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DIFFERENTIAL MOVEMENTS IN MASONRY CAVITY WALLS

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INTRODUCTION

Differential movements between the two wythes of a cavity wall and/or between a brick veneer and it's backup system have been the topic of many engineering reports, particularly dealing with failures and failure investigations.

Because of the existence of information in the form of test data and reports documenting expansion of burned clay units after manufacturing, many of the failures of brick cladding systems have been attributed to this observed expansion. It is thus commonly believed that the expansion of burned clay units is the main contributing factor to the observed distress in masonry cladding systems where the expansion of the clay unit was not accommodated by means of a horizontal, and vertical control (expansion) joints.

The available literature mainly from the masonry industry, and in particular the burned clay industry, is primarily based on measurements and experimental work on units or small walls constructed and monitored in laboratories. These conditions do not represent the exposure and weathering of units and wall assemblies of actual structures.

In order to expand the database to field conditions, it was decided to carry out an investigation over a long period of time in an actual permanent structure built for the sole purpose of establishing the magnitude of shrinkage, expansion, temperature related movements and differential movements in cavity walls.

EXPERIMENTAL PROGRAM

The experimental program undertaken in order to account for the effects of construction procedures and to reflect site conditions and exposure of the masonry units, consisted in the design and construction of a 21 meter high clock towershown in Fig.1 (a). The tower is rectangular in shape and it was constructed utilizing cavity walls with the vertical loads applied only at the corners where reinforced masonry pilasters were incorporated. The sections of the cavity walls between the load bearing corner elements were laterally braced only at floor levels and were left free at the top of the 12000 mm elevation part of the structure. A complete description of the tower and its construction stages was published by Elwi et al. (1995).

Figure 1(b) shows an elevation cross-section of the tower and Photo. 1 shows the completed tower itself. Figure 1(c) shows a plan cross section indicating the different cavity widths and type of masonry connectors used to tie the brick and block wythes.

In order to incorporate as many variables as possible it was decided to vary the cavity, the type of ties and the age of the masonry units. To this effect four cavity widths were incorporated (25mm, 50 mm, 75mm and a 100 mm cavity) and two types of ties were used. Slotted ties that allow vertical movement were used on the north wall and ties providing partial shear connection between the wythes on the other three walls. The ties used in the project are shear connectors that were first invented by the first author and thoroughly tested by the second author of this paper (Wang et al. 1997).

The corners, which are independent from the rest of the walls, were constructed using 300 mm concrete masonry units, which at the time of placement were five years old. The corners were fully grouted and reinforced. The straight portion between the corners was constructed using 200 mm concrete masonry units that were eight days old when they arrived to the site, (manufactured on June 8, 1995). Samples of five concrete masonry units from both the old and the new were taken to the laboratory and instrumented for shrinkage measurements. Edcon Block of Edmonton manufactured the concrete masonry units, using lightweight aggregate clay units manufactured the concrete masonry units. The units were manufactured in accordance with and satisfying the requirements of the applicable CSA Standards.

The exterior wythes were constructed using burned clay units that arrived at the job site on Jun 16, 1995 and were eight days old at the time. Five clay units were taken to the laboratory and were instrumented for expansion measurements the day they came out of the kiln at the I.XL Edmonton Brick Plant on June 8, 1995. The units were fired to 2170^{0}F and satisfied the requirements of CSA Standard A82.1 "Burned Clay Brick".

The walls were constructed by Gracom Masonry Ltd., a prominent masonry contracting firm in Western Canada using Type S mortar mixed in proportion by volume - 1 part normal cement, 1/2 part hydrated lime and 4 parts of sand.

INSTRUMENTATION

The project was designed for long term monitoring and to this effect it was decided to use mechanical means for monitoring differential movements between the two wythes of the cavity walls.

The movement of the concrete masonry interior wythes is measured at eight locations at each floor level, by means of stainless steel surveying tapes. Surveying targets were also fixed to the exterior of all four brick wythes. In order to measure the differential movements between the block and brick wythes, Demec gages were installed at the top of the wall and in the interior of the tower, at four locations. The gages consisted of a steel arm with a Demec point at the end, was fixed to the brick wythe extending to the interior face of the concrete block wythe. A Demec point on a copper plate was permanently fixed to the block wall. The two Demec points were installed 200 mm apart. A report of the measurements made on the survey tapes was already presented by Elwi et al. (1995). This papers deals mainly with the continued measurements of the differential movements at the Demec points.

Photo 1 shows the mechanical arrangement for measuring the differential movement between the brick and block wythes. Monitoring of the assemblies commenced with the construction of the block wythe and data was collected during all stages of construction. Monitoring the exterior target surveying did not begin until the scaffolding was removed.

UNIT DIMENTIONAL MONITORING UNDER ROOM TEMPERATURE

Five samples of blocks (Series A) manufactured on June 8, 1995, ten samples of bricks (Series C) manufactured on June 8, 1995 and five of the five-year-old 300 mm concrete masonry units (Series B) were taken to the CMRI laboratory for shrinkage and expansion dimensional measurement. The length changes of the block samples were measured using a 50 mm Demec gauge. The shrinkage measurement started on the seventh day after the manufacture of the blocks of Series A and on the eleventh day after the manufacture of the bricks. The strain versus the days from the date of manufacture is plotted in Figs. 2, 3 and 4 for the brick samples, Series A, B blocks and for Series C brick samples in that order.

Figure 2 indicates that most of the shrinkage takes place within the first 30 days of life of the block of Series A. Series B, which was much older reacted erratically probably because of transfer from the outdoors to the indoors environment. That series however reached equilibrium after about 70 days. The change at 600 days relative to 400 days reflects a move of the CMRI laboratory to other premises with different conditions that took place during this period.

The strain change for brick samples was found to be inconsistent among the samples. This is partially because the size of the Demec gauge being smaller for the brick samples than that used for the block samples, a fact, which most likely affected the accuracy of the readings. The strain average of the ten samples, from Figure 3 indicates the bricks have expanded slightly during 93 days of monitoring. However, the strains on bricks are much smaller than those measured on the block samples.

Seven of the ten samples reached equilibrium within three weeks. Three samples took ten weeks to reach equilibrium as can be seen in Fig. 3. The average brick expansion is found to be 0.18 mm/m after 90 days. After 625 days of monitoring, Series A showed shrinkage of 0.64 mm/m. S304 (1995) lists expansion coefficient for clay units of 0.2 to 0.7 mm/mm (2.0×10^{-4} to 7.0×10^{-4} mm) and 0.2 to 0.6 mm/mm (2.0×10^{-4} to 6.0×10^{-4} mm/mm) expected shrinkage for light weight aggregate concrete masonry units. This shows that the brick expansion stopped quickly well within the minimum required values, while the block shrinkage stopped within three month at about the maximum required by the code. It is also interesting that these are "room measurements" indicating that code requirements are in fact based on laboratory type data also.

The above coefficients do not include the expansion and shrinkage that occurred for 11 days for the burned clay units and eight days for the lightweight concrete blocks. Because of construction and manufacturing practices and procedures, it is not realistic to assume that large portions of a structure can be constructed using units that are less than 14 days old.

RESULTS FROM LONG TERM MONITORING

Temperature effects

Figures 4 and 5 show the results obtained by measuring the movements in all walls during two single days on June 22 and July 14, 1996 during which the temperature varied from 10 °C to 40 °C. The full set is combined in Fig. 6. On the same figures the values suggested for use by CSA S304.1-M94 (1995) are also shown. The set suggests that the thermal movement of the block walls and those of the brick wythe can be respectively approximated by linear regression relations of the form:

$$Y=0.001X-0.0234 \qquad \text{(blocks)} \qquad [1]$$

$$Y=0.0025X-0.0435 \qquad \text{(bricks)} \qquad [2]$$

Wall movements

Figures 7 and 8 show the measured movements in mm/m over 625 days on the block walls and those on the brick wythe respectively. Here the temperature effects have excluded making use of the regression relations 1 and 2. A linear regression line through each set of data resulted in the following relations:

Figure 7 shows a regular relation in the long term with nearly similar rates of change for all walls indicating that the rate of shrinkage of the block walls is nearly constant for the first 18 months. After about 500 days movement of the north and, more so, the east and south block walls have leveled off. The authors acknowledge that a linear regression analysis has severe limitations when applied to wall movements, especially when they are the results of shrinkage. However, the results obtained show considerable regularity and, therefore, linear regression relations are suggested for the first 18 months as:

$Y = -0.0006X + 0.0634$ (Block wall – North) [3]

$Y = -0.0006X + 0.0448$ (Block wall – East) [4]

$Y = -0.0005X - 0.0105$ (Block wall – South) [5]

$Y = -0.0006X - 0.0207$ (Block wall – West) [6]

Movements of the brick wythes are much more erratic. However, it is clear that these are shrinkage movements about half as large as those obtained from Series C above, and that they are not increasing with time. A linear regression analysis yields the following relations

$Y = -2E\text{-}05X - 0.0049$ (Brick wythe – North) [7]

$Y = -1E\text{-}06X - 0.0824$ (Brick wythe – East) [8]

$Y = -4E\text{-}06X - 0.0458$ (Brick wythe – South) [9]

$Y = --0.0001X - 0.0463$ (Brick wythe – West) [10]

Differential movements

Figures 9 and 10 show the results obtained from the measurements taken over a period of 625 days of the north and east walls. Similar results are obtained for the other walls. The figures show the temperature movements and the differential movement between the brick wythe and the block back up walls. . Clearly the temperature movements dominate the behavior. Note also that the brick wythe and the block back up walls become permanently shorter with time and that the overall differential movement was positive (the block walls moved down more than the brickwork).

On the same figures, the values suggested for use by the CSA S304.1 (1995) and the values expected based on the movements taken by monitoring the units at room temperature are also shown. It is easy to see that the differential movements are well within the minimum expansion an contraction code requirements.

CONCLUSIONS

This experimental program has shown that shrinkage properties of block walls are regular and about half as much as those suggested by the code and a quarter of those expected if creep movements are also excluded. The code values however agree well with our results under similar conditions (unstressed room type experiments disregarding creep behaviour). Again our measurements of brick expansion in an unstressed state at room type temperature over a long period of time is less than the minimum required by the code.

Full scale measurement over 625 days on the Perron tower has shown block contraction to be half as much as those obtained from room type experiments. In addition those measurements do not exclude creep of blocks under own weight Since the environment inside the tower was reasonably controlled, the authors feel strongly that code recommendations for block shrinkage should be reduced substantially.

The authors also point out that tower measurements showed no evidence of brick expansion in any wall. Although it may be argued that the brick wythes may have been constrained by the shear connectors on the east, west and south walls, the north wall which was not restrained at all also showed contraction to the same magnitude. It is further concluded that distress in brick veneer walls is the result of the deformation of the main structural element and not due to expansion of the brick work. The values obtained strongly suggest that the expansion of brick work is not a factor in the design of brick structures and that the shrinkage of concrete block walls in actual buildings where units from one lot are used is exaggerated.

One would add that it is also preferred that codes and standards provide guidelines relating to the age of the materials at the time of use rather than stating absolute shrinkage and expansion values.

ACKNOWLEDGEMENTS

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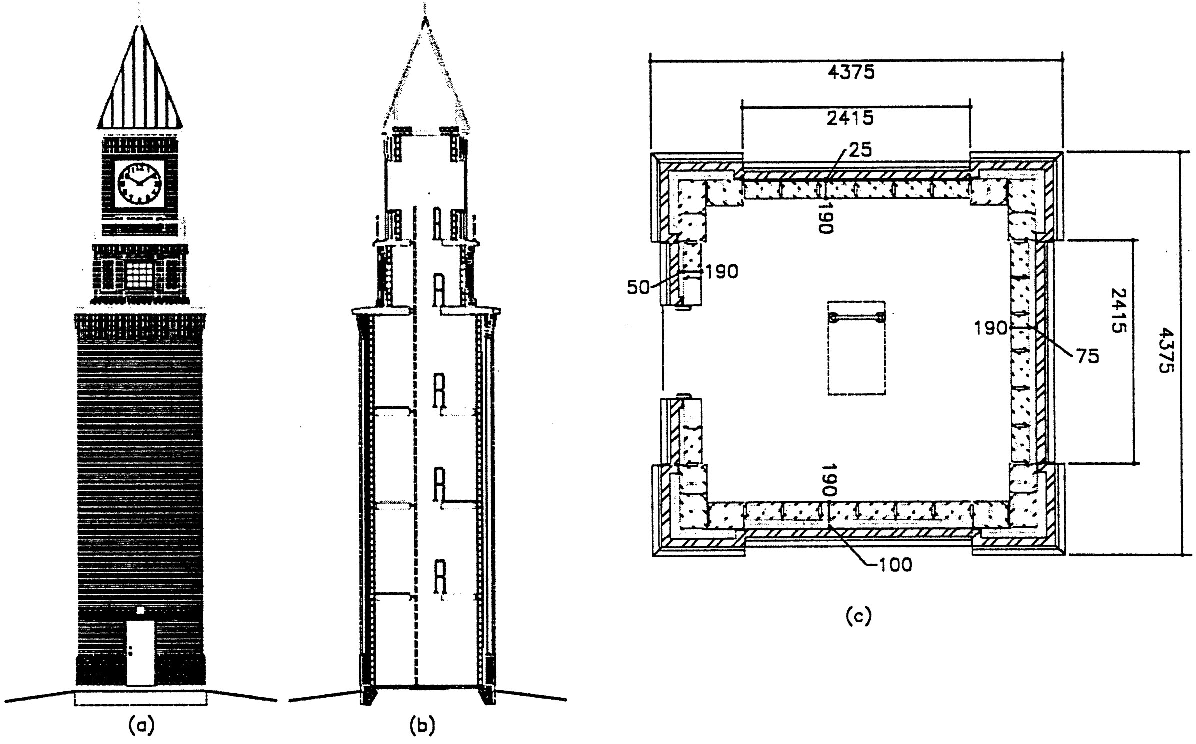

Fig. 1 The Perron Tower

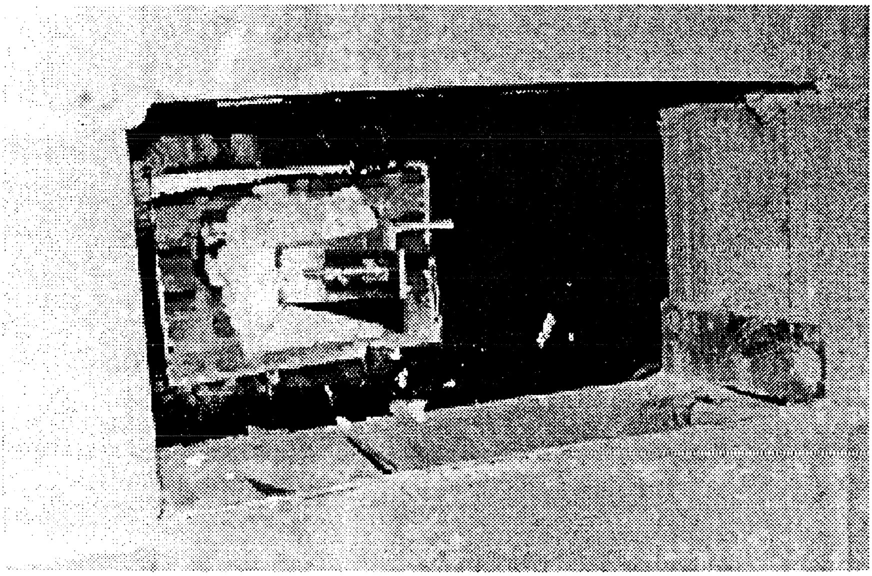

Photo 1 The Demec point arrangement

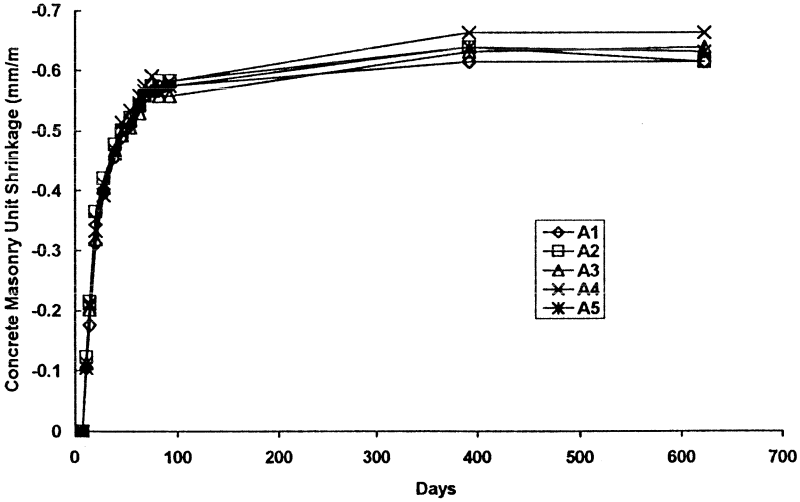

Fig. 2 Shrinkage of blocks of Series A at room temperature

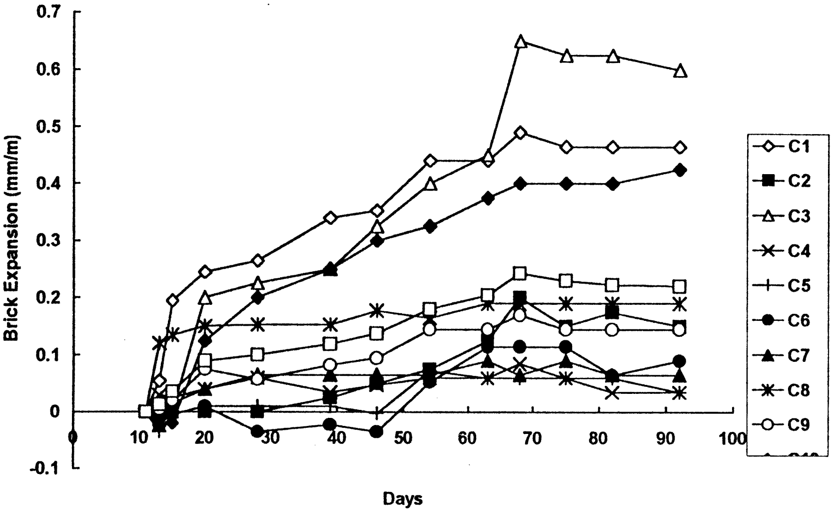

Fig. 3 Shrinkage of bricks of Series C at room temperature

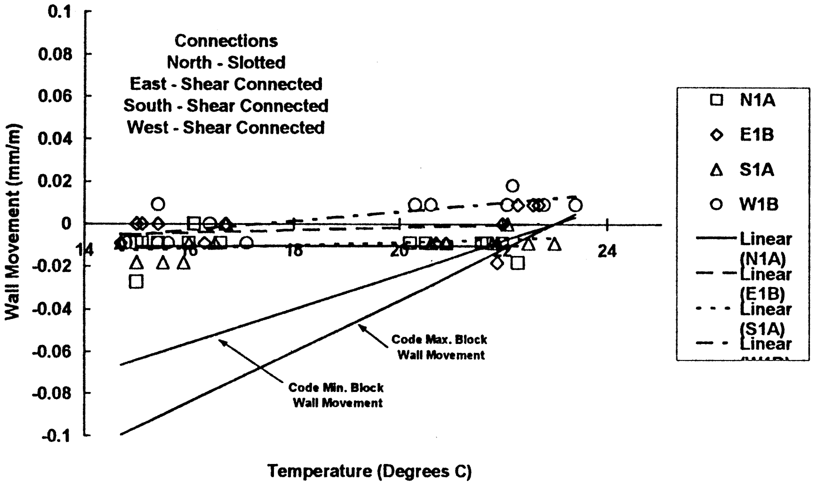

Fig.4 full day measurements of block wall movements

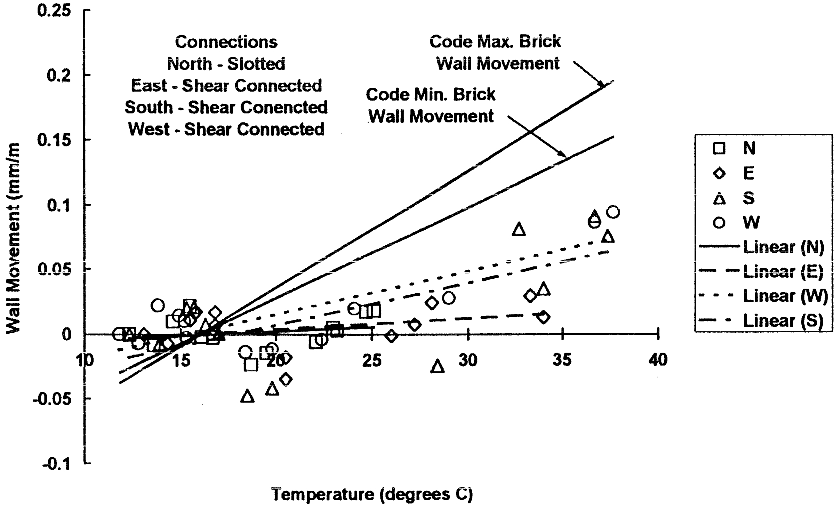

Fig. 5 Full day measurements of brick wythe movements

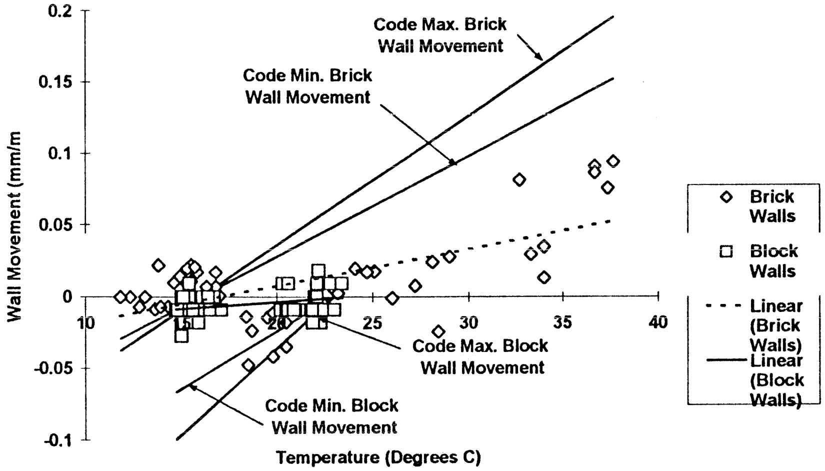

Fig.6 Full day measurements of brick and block wall movements

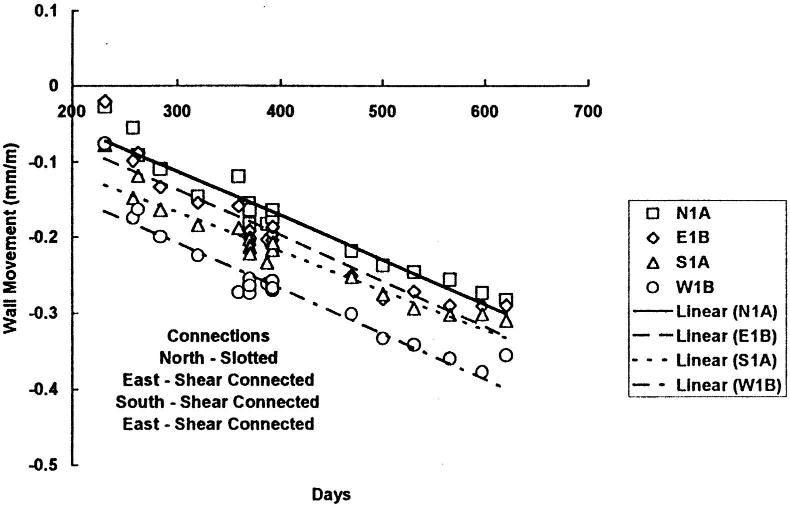

Fig. 7 Block wall movement (temperature effects removed)

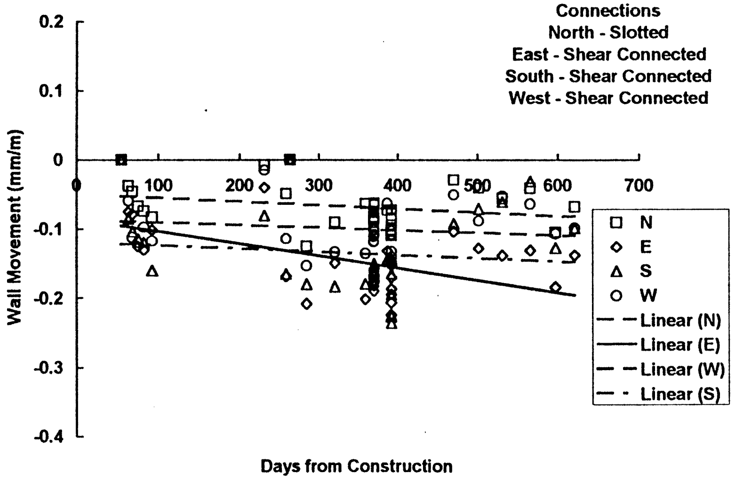

Fig. 8 Brick wythe movements (temperature effects removed)

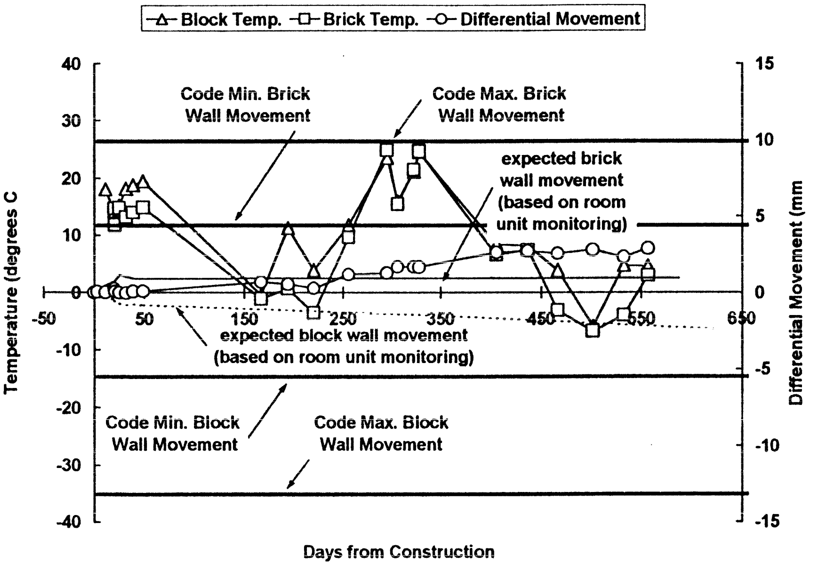

Fig. 9 Differential movements and temperature changes in North Wall

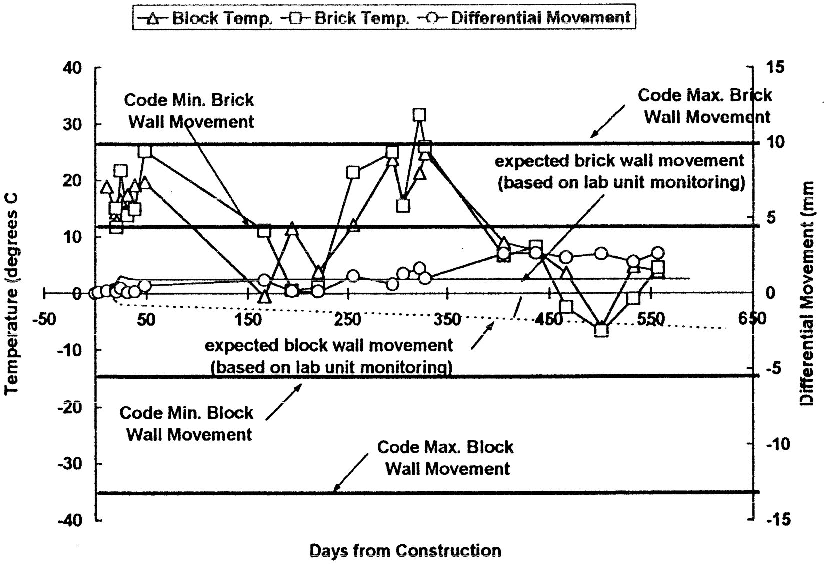

Fig. 10 Differential movements and temperature changes in East Wall