The Expansion of Clay Bricks After 30 Years and a Method for its Prediction

S. Zsembery, former research manager, BDRI/CBPI
R.T. Waechter, Department of Economics, University of Melbourne
T. H. McNeilly, former director, BDRI

First published in Proceedings of 7th Australian Masonry Conference, Newcastle, July 2004
Published in PDF (Acrobat) format August 2004

SUMMARY

This report updates Zsembery, Sharpe and McDowall (1986) where the results of analysing the measurements of moisture expansion on bricks up to 20 years old were discussed. The authors present the results of the latest sets of measurements carried out on those same samples of bricks collected since the 1960s by the Brick Development Research Institute (BDRI) – now the Clay Brick and Paver Institute (CBPI). The aim of the study was to develop a method to predict the extent of unrestrained expansion that bricks are likely to undergo over time. The results of these last sets of measurements that are now up to 35 years old were again used to re-examine the relationship established earlier between the accelerated expansion by steaming and natural expansion over 15 years and to extend the prediction period to 30 years. The work reported here adds to the evidence that brick expansion can be confidently predicted by the accelerated steam expansion test.

1.0 INTRODUCTION

The construction industry has been aware of the phenomenon of expansion of clay fired bricks for more than 50 years and usually gives it the name "moisture expansion". Bowman (1985) has questioned the assumption that the adsorption of moisture (water) is the sole cause of the total expansion that takes place after bricks emerge from the kiln and discusses other mechanisms that could contribute to the total expansion of the incorporated bricks with which a completed building must cope. There is also some indication that bricks exposed externally in the wall are subject to expansions that do not occur for the bricks on the laboratory shelf. The Australian/New Zealand Standard AS/NZS 4456.11:1997, *Determining the Coefficients of Expansion* (1997), which is a major topic in this paper is presumed to relate entirely to water adsorption and may therefore not be measuring all of the mechanisms that are components of the total expansion.

The method enables the coefficient of expansion (e_m) to be determined from kiln-fresh bricks, based on Zsembery, Sharp and McDowall (1986) and non kiln-fresh bricks by re-firing, based on Zsembery, Sharp and Vucko (1985). However, as previous papers, including one by McNeilly (1985), have shown and this paper positively confirms, e_m correlates well with the total unrestrained natural expansion of matching bricks kept on the shelf. It was also shown by Zsembery and McNeilly (1990), that the expansion of an unrestrained wall built in the laboratory matched the expansion predicted by the test method. Therefore, regardless of these unmeasured additional expansion factors described above, e_m is seen as providing an adequate basis for devising control measures that will eliminate damage due to brick expansion by whatever means it is caused. Another important benefit that the whole construction industry has gained from the development of the steam test has been to enable brick makers to eliminate or reduce the use of clays from their production that cause high expansion.

Nothing in this paper suggests the need for any changes to the steam test, but it could be seen to indicate the advisability of revising the way in which e_m is used to determine control joint spacing and width.

The paper of Zsembery, Sharpe, and McDowall (1986) was based on data accumulated over about 20 years and the question to be resolved here is how the additional data that have since been accrued might be used to provide more reliable predictions of the natural expansion of clay bricks and to determine whether that expansion might approach a limit. We cannot completely resolve this question even with 35 years of data, but further measurement of these bricks in 5 or 10 years should enable a more precise expression of natural expansion at 35 years, which, for the preparation of this report, required a fair amount of extrapolation.

2.0 SAMPLES

As has been described in earlier papers, for each brick type under examination, batches of five matching pairs were taken from varying positions in the kiln to represent the range of different firing conditions in the kiln that induce variability in the magnitude of expansion.

We have distinguished between "intact" and "broken" sets of bricks. Intact sets have at least three of the five members of a set present for measurement for the whole span of 35 years. There were 58 complete sets of 5 and 7 sets of 4 bricks, making up a total of 318 bricks altogether. This number reduced to 312 after 25 years. Our broken sets, at the outset, contained 88 bricks that were subjected to natural expansion. However, some bricks were lost for diverse reasons and after 35 years only 9 of those bricks remain. Space does not permit the analysis of these broken sets to be included here.

The tabulations predicted by our quadratic model are restricted to steam expansions to the range of 0.005 to 0.075 per cent; few bricks now have steam expansions less than 0.005 per cent or greater than 0.075 per cent.

3.0 PROCEDURE

For the purpose of determining the relationship between steam and natural expansion of each brick type examined, five matching pairs were sampled with one of each pair being subjected to the steam test and then abandoned while the other of the pair was set aside on a rack for periodic measurement of its natural unrestrained expansion.

We found that the data best fitted the quadratic model:

$$Y(t) = b_1(t)X + b_2(t)X^2$$

where $Y(t)$ is the percentage of natural expansion at time t measured in years, and X is the percentage steam accelerated expansion measured on the other member of the matched pair. Our objective is to present $b_1(t)$, $b_2(t)$, and the coefficient of determination $r^2(t)$ as tabulated functions for steam expansions varying from 0.005 to 0.075 per cent at regular time intervals over a period of 35 years. This approach is more direct than that of Zsembery, Sharpe and McDowall (1996) and avoids the need to fit arbitrarily chosen functions of time as composite functions that comprise the structure of $b_1(t)$ and $b_2(t)$. The tabulations provided in Tables 3 and 4 allow the reader to estimate the predicted percentage of natural expansion at any value X of steam expansion and time t in the ranges from 1 month to 5 years and from 5 to 35 years by simple linear interpolation. Our analysis may also be compared with the previous modelling as reported in the earlier papers (see Table 6).

The first specimens were collected in 1964 and samples have been measured at more or less regular intervals over almost 40 years. For the preparation of this paper, linear interpolation between two time points was used to obtain the predicted percentage natural expansion at 1 month, 3 months, 6 months, and 1, 2, 3, 4 and 5 years, and regular intervals of 5 years through to 35 years. Every set of five bricks has been measured at ten to fifteen times throughout the period of 35 years. Whilst the use of linear interpolation might produce an additional source of error, we found that the quadratic model is remarkably consistent over the range of steam expansion varying from 0.005 to 0.075 per cent. The spreadsheet of natural expansions at times of 1 month through to 35 years, obtained by direct measurement at those times, or by interpolation, was then determined and processed by Microsoft Excel 2000, using the regression function, and the numerical coefficients $b_1(t)$, $b_2(t)$ and the coefficient of determination $r^2(t)$ were then calculated and tabulated in Table 1.

4.0 ACCURACY OF MEASUREMENTS AND PREDICTIONS

The accelerated steam expansions and natural expansion percentages were determined by averaging a number of sets of readings, usually between 9 and 13, and recording the results correct to three decimal places, thereby giving us either two or three significant figures. The predicted value of natural expansion for a given time and given accelerated steam expansion should be interpreted with appropriate confidence intervals, rather than by any precise number; however, the determination of confidence intervals is now to be deferred for the time being.

5.0 RESULTS

5.1 The mean steam and observed natural expansion of bricks after 35 years

The mean of the steam expansion for the 318 bricks in the sample, representing the bricks made mainly in Victoria from the mid sixties to the mid seventies, was found to be 0.035% with a median value of 0.027%. Table 2 also shows the mean natural expansion observed on the accompanying bricks stored on the shelves in the laboratory at each of the nominated time intervals.

Table 1. The tabulations of $b_1(t)$, $b_2(t)$, and the coefficient of determination $r^2(t)$ for times of 1 to 35 years, based on individual bricks in intact sets

Time (years)	$b_1(t)$	$b_2(t)$	$r^2(t)$	Sample size
1	1.34848	- 1.30854	0.845235	318
2	1.87071	- 3.89345	0.841857	318
3	2.24922	- 5.98618	0.847867	318
4	2.59764	- 8.39345	0.844394	318
5	2.90307	- 10.2114	0.864459	318
10	3.90953	- 17.8754	0.836782	313
15	4.56067	- 23.2218	0.775891	313
20	5.06080	- 27.1206	0.718940	313
25	5.54821	- 30.9067	0.638533	312
30	5.87866	- 33.0141	0.593512	312
35	6.35590	- 36.3938	0.517114	312

Table 2. The mean observed natural and steam expansion data for individual bricks in the intact sets and the descriptive statistics

	Mean (%)	Median (%)	Variance	Skewness	Sample size
Steam Expansion	0.0359	0.027	0.00070	1.7739	318
3 month natural	0.0260	0.018	0.00048	2.1660	318
6 month natural	0.0357	0.024	0.00083	1.7205	318
1 year natural	0.0456	0.033	0.00121	1.5555	318
2 year natural	0.0587	0.045	0.00177	1.2579	318
3 year natural	0.0680	0.055	0.00215	1.0813	318
4 year natural	0.0755	0.063	0.00242	0.9305	318
5 year natural	0.0831	0.070	0.00261	0.7960	318
10 year natural	0.1053	0.098	0.00302	0.4138	318
15 year natural	0.1188	0.114	0.00310	0.1961	313
20 year natural	0.1305	0.128	0.00317	0.0725	313
25 year natural	0.1420	0.143	0.00332	- 0.1376	313
30 year natural	0.1506	0.153	0.00354	- 0.1376	312
35 year natural	0.1623	0.172	0.00385	- 0.2498	312

Table 2 has been constructed using the Excel Descriptive Statistics on both the steam expansion data and the natural expansion data. The skewness of the natural expansion distributions diminishes with time, being greatest for the steam data and becoming negative after about 20 years.

Table 3. The percentage natural expansion based on individual bricks in intact sets as a function of percentage steam expansion at times of 1 month to 5 years

Steam expansion %	1month	3 months	6 months	1 year	2 years	3 years	4 years	5 years
0.005	0.002	0.003	0.005	0.007	0.009	0.011	0.013	0.014
0.010	0.004	0.007	0.010	0.013	0.018	0.022	0.025	0.028
0.015	0.006	0.010	0.015	0.020	0.027	0.032	0.037	0.041
0.020	0.008	0.013	0.020	0.026	0.036	0.043	0.049	0.054
0.025	0.011	0.017	0.025	0.033	0.044	0.052	0.060	0.066
0.030	0.013	0.020	0.030	0.039	0.053	0.062	0.070	0.078
0.035	0.015	0.024	0.035	0.046	0.061	0.071	0.081	0.089
0.040	0.018	0.028	0.040	0.052	0.069	0.080	0.090	0.100
0.045	0.021	0.031	0.045	0.058	0.076	0.089	0.100	0.110
0.050	0.023	0.035	0.050	0.064	0.084	0.097	0.109	0.120
0.055	0.026	0.039	0.055	0.070	0.091	0.106	0.117	0.129
0.060	0.029	0.043	0.060	0.076	0.098	0.113	0.126	0.137
0.065	0.032	0.047	0.065	0.082	0.105	0.121	0.133	0.146
0.070	0.034	0.051	0.070	0.088	0.112	0.128	0.141	0.153
0.075	0.037	0.055	0.075	0.094	0.118	0.135	0.148	0.160

Table 4. The percentage natural expansion based on individual bricks in intact sets as a function of percentage steam expansion at times of 5 to 35 years

Steam expansion %	5 years	10 years	15 years	20 years	25 years	30 years	35 years
0.005	0.014	0.019	0.022	0.025	0.027	0.029	0.031
0.010	0.028	0.037	0.043	0.048	0.052	0.055	0.060
0.015	0.041	0.055	0.063	0.070	0.076	0.081	0.087
0.020	0.054	0.071	0.082	0.090	0.099	0.104	0.113
0.025	0.066	0.087	0.100	0.110	0.119	0.126	0.136
0.030	0.078	0.101	0.116	0.127	0.139	0.147	0.158
0.035	0.089	0.115	0.131	0.144	0.156	0.165	0.178
0.040	0.100	0.128	0.145	0.159	0.172	0.182	0.196
0.045	0.110	0.140	0.158	0.173	0.187	0.198	0.212
0.050	0.120	0.151	0.170	0.185	0.200	0.211	0.227
0.055	0.129	0.161	0.181	0.196	0.212	0.223	0.239
0.060	0.137	0.170	0.190	0.206	0.222	0.243	0.250
0.065	0.146	0.179	0.198	0.214	0.230	0.243	0.259
0.070	0.153	0.186	0.205	0.221	0.237	0.250	0.267
0.075	0.160	0.193	0.211	0.227	0.242	0.255	0.272

5.2 Predicted natural expansion as a function of steam expansion

(a) Predictions based on the steam expansion of individual bricks in intact sets.

From the numerical coefficients $b_1(t)$, $b_2(t)$ as given in Table 1 for the selected quadratic model, Tables 3 and 4 were constructed.

(b) Predictions based on the means of the steam expansion of intact sets

We have also calculated predictions based on the means of sets of bricks, where each set is an intact set in the sense described above. The model equation is a quadratic function with zero constant, using the steam expansion as the explanatory variable X . It is a simple matter to include a non-zero constant in the model equation; however, the improvement in the predicted results is rather slight and we do not include the non-zero constant in the results of this paper. The predictions based on observations on individual bricks as given in Table 4 are remarkably close to those obtained for sets of bricks as shown in Table 5 below. Table 5 also compare well of McDowall and Birtwistle (1969) for sets of untreated bricks at times of exposure of 1, 2, 3, 6, 12 and 24 months.

Table 5. The mean percentage predicted natural expansion as a function of mean percentage steam expansion at five year intervals, based on the means for brick sets

Steam expansion %	5 years	10 years	15 years	20 years	25 years	30 years	35 years
0.005	0.014	0.019	0.022	0.024	0.027	0.029	0.031
0.010	0.028	0.037	0.043	0.048	0.052	0.055	0.060
0.015	0.041	0.054	0.063	0.069	0.076	0.081	0.087
0.020	0.054	0.071	0.082	0.090	0.098	0.104	0.113
0.025	0.066	0.086	0.099	0.109	0.119	0.126	0.136
0.030	0.077	0.101	0.115	0.127	0.138	0.146	0.158
0.035	0.089	0.114	0.131	0.143	0.156	0.165	0.178
0.040	0.099	0.127	0.145	0.158	0.172	0.182	0.196
0.045	0.109	0.139	0.158	0.172	0.186	0.197	0.212
0.050	0.119	0.150	0.169	0.184	0.199	0.211	0.227
0.055	0.128	0.160	0.180	0.195	0.212	0.223	0.239
0.060	0.137	0.170	0.189	0.205	0.221	0.233	0.250
0.065	0.145	0.178	0.198	0.213	0.229	0.242	0.259
0.070	0.153	0.186	0.205	0.220	0.236	0.249	0.266
0.075	0.160	0.192	0.211	0.226	0.241	0.254	0.271

6.0 COMPARISON WITH EARLIER PREDICTIONS

The work of McDowall and Birtwistle (1971) is based on observations made on 378 pairs of bricks drawn from all over Australia. However, they suggest that "the small amount of growth which will occur after 5 years is unlikely to have much practical effect, and the expansion can be considered to be complete in this time".

The prediction of long-term natural expansion of fired clay bricks of Zsembery et al. (1986) excluded "extreme outliers" leaving 190 pairs of bricks, and no predictions were made beyond twenty years. Our analysis is based on 318 pairs of bricks.

Table 6. Comparison with earlier predictions of percentage of natural expansions for a given steam expansion

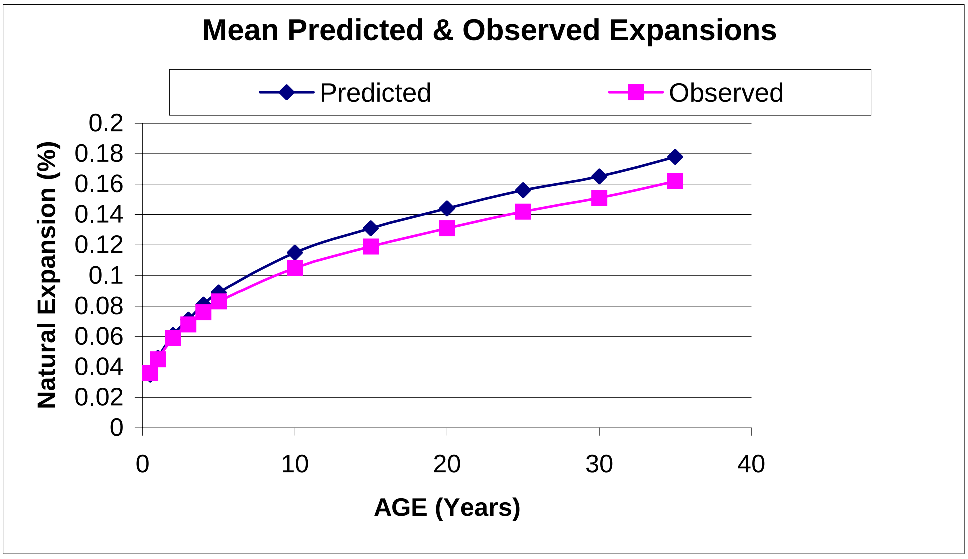
Steam expansion %	5 years		10 years		15 years		20 years	
	old	new	old	new	old	new	old	new
0.01	0.029	0.028	0.038	0.037	0.043	0.043	0.047	0.048
0.02	0.057	0.054	0.072	0.071	0.081	0.082	0.089	0.090
0.03	0.082	0.077	0.102	0.101	0.115	0.116	0.127	0.127
0.04	0.106	0.099	0.129	0.128	0.144	0.145	0.160	0.159
0.05	0.128	0.119	0.152	0.151	0.168	0.170	0.188	0.185
0.06	0.147	0.137	0.171	0.170	0.188	0.190	0.211	0.206
0.07	0.165	0.153	0.186	0.186	0.203	0.205	0.229	0.221
0.08	0.181	0.167	0.198	0.198	0.213	0.216	0.243	0.231

The predictions Zsembery, Sharpe, and McDowall (1986) for the five year natural expansion are taken from column 4 of their Table 1. As shown in Table 6, the comparison between the predictions over twenty years of our Table 3 ('new') and the Zsembery *et al* table ('old') is remarkably good. However, we find that the natural expansion after about 30 years to be nearly double that of the 5-year expansion.

7.0 COMPARISON OF PREDICTED AND OBSERVED EXPANSIONS

The work reported here adds to the evidence that brick expansion can be predicted by the steam expansion test and the close but conservative match between predicted and observed expansions, illustrated in Figure 1, adds further confirmation.

Figure 1. Mean predicted and observed expansions



The mean predicted and observed natural expansions are those determined at the sample mean accelerated steam expansion of 0.036 per cent. See Tables 1, 2, and 4.

Table 7 was constructed from data presented in Tables 3, 4 for the predicted expansion based on the mean of 0.036% steam expansion shown in Table 2, which also reports the observed expansion.

Table 7. The mean predicted and observed moisture expansion of bricks

Age of bricks (years)	Expansion (%)	
	Predicted	Observed
0.25	0.024	0.026
0.5	0.035	0.036
1	0.046	0.046
2	0.061	0.059
3	0.071	0.068
4	0.081	0.076
5	0.089	0.083
10	0.115	0.105
15	0.131	0.119
20	0.144	0.131
25	0.156	0.142
30	0.165	0.151
35	0.178	0.162

8.0 DISCUSSION

It is very interesting to note that the percentage natural expansion at six months almost exactly matches the percentage four-hour accelerated steam expansion; see Tables 2 and 7. Moreover, the ratio of natural expansion at 35 years to that at 5 years is approximately equal to 2 for bricks at the median level of steam expansion of 0.027 per cent for the individual bricks of our intact sets.

Control gap spacing and width design to eliminate damage due to the expansion phenomenon was originally based on the BDRI/CBPI proposal, McNeilly (1987) that, in ordinarily restrained brickwork, provision needs to be made to accommodate half of the e_m of the brick that was being used. The e_m value originally represented an estimate of the 5 year unrestrained growth and was calculated from the steam expansion result.

As a result of Zsembery, Sharpe and McDowall (1986), e_m has since been modified to represent the 15 year expansion and the control gap spacing and width design method has been amended accordingly, Lawrence (2000). As a result of the information provided here, it seems probable that the method of calculating and using e_m could be further changed.

This paper is seen to show that the Australian clay brick industry has a nearly complete understanding of the phenomenon of brick expansion and has published adequate and conservative methods of allowing for it within buildings. However, the magnitude of the 5 to 35 years of expansion of unrestrained expansion of bricks on the shelf suggests that the effects of restraint of brickwork deserves further consideration. The only known study that has been reported is that of Zsembery and McNeilly (1990), where the results of the Demec gauge measurements of movements within bricks and mortar in one restrained and unrestrained wall are considered. Results are given for the walls when they were at various ages up to 10.7 years, after which unfortunately the walls were demolished.

It seems highly desirable for resources to be made available to measure the further growth of the bricks in this collection to both increase the construction industry's knowledge of their continuing expansion and to finally test the Cole and Birtwistle (1969) suggestion of a relationship between the natural expansion and the logarithm of time. The long time trend suggested in Table 7 may be logarithmic in time; we remain of an open mind.

However, we are able to reinforce the value of the four-hour steam expansion data as a reliable explanatory variable to predict the natural expansion of a given batch of bricks over times ranging up to 30 years.

9.0 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of CBPI for the preparation of this paper. Gratitude is also expressed to the Brick and Mortar Research Laboratory for their agreement to store the brick samples that are the subject of this study for future research.

10.0 REFERENCES

Australian/New Zealand Standard, Masonry Units and Segmental Pavers - Methods of Test. Method 11: Determining Coefficients of Expansion. AS/NZS 4456.11: (1997)

Bowman, R., "Theoretical Reconsideration of Certain Aspects of Brick Expansion", *Proceedings of the Seventh International Brick Masonry Conference*, 1985, pp. 297–304

Cole, W.F., and Birtwistle, R., "Kinematics of Moisture Expansion of Ceramic Bodies", *Ceramic Bulletin*, Vol, 48, 1969, pp. 1128–1132

Lawrence, S., Manual 9, *Detailing of Clay Masonry Walls*, CBPI, May 2000, pp. 28–31

McDowall, I.C., and Birtwistle, R., "Predicting the Long-term Moisture Expansion of Fired Clay Products", *Proceedings of the Second International Brick Masonry Conference*, 1971

McNeilly, T., "Moisture Expansion of Clay Bricks: An Appraisal of Past Experience and Current Knowledge", *Proceedings of the Seventh International Brick Masonry Conference*, Melbourne Australia, 1985, pp 67–80

McNeilly, T., Technical Note 1a, *The Design of Clay Brickwork Expansion Gaps*, BDRI/CBPI, July 1987

Zsembery, S., and McNeilly, T., "The Moisture Expansion of Bricks and Walls", *Proceedings of the International Ceramics Conference*, Perth, AUSCERAM 90, Australia 1990, pp 202–207

Zsembery, S., Sharpe, K., and McDowall, I.C., "Review of the Experimental Data on Prediction of Long-Term Natural Expansion of Fired Clay Bricks", *Proceedings of the Twelfth Australian Ceramics Conference*, AUSCEREM 86, Melbourne Australia 1986, pp 327–334

Zsembery, S., Sharpe, K., and Vucko, J., "Determination of the Expansion of Non-Kiln-Fresh Bricks ", *Proceedings of Seventh International Masonry Conference,* Melbourne, Australia, 1985, pp 351–360