Research Paper 16

The Moisture Expansion of Bricks and Walls

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1.0 Introduction

By 1969 the Brick Development Research Institute (BDRI) had published a method for predicting the amount of expansion over five years – called characteristic expansion – from bricks fresh from the kiln [1]. The method has since been published as Australian Standard 1226.5 [2] and a result has been that by 1975, collaboration with G W Anderson at the Experimental Building Station (EBS) had enabled them both to describe how the value could be used to design the spacings and widths of the gaps needed to control differential movements within a building made from or clad with clay bricks [3] [4].

The BDRI/EBS control gap design method is empirically based on field observations of brickwork damaged by brick growth and, in an attempt to develop a method for checking the assumptions on which the method is based, two brick walls were built from a cream coloured, stiff-plastic pressed and Hoffman kiln fired bricks and were instrumented with Demec gauge points for measurement of movements within them. The brickmaker was asked-to supply matching bricks for each wall that had been drawn from the kiln on the same days as those on which they were delivered and built.

2.0 Experimental design

One wall – about 7 m long and 3.7 m high – was lightly built within a frame of columns and floor slabs on the ground floor of a 12 year old, five storey, RC framed building to make it fully restrained. The second wall, built close-by and thus subject to virtually identical conditions, was about 5.3 m long and 2.3 m high. It was unrestrained, joining at its top and ends to timber framed highlights and doors. The walls were built on consecutive days using an accurately batched mortar of 1 part cement, 2 lime and 9 sand by volume. On each day two samples of five bricks taken from the delivery had their ends drilled with seats for micrometer measurement of expansion using the method of AS 1226.5. One sample from each day was steamed by the standard method and the other was set aside for measurement of natural expansion. An additional ten bricks were taken from the unrestrained wall for measurement of natural expansion by fixing three sets of Demec gauge points along the length of the bed face of each. Samples were all random and so do not fully comply with the standard's requirement for selection at the kiln to cover the range of firing conditions.

Horizontal and vertical strings of gauges were fixed across and up the walls in the centres of their height and length to measure overall changes in the two dimensions in both walls. Setting of the glue fixing the gauge points caused initial readings to be delayed until day 5 for the unrestrained wall, 6 for the restrained wall and 7 for the Demec gauged bricks. Subsequent readings were taken on walls and brick samples two days after the initial readings and then at the limes listed in Table 1.

The project was carried out with the initial help of Dr G D Base of the Department of Civil Engineering, University of Melbourne. It was hurriedly put together to gain information from walls being built to enclose more space for an expanding BDRI and was intended as a trial of the method. There was an unfulfilled expectation that a postgraduate student would further develop the techniques and use them in a more ambitious program.

3.0 Results

The expansions in the bricks on the shelf and in the strings of horizontal and vertical gauges are listed in Table 1 (page 3) where, with the exception of the time of demolition, stated times beyond 45 days are rounded by a few days to the nearest whole month or year. They are graphed in Figures 1 and 2 (page 4).

The Zsembery, Sharpe and McDowall [5] formula was used to calculate the expansions that would be predicted from the accelerated tests on the samples taken at the time of delivery and, as time passed, a major discrepancy between predicted and naturally occurring expansions became apparent and it was concluded that the bricks had probably not been delivered kiln-fresh.

In an attempt to resolve this dilemma, five of the ten Demec gauged bricks that were then 15 years old were halved lengthwise and tested by re-firing and steaming. Results were encouraging and, in order to provide more data, the bricks on the shelf being measured for natural expansion by micrometer gauge were similarly halved and had new reference points drilled in their ends. After measurement of length, one of each half was put back on the shelf while the other was refired and steamed.

Refiring and steaming methods were as described by Zsembery, Sharpe and Vucko [6] and also published as BDRI Test Methods W03 [7] and D04 [8]. Results of the original steaming and of these tests are given in Table 2. They suggest that different bricks were used in the two walls and they were seven or eight days old when built in.

The Demec gauged bricks on the shelf can be seen to have expanded much less than the companion bricks measured by the micrometer. First consideration of this result may seem to cast doubt on the suitability of the Demec gauge for the task. However, a study of individual results shows a disproportionate number of low-growth bricks in this sample to emphasise that it – taken by a non-standard method – did not represent the bricks in the wall.

Table 1. Expansion measurements: bricks and walls

Gauge location		Average expansion (mm/m x 10^{-3}) over time												
	No. of gauges	2D	5D	7D	13D	45D	6M	1Y	2Y	3Y	5Y	10.7Y	15Y	16Y
Demec shelf bricks	3 each on 10	–	8	–	–	–	130	202	289	350	482	718	861	890
Other shelf bricks Restrained wall*	1 each on *5*	–	–	–	–	–	–	–	500	–	683	960	1150	1180
Other shelf bricks Unrestrained wall*	1 each on 5	–	–	–	–	–	–	–	369	–	570	830	980	1010
Bricks in restrained wall** – vertical direction	n.a.	23	–	45	39	15	103	154	265	394	531	787	–	–
Bricks in restrained wall – horizontal direction	1 each on 5	8	–	29	32	52	71	113	179	238	294	406	–	–
Bricks in unrestrained wall – horizontal direction	1 each on 4	30	–	41	50	83	175	244	334	383	569	850	–	–
Restrained wall –vertical direction	String of 17	5	–	-11	-31	-60	-20	-2	88	167	262	506	–	–
Restrained wall – horizontal direction	String of 33	1	–	8	1	10	11	41	93	147	188	261	–	–
Unrestrained wall – vertical direction	String of 10	3	–	10	1	-22	37	89	229	324	522	858	–	–
Unrestrained wall – horizontal direction	String of 25	17	–	25	25	47	124	176	276	318	526	759	–	–

* Measured using the equipment described in AS 1226.4-1984.

** Calculated from the difference between movement over 3 and 2 joints. Not enough data for a similar calculation on the unrestrained wall.

Table 2. Natural v accelerated expansion prediction

	Bricks from:						
	Restrained wall			Unrestrained wall			
	Observed natural expansion (standard method)	Prediction based on:		Observed natural expansion measured by:		Prediction based on:	
		old steam value (mm/m)	new steam value (mm/m)	standard method	Demec gauge (mm/m)	old steam value (mm/m)	new steam value (mm/m)
Steam value	–	0.152	0.279	–	0.246	0.162	0.242
Age (m)	Average expansion (mm/m)						
27	0.50	0.31	0.56	0.37	0.29*	0.33	0.49
60	0.68	0.44	0.77	0.57	0.48	0.47	0.68
116	0.93	0.55	0.95	0.80	–	0.59	0.84
128	0.96	0.57	0.98	0.83	0.72	0.61	0.87
165	1.12	0.62	1.05	0.97	–	0.66	0.94
183	1.15	0.64	1.09	0.98	0.86	0.68	0.97
192	1.18	0.65	1.11	1.01	0.89	0.69	0.98

* 24 months old

Figure 1. Expansion v Time: Restrained wall

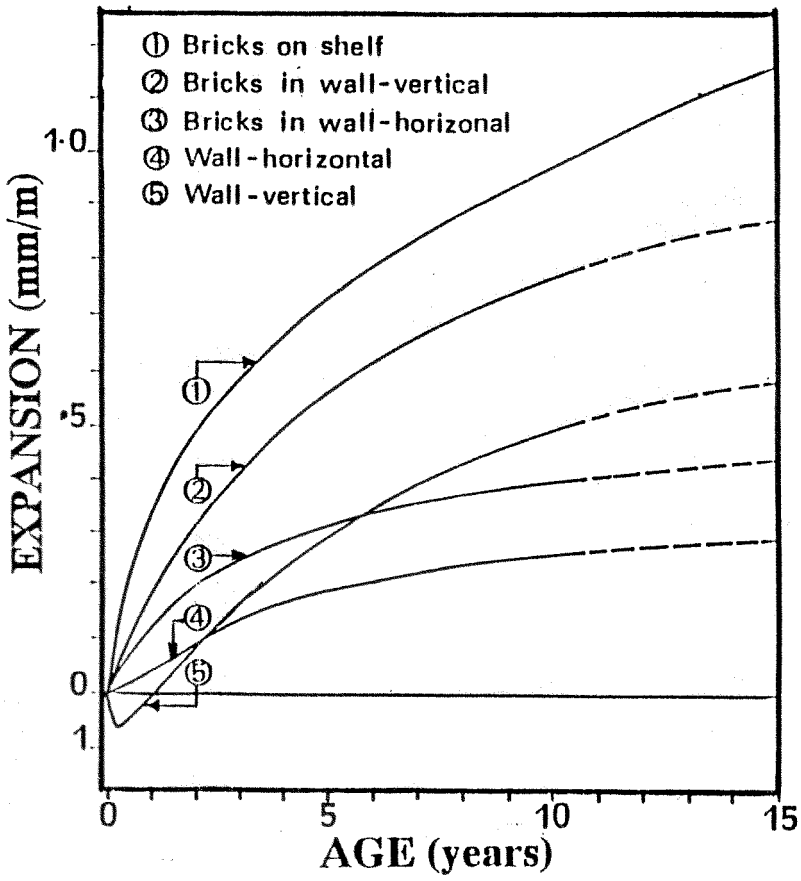
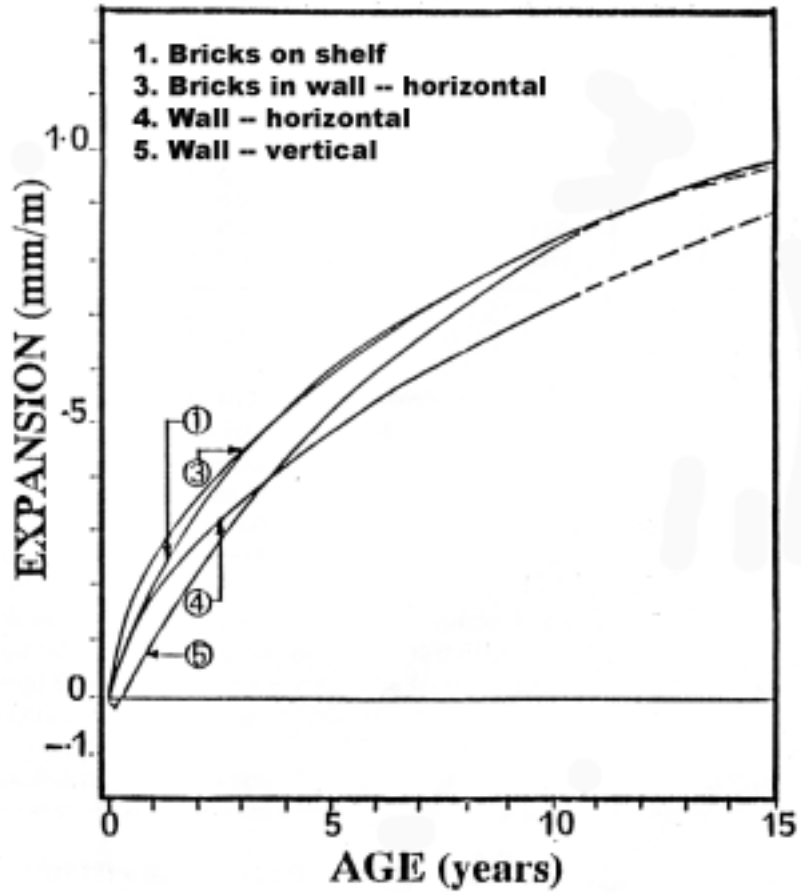


Figure 2. Expansion v Time: Unrestrained wall



4.0 Discussion

The BDRI/EDS method for designing control gap widths and spacings assumes that, in a restrained wall, horizontal expansion of brickwork will be half of the characteristic expansion of the bricks. For unrestrained brickwork, as in parapets and freestanding walls, horizontal brickwork expansion is expected to equal that of the bricks. Vertically it is assumed that the full expansion will occur in all walls. The design method assumes that, by providing a safety margin plus space for the characteristic expansion, or half of it in the horizontal direction in a restrained wall, any further expansion will be harmlessly contained within the structure.

Characteristic expansion is the average expansion induced in a sample of five bricks steamed at atmospheric pressure for four hours multiplied by a factor that depends on the magnitude of that expansion. The brick sample is selected at the kiln to represent the range of firing temperatures and must be taken so that initial length can be measured between 24 and 32 hours after the bricks are drawn from the kiln.

Zsembery et al [5, 6] have shown that characteristic expansion reasonably represents natural expansion over five years and that steam result from the lest can be used to predict natural expansion to 15 years. The formula is:

$$y(t) = -3.4S + 1.51S\ln(t + 11) - 3.5S^2 + 0.253S^2t + 0.00058S^2t^2$$

Where y = natural expansion %, S = accelerated expansion %, t = predict. time in months

The sampling of bricks for expansion measurement did not to comply with the Standard method and results show that the requirement for brick age when first steamed was not met. Further discussion relates to the corrected accelerated expansions from the refired bricks.

In the unrestrained wall, the results show that after 5 years, micrometer measured expansions in the five companion bricks on the shelf and the characteristic expansion value are similar and give a small margin of safely over observed vertical and horizontal expansions. At the same age, the horizontal expansion in the restrained wall is much less than half the characteristic expansion of the brick (24%) and its vertical expansion is substantially less than the method predicts (34% of characteristic). At this age, the method produced accurate or conservative results for both walls.

When the walls were demolished after 10.7 years, horizontal expansion in the restrained wall was still less than half (34%) of characteristic and, vertically, only 66%. In the unrestrained wall, horizontal expansion was greater than characteristic (111%); vertically it was 26% higher.

When wall expansions are extrapolated to 15 years, half of characteristic expansion for horizontal expansion plus its total for vertical are still above the wall expansions actually realised in the restrained case. This is not so for the unrestrained wall; horizontal growth is about 140% and vertical about 150% of characteristic. This substantial increase in growth in both bricks and brickwork between five and 15 years after construction suggests the need for reconsideration of the adequacy of a method that bases control gap design on an estimate of the five year expansion.

Also in need of consideration is the observation that the total vertical wall movement in (he unrestrained wall, including recovery from the substantial shortening in the first six to 12 months virtually matches the growth of the bricks on the shelf. This is most unexpected and means that vertically, the bricks in the wall grew more than their companions on the shelf whereas horizontally, growth in the two matches almost exactly.

In the restrained wall there were substantial differences between brick and wall expansions in the vertical and horizontal directions. For the bricks in the wall, vertical expansion was 1.8 times the horizontal. From the overall expansions of the wall itself, vertical growth is found to be only 1.5 times horizontal. The differences can be partly explained by the shrinkage of the mortar as it sets and dries, the lower modulus of elasticity of the mortar compared with the brick and by the different proportions of brick and mortar in the two directions. Using a 230 x 110 x 76 mm brick and 10 mm joints, mortar makes up 4.2% of the material in the horizontal direction, but 11.6% vertically and there is thus less vertical restraint. Also relevant is the fact that wall measurements were in the centres of the height and length of the walls and it seems probable that columns are stiffer than beams so that greater restraint is applied horizontally than vertically at the centre.

The authors support a re-examination of current control gap design methods, but draw attention to the following:

- At the time of their demolition, neither wall was distressed nor had caused distress to other elements. It is probably relevant that there was no known eccentricity in the support (or restraint) of the walls.
- During the years since it was issued, no wall constructed to the BDRI/EDS gap design method using the characteristic (five year) expansion value is known to have suffered any brick expansion damage.

For the authors, this study has drawn attention to the need for further consideration of an aspect of the design method. If an otherwise restrained wall has a control gap, is it reasonable to continue to regard it as one in which only some part of the predicted expansion will take place? A negative answer is likely with the important question becoming the size to which a restrained wall can be built without it damaging itself or its restraints.

In the building in which this project took place, there are many walls of the same form as the restrained wall here described. They were built from a brick of a similar appearance and probably similar expansive properties and have caused no problems in the building's near 30 year life. However, there are horizontal cracks through some of its reinforced concrete columns that suggest that it is now the expanded brickwork built within the frame rather than the frame itself that is carrying vertical loads.

Although the magnitudes of expansions in bricks that have to be dealt with vary from country to country, it is likely that it is the same phenomenon occurring in all of them. Gaining understanding of it and developing techniques that reduce or eliminate brick growth problems will benefit from international agreement on a uniform method of accelerating expansion so that it is always the same parameter under consideration. It will be even better if uniform methods for controlling brick growth are agreed.

5.0 Conclusions

1. The Demec gauge performed well as a device for measuring movements in growing brickwork.
2. The BDRI/EBS method for control gaps design needs reconsideration, but the absence of distress to these walls, plus experience of little damage to many others built to the method suggest that only minor changes are needed. Control joint design should probably be based on an estimate of 15, rather than 5 year unrestrained brick expansion.
3. The acceptance of internationally uniform methods of test and prediction of long-term expansion is desirable.
4. The substitution of "expansion index" for "characteristic expansion" seems desirable because the term characteristic is so often used to describe a statistically determined value for a strength properly below which not more than 5% of results should fall.

6.0 Acknowledgements

The work of J Vucko in providing computational support, of G W Anderson for a critical review of the paper, of the Faculty of Architecture and Planning at the University of Melbourne in whose building the walls were constructed, together with permission to publish from the Clay Brick and Paver Institute are all gratefully acknowledged.

7.0 References

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[2] AS 1226.5, SAA, Sydney, 1984

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[8] NATA Registered Test Method No B04: BDRI, Melbourne, May 1988