Brickwork for Differential Movement." Techniques, Second Series, No.4, Melbourne, Australia (1973).
- (5) BRICK DEVELOPMENT RESEARCH INSTITUTE. "BDRI Specification and Methods of Test for Clay Bricks, Part H, Method of Determining Permanent Expansion." Melbourne, Australia (1977).

- (6) BRICK DEVELOPMENT RESEARCH INSTITUTE. "Permanent Expansion of Clay Bricks: A Chronological Summary of the Publication of Information for the Construction Industry." Techniques, Second Series, No.5, Melbourne, Australia (1977).
- (7) BRICK DEVELOPMENT RESEARCH INSTITUTE. "Properties of Clay Bricks." Technical Notes on Clay Bricks, No.7, Melbourne, Australia (1980).
- (8) BRICK DEVELOPMENT RESEARCH INSTITUTE. "Clay Brick Expansion Gaps." Brickwork Facts No.1, Melbourne, Australia (1984).
- (9) COLE, W.F. "Possible Significance of Linear Plots of Moisture Expansion against log of a Time Function." Nature, No.196, p.431 (1962).
- (10) COLE, W.F. "Some Relationships between Mineralogical and Chemical Compositions and Moisture Expansion of Fired Clay Bodies." Jnl. Aust. Ceram. Soc., Vol.4, No.1, pp.5-9 (1968).
- (11) COLE, W.F. "Predictions of Moisture Expansion from Chemical Data." Jnl. Aust. Ceram. Soc., Vol.11, No.1, pp.20-21 (1975).
- (12) COLE, W.F. "Aspects of Early Australian Experience." Jnl. Brit. Ceram. Soc., Vol.82, No.5, pp.154-155 (1983).
- (13) CULLEN, G.V., KLUCIS, E.S., and McDOWALL, I.C. "Accelerated Moisture Expansion in Clay Brick." Jnl. Amer. Ceram. Soc., Vol.47, No.8, p.415 (1964).
- (14) DE VEKEY, R.C. "Moisture Expansion of Clay Masonry." Jnl. Brit. Ceram. Soc., Vol.82, No.2, pp.55-57 (1983).
- (15) EXPERIMENTAL BUILDING STATION. "Differential Movement in Buildings Clad with Clay Bricks. 2: The Design of Expansion Gaps." Notes on the Science of Building No.135, Aust. Govt. Publishing Service, Canberra, Australia (1975).
- (16) FOSTER, D. "Some observations on the design of brickwork cladding to multi-storey rc framed structures." BDA Technical Note, Vol.1, No.4, London, UK (1971).
- (17) FOSTER, D., and JOHNSON, G.D. "Design for Movement in Clay Brickwork in the UK." Proc. Brit. Ceram. Soc., No.30, pp.1-12 (1982).
- (18) FREEMAN, I.L., and SMITH, R.G. "Moisture Expansion of Structural Ceramics. 1: Unrestrained Expansion." Trans. Brit. Ceram. Soc., Vol.66, No.1, p.13 (1967).
- (19) GOLDFINCH, W. "Moisture Expansion: Update and Review." Paper accepted for the Proceedings of 7th IBMaC, Melbourne, Australia (1985).
- (20) HOSKING, J.S., and HUEBER, H.V. "Permanent Moisture Expansion of Clay Products on Autoclaving." Nature, No.182, pp.1142-1144 (1958).
- (21) HOSKING, J.S., WHITE, W.A., and PARHAM, W.E. "Long-term Dimensional Changes in Illinois Bricks and other Clay Products." Circular 405, Illinois State Geological Survey, Urbana, USA (1966).
- (22) LOMAX, J., and FORD, R.W. "Moisture Expansion." Jnl. Brit. Ceram. Soc., Vol.82, No.3, pp.79-82 (1983).

- (23) McBURNEY, J.W. "Masonry Cracking and Damage caused by Moisture Expansion of Structural Clay Tiles." Proc. ASTM, Vol.54, pp.1219-1241 (1954).
- (24) McDOWALL, I.C., and BIRTWISTLE, R. "Predicting the Long-term Moisture Expansion of Fired Clay Products." Proc. SIBMAC, Brit. Ceram. Res. Assoc., pp.75-79 (1970).
- (25) McNEILLY, T. "Brick Expansion: Aspects of the Australian Experience." Jnl. Brit. Ceram. Soc., Vol.82, No.1, pp.14-16 (1983).
- (26) MASONRY CODE OF PRACTICE. Clause 2.1.8: Dimensional Changes. Ed. L.R. Baker, Association of Consulting Structural Engineers of New South Wales, Sydney, Australia (1984).
- (27) MILLS, R.G. "The Use of the Autoclave in Testing Ceramic Products for Resistance to Crazeing." Jnl. Amer. Ceram. Soc., Vol.13, No.12, pp.903-914 (1930).
- (28) SCHELLBACH, G., and SCHMIDT, H. "Influence of the raw material and production methods on the deformation behaviour of clay bricks and blocks - effects of these deformations on building construction." ZI International, pp.651-663 (October 1980).
- (29) SCHUBERT, T.J. "Long-term Expansion of Brickwork. Techniques for the control of horizontal expansion in walls of Sydney texture bricks." Technical Record 52/75/383, Department of Works, Commonwealth Experimental Building Station, Sydney, Australia (February 1968).
- (30) SCHURECHT, H.G. "Methods for Testing Crazeing of Glazes caused by Increases in Size of Ceramic Bodies." Jnl. Amer. Ceram. Soc., Vol.11, No.5, pp.271-277 (1928).
- (31) STANDARDS ASSOCIATION OF AUSTRALIA. Australian Standard Methods of Sampling and Testing Clay Building Bricks: AS1226.5 Method for Determining Characteristic Expansion (1984).
- (32) Tentative Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick and Solid Masonry Units (C126-52), 1952 Book of ASTM Standards, Part 3, p.446 (1952).
- (33) THOMAS, A. "Moisture Expansion in Brickwork." Trans. and Jnl. Brit. Ceram. Soc., Vol.70, No.1, pp.35-38 (1971).
- (34) TREISCHEL, C.C. "Some Notes on Moisture Expansion Tests." Ceram. Age, Vol.25, No.2, pp.46-48 (1935).
- (35) WATERS, E.H., HOSKING, J.S., and HUEBER, H.V. "Tests for Potential and Past Moisture Expansion of Ceramic Building Units." ASTM Bulletin No.245, pp.55-59 (1960).
- (36) WYATT, K.J. "Restrained Moisture Expansion of Clay Masonry." Jnl. Aust. Ceram. Soc., Vol.12, No.2, pp.34-37 (1976).