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# IRREVERSIBLE MOISTURE EXPANSION OF UNBONDED CLAY BRICK UNITS AND BRICKWORK PANELS

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## ABSTRACT

This paper presents experimental data for Phase I of a research project investigating the behaviour of brickwork subject to imposed loading and restraint. Moisture movement strains of fired-clay masonry panels and their corresponding unbonded brick units are presented. Thirteen courses high by two brick wide single-leaf test panels were constructed using twenty different types of brick unit combined with a class (ii) mortar. Measurements were taken in the vertical and horizontal direction over a one-year period.

The magnitude of moisture movement strain was found to be linked to the moisture transport properties of the brick units, namely, initial rate of suction, porosity and compressive strength. Overall, the brick unit type dominated the pattern of moisture movement strains generated in the panels.

A significant difference was found to exist between the unbonded unit and panel movement measured in the vertical direction. Test panels generally exhibited an initial shrinkage followed by a long-term expansion, whereas corresponding unbonded units displayed relatively little continuous expansion. The results are of interest in assessing the feasibility and practicality of restraining clay brickwork, in particular the level of induced compression which may occur.

**Keywords**: Moisture Expansion Bricks Brickwork Movement

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## INTRODUCTION

The cause of moisture expansion in fired-clay bricks has been researched for many years, with early articles from as far back as Schurecht and Pole (1928). It has been shown by Brownell (1959) that the internal surface area and amorphous glassy material, both controlled by the vitrification process, are two of the governing factors in this irreversible moisture expansion. Later research focussed on methods to extrapolate long term expansions from short-term tests. Work by Ford (1983) and Pavlovic & Tosic (1999) showed that there is linearity between the logarithm of the expansion rate and the reciprocal of the absolute temperature at which it takes place. This has enabled accelerated tests to be conducted in steam to gain long-term expansion data.

The UK Code of Practice for Structural Masonry, BS5628 ( provides typical values of moisture movement for a range of commonly used units and brickwork. Tests by Lomax & Ford (1983) categorised brick units into three expansion bands, Low (<0.4mm/m), Medium (0.4-0.8mm/m) and High (>0.8mm/m) from extrapolated 50 year expansions.

Tests by Brooks & Bingel (1988), Forth (1994) and Bingel *et al* (2000) have shown that in addition to moisture expansion an enlarged expansion can occur in free standing unloaded clay brick walls which is not replicated in unbonded corresponding brick units. This confirms previous findings reported by West (1960) and Beard et al (1983) that vertical expansion of test walls were sometimes considerably greater than that measured in the horizontal direction. A difference also existed in the level of expansion at the top and bottom of the walls.

Forth (1994) has attributed this enlarged expansion to the moisture transport properties of the brick units coupled with a transition zone effect at the brick/mortar interface. Units with high water absorption characteristics generally produce the largest brickwork expansions, with the expansions being the greatest at the top of an unrestrained wall where the effect of dead load is the least. This phenomena has implications for the measurement of creep of brickwork, because creep is determined after allowing for moisture expansion as measured on a corresponding control (external load-free) wall. Consequently, on smaller control walls the apparent creep will be higher than if larger control walls are used.

## EXPERIMENTAL DETAILS

Twenty types of clay unit were initially selected according to a range of physical and chemical properties, which from previous work were believed to produce this enlarged expansion:

- Irreversible moisture expansion
- Soluble salt content and range
- Water absorption

- Initial rate of suction
- Compressive strength
- Clay type

Test panels were thirteen course high by two brick wide single-leaf walls, 975 x 440 x 100mm (Figure 1). The mortar mix used was a class (ii) 1: ½ : 4½ (cement : lime : sand) by volume, with a consistency of 10mm as determined using the dropping ball test, as specified in BS4551 (1980). All the test panels were constructed and tested within environment rooms controlled to a relative humidity of 65 ± 5% and a temperature of 21 ± 1°C. The water/cement ratio by mass for the mortar was 0.83. Test panels were sealed in polythene immediately after construction for a seven-day moist curing period, after which time the panels were exposed to the controlled environment conditions. Demec strain gauge points were fixed to the panels immediately after construction (Figure 1) and strain measurements commenced at the age of one day. Strains were measured in the vertical direction using 50mm, 150mm and 750mm Demec gauges and in the horizontal direction using 50mm, 150mm and 200mm gauges. Four unbonded brick units were stored alongside their corresponding test panels and measured between header and stretcher faces at the same time as the panels. Eight mortar prisms were taken from each mortar mix, with four left unsealed and four sealed to the same volume/exposed surface area ratio as the mortar beds in the test panels. Measurements on mortar prisms were taken using 50mm and 150mm gauges.

To obtain the brick unit compressive strength, ten bricks were cold soaked for 24 hours and then crushed between plywood sheets. Ten bricks were also tested to determine water absorption characteristics using the 5-hour boiling water and initial rate of suction tests, all tests were carried out according to BS3921 (1985).

Compressive strength tests were also carried out on 100x100x100mm mortar cubes at 7, 14 and 28 days.

## RESULTS AND DISCUSSION

Results of compressive strength, initial rate of suction (IRS) and water absorption (WA) tests for the brick units are presented in Table 1. Irreversible moisture expansion (IME) values and average soluble salt contents for the units were provided by the brick manufacturer. The average compressive strengths and standard deviations for 100 x 100mm mortar cubes at 7, 14 & 28 days were 11.4(0.70), 13.3(0.74) and 15.5(0.44) MPa respectively.

Vertical and horizontal movement strains for a one-year period are presented in Tables 2 and 3 respectively, along with the corresponding brickwork/brick ratio. It is evident from these tables that brickwork/brick ratios greater than one are produced in both the vertical and horizontal directions. The magnitude of moisture movement strain in the two directions though is markedly different, with the vertical expansion being significantly higher in the majority of cases. For example the expansion values for brickwork constructed from unit 12 (Fletton common), the brickwork/brick ratio in the horizontal direction is 0.5 which is similar to that reported by Beard (1966) of 0.6, but because of anisotropy the ratio of the vertical expansion is 2.3.

When vertical expansion results were plotted graphically as strain against time, patterns of moisture movement were evident. Figure 2 shows that brickwork built with stronger units exhibited continuous long-term shrinkage (unit 14), or initial shrinkage followed by a small expansion (unit 1). Relatively weaker bricks produced expansions either immediately after the moist curing period, or after an initial contraction (unit 12).

With reference to Figure 1 measurements were taken at different heights along the centre line of the test panels using a 150mm gauge. The average of these measurements were then checked against those obtained using the 750mm gauge and a good correlation was found. When the 150 gauge readings were looked at in isolation a difference in expansion between the top and bottom of the panels was evident. In 70% of cases the highest expansion was produced at the top of the panels regardless of unit type. Figure 3 shows the expansion profiles for unit 5, 8 and 12 test panels. It appears that the small amount of stress induced by the brickwork above restrains the magnitude of expansion, this was postulated by West (1960) and shown by Bingel *et al* (2000).

As stated earlier, moisture expansion of brick units is governed largely by the internal surface area and glassy phase produced during firing. The water transport properties of the brick units will therefore have a major influence on the rate at which water will reach the interior surface and hence the rate of moisture expansion. The ability of a brick to absorb water is measured by the initial rate of suction test, which is defined by BS3921 (1985) as the weight of water absorbed by the bed face of the unit over a one minute period, when immersed in water to a depth of 3mm. When the initial rate of suction of the units is correlated with expansion, the low expansion panel units fall within the range of 0.3 to 0.7 kg/m$^2$/min and those with high expansions range between 0.8 to 3.8 kg/m$^2$/min.

Overall, relatively weaker bricks, such as units 10, 12 and 17 that have high water absorption and initial rate of suction properties produce larger vertical brickwork/brick ratios. Conversely, relatively strong bricks such as units 4, 5 and 14 with low water absorption and initial rate of suction produce the smallest ratios. Exceptions to these criteria are produced by units 13 and 16 which have brickwork/brick ratios of 1.8 and 2.5 respectively; the unit compressive strengths/water absorptions were 63.7MPa/12.7% and 75.3MPa/7.5% respectively, and the initial rates of suction were 1.0 and 1.3 kg/m$^2$/min.

Table 4 presents the type of clay used and gives ultimate panel/unit expansion results. The ultimate values are obtained using regression analysis of the Ross (1937) hyperbolic-time function that was developed for concrete. Previous researchers such as Lenczner (1986) and Brooks & Abdullah (1990) reported that the function underestimates short-term deformations, but if the first forty days data are ignored long-term predictions are reasonable. The hyperbolic time-function is:

$$Me = \frac{t}{(a + bt)} \qquad (1)$$

Rearranging into rectified form:

$$\frac{t}{Me} = a + bt$$

Where Me = Moisture Expansion ($10^{-6}$)
t = Time
a = Constant
B = Constant = 1/$Me_u$
$Me_u$ = Ultimate moisture expansion

Analysis was made using the rectified form of Equation (1) using data values at twenty day intervals obtained from freehand 'smoothed' expansion-time curves of Figure 2.

## CONCLUSIONS

1. An enlarged expansion has been found in many types of clay brickwork. Using the ultimate vertical strain movement values from table 4, Brick-earth units 10/17, Keuper marl unit 19, Lower Oxford unit 12 and Fireclay shale units 8/13 show high levels of expansion in the brickwork which is not replicated in the unbonded units.

2. An expansion in the vertical direction in excess of that produced in the horizontal direction has been observed, which confirms that reported by other researchers such as West (1960), Edgell (1993) Beard *et al* (1983), Brooks & Bingel (1988) and Bingel et al (2000).

3. Generally there is greater vertical expansion at the top of a wall than at the bottom of a wall, regardless of unit type.

4. The enlarged expansion appears to be linked to the moisture transport properties of the units as measured by the initial rate of suction test. The reasons for this are not clear at this stage of the project, but the increased surface porosity of these units may promote the precipitation and crystallisation of expansive products at the brick/mortar interface.

## ACKNOWLEDGEMENTS

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Table 1. Brick Unit Properties

| **Brick Unit** | **W.A (%)** | **I.M.E.** | **Strength ($N/mm^2$)** | **Soluble Salts** | | | | **I.R.S. ($kg/m^2/min$)** |
|---|---|---|---|---|---|---|---|---|
| | | | | **Mg** | **Na** | **K** | **$SO_4$** | |
| 1 | 6.1 (0.3) | L | 72.9 (6.8) | <0.01 | 0.01 | <0.01 | 0.05 | 0.6 (0.04) |
| 2 | 6.8 (0.6) | M | 70.5 (5.3) | <0.01 | <0.01 | <0.01 | 0.03 | 0.3 (0.06) |
| 3 | 6.6 (0.5) | L | 75.7 (10.2) | <0.01 | 0.01 | 0.01 | 0.11 | 0.3 (0.08) |
| 4 | 6.7 (0.4) | 0.40 | 69.5 (6.4) | 0.030 | 0.003 | 0.005 | 0.024 | 0.6 (0.10) |
| 5 | 8.0 (0.7) | 0.45 | 77.9 (4.7) | 0.060 | 0.003 | 0.005 | 0.020 | 0.6 (0.07) |
| 6 | 7.7 (0.7) | 0.50 | 54.1 (3.1) | 0.050 | 0.001 | 0.008 | 0.037 | 0.7 (0.09) |
| 7 | 5.1 (0.4) | 0.50? | 64.0 (2.5) | 0.070 | 0.004 | 0.004 | 0.026 | 0.7 (0.04) |
| 8 | 9.6 (0.2) | 0.95 | 46.6 (2.2) | 0.090 | 0.002 | 0.009 | 0.014 | 0.8 (0.13) |
| 9 | 5.1 (0.3) | 0.20? | 71.4 (4.5) | 0.040 | 0.001 | 0.004 | 0.013 | 0.3 (0.04) |
| 10 | 23.3 (2.0) | ? | 28.5 (10.6) | 0.001 | 0.004 | 0.008 | 0.059 | 3.8 (1.90) |
| 11 | 14.6 (1.1) | 0.525 | 18.2 (2.3) | 0.007 | 0.010 | 0.023 | 0.135 | 0.7 (2.30) |
| 12 | 20.3 (1.0) | L/M | 25.6 (3.3) | 0.002 | 0.007 | <0.01 | 0.65 | 1.8 (0.48) |
| 13 | 12.7 (0.8) | H | 63.7 (3.8) | 0.001 | 0.003 | 0.002 | <0.01 | 1.0 (0.12) |
| 14 | 4.2 (0.5) | M | 120.7 (11.5) | 0.001 | 0.003 | 0.002 | 0.01 | 0.2 (0.02) |
| 15 | 13.6 (0.9) | M | 18.9 (0.8) | 0.006 | 0.008 | 0.064 | 0.45 | 1.4 (0.48) |
| 16 | 7.5 (0.2) | L | 75.3 (4.6) | 0.001 | 0.002 | 0.003 | <0.01 | 1.3 (0.21) |
| 17 | 25.1 (1.1) | M | 18.2 (2.3) | 0.001 | 0.001 | 0.004 | 0.15 | 3.4 (0.16) |
| 18 | 34.1 (0.6) | M | 21.3 (2.7) | 0.003 | 0.011 | 0.023 | 0.06 | 3.8 (0.37) |
| 19 | 24.0 (1.1) | M | 34.1 (3.8) | 0.008 | 0.003 | 0.016 | 0.02 | 2.0 (0.30) |
| 20 | 19.0 (1.3) | M | 22.1 (2.2) | 0.003 | 0.001 | 0.037 | 0.45 | 1.5 (0.58) |

I.M.E. Values are expressed relative to those established by Ford (1983), Low, Medium and High or as a % of the original length.

Table 2. One Year Vertical Movement Strains & Brickwork/Brick Ratios

| Brick Unit | Wall | Brick | Ratio | Brick Unit | Wall | Brick | Ratio |
|---|---|---|---|---|---|---|---|
| 1 | -139 | -346 | 0.4 | 11 | -35 | -235 | 0.1 |
| 2 | -38 | -272 | 0.1 | 12 | -903 | -386 | 2.3 |
| 3 | -102 | -444 | 0.2 | 13 | -680 | -376 | 1.8 |
| 4 | -37 | -259 | 0.1 | 14 | 19 | -172 | -0.1 |
| 5 | -34 | -275 | 0.1 | 15 | -537 | -306 | 1.8 |
| 6 | -130 | -263 | 0.5 | 16 | -545 | -220 | 2.5 |
| 7 | -273 | -288 | 0.9 | 17 | -843 | -237 | 3.6 |
| 8 | -632 | -429 | 1.5 | 18 | -558 | -275 | 2.0 |
| 9 | -206 | -182 | 1.1 | 19 | -918 | -202 | 4.5 |
| 10 | -856 | -288 | 3.0 | 20 | -478 | -197 | 2.4 |

Table 3. One Year Horizontal Movement Strains & Brickwork/Brick Ratios

| Brick Unit | Wall | Brick | Ratio | Brick Unit | Wall | Brick | Ratio |
|---|---|---|---|---|---|---|---|
| 1 | -76 | -123 | 0.6 | 11 | -128 | -81 | 1.6 |
| 2 | -70 | -126 | 0.6 | 12 | -118 | -224 | 0.5 |
| 3 | -129 | -123 | 1.0 | 13 | -271 | -301 | 0.9 |
| 4 | -173 | -119 | 1.5 | 14 | -142 | -113 | 1.3 |
| 5 | -148 | -85 | 1.7 | 15 | -82 | -176 | 0.5 |
| 6 | -139 | -126 | 1.1 | 16 | -184 | -81 | 2.2 |
| 7 | -170 | -229 | 0.7 | 17 | 134 | -98 | -1.4 |
| 8 | -291 | -276 | 1.1 | 18 | -72 | -63 | 1.1 |
| 9 | -125 | -61 | 2.0 | 19 | 113 | -41 | -2.8 |
| 10 | -64 | -94 | 0.7 | 20 | 122 | -80 | -1.5 |

The sign convention for movement is taken as expansion being negative and contraction as positive. For brickwork/brick ratios a negative sign indicates shrinkage.

Table 4. Estimated Ultimate Vertical Expansion Characteristics

| Brick Unit | Clay Type | Ultimate Panel Expansion | Ultimate Brick Expansion | Ultimate Brickwork/Brick Ratio |
|---|---|---|---|---|
| 1 | Coal Measure shale | -270 | -476 | 0.6 |
| 2 | Coal Measure shale | -125 | -417 | 0.3 |
| 3 | Fireclay Mixture | -123 | -500 | 0.2 |
| 4 | Mudstone shale | -45 | -323 | 0.1 |
| 5 | Weald | -40 | -313 | 0.1 |
| 6 | Ball Clays/Shale | -357 | -435 | 0.8 |
| 7 | Coal Measure Fireclay | -400 | -435 | 0.9 |
| 8 | Fireclay shale | -1111 | -625 | 1.8 |
| 9 | Etruria Marl | -357 | -244 | 1.5 |
| 10 | Brick-earth/Chalk Breeze | -909 | -400 | 2.3 |
| 11 | Wadhurst | -46 | -303 | 0.2 |
| 12 | Lower Oxford | -1429 | -556 | 2.6 |
| 13 | Fireclay shale | -1111 | -500 | 2.2 |
| 14 | Coal Measure shale | -17 | -323 | 0.1 |
| 15 | Weald | -909 | -435 | 2.1 |
| 16 | Fireclay Mixture | -769 | -345 | 2.2 |
| 17 | Brick-earth | -1000 | -270 | 3.7 |
| 18 | Keuper Marl (lower) | -714 | -385 | 1.9 |
| 19 | Keuper Marl (lower) | -1250 | -250 | 5.0 |
| 20 | Gault shale | -714 | -345 | 2.1 |

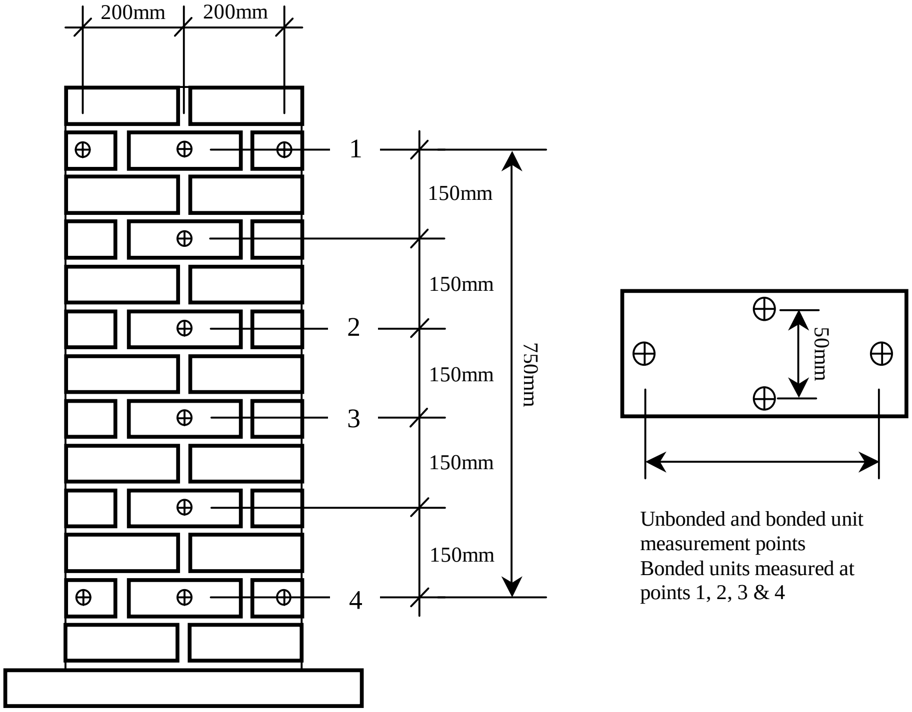

Figure 1. Single-leaf Test Panel & Brick Unit Strain Measurement Point*s*

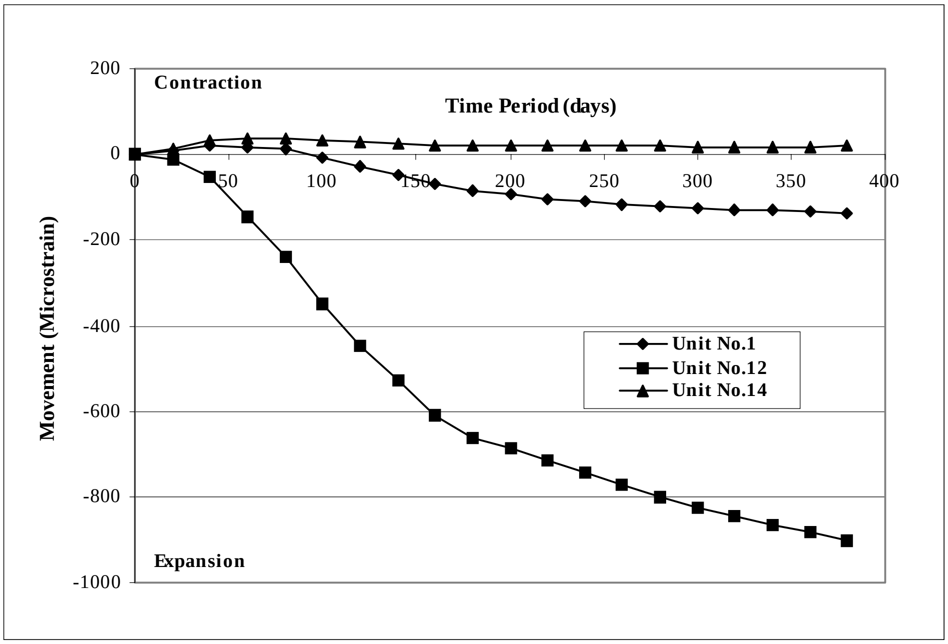

Figure No.2 Vertical Moisture Movement Patterns of Brickwork built from different units

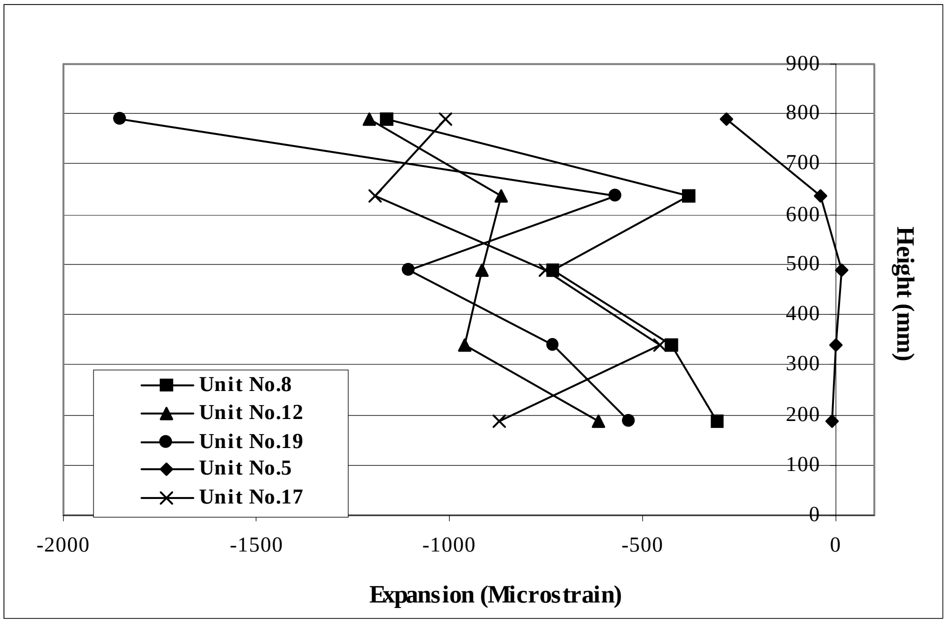

Figure 3. Variation of Vertical Expansion of Brickwork with Height