Long-Term Differential Movements in Masonry Cavity Walls

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LONG-TERM DIFFERENTIAL MOVEMENTS IN MASONRY CAVITY WALLS

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Abstract

Differential movement between concrete block and clay brick wythes in cavity walls is typically calculated using values determined from the monitoring of individual units. Many engineering reports dealing with masonry cavity and veneer wall failures focus on brick wythe expansion as the root cause. To assess the validity of such claims, a 21 m tall clock tower structure was built in the field to monitor the differential movement in masonry cavity walls. The data presented has extended the previous database of 631 days to 1322 days. This data and analysis supercede the preliminary results published by Elwi and Hatzinikolas (1998) at the 8th Canadian Masonry Symposium. A more rigorous analysis of the preliminary results revealed some inconsistencies within the original analysis. Now corrected and more complete, the results clearly show recognizable and stable long-term permanent patterns in the data. Laboratory results from the monitoring of sample units show that the brick expansion and block shrinkage are within the recommended values published by both the Brick Institute of America and the Canadian Standards Association. The differential movement obtained from the field monitoring of the cavity walls was conclusively found to be governed by the movement of the back-up system and not by the expansion of the brick wythe. In addition, the results clearly indicate that the clay brick expansion is counteracted by the shrinkage of the mortar; as such, the brick wythe and thus a brick veneer wall are dimensionally stable.

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Introduction

The amount of differential movement between clay brick and concrete block wythes in cavity walls is perceived as a trivial calculation. Typically, the calculation is based on published values derived from the monitoring of individual laboratory masonry units. Many investigations dealing with cavity wall failures have concluded that insufficient room for burned clay unit expansion was provided. This anticipated expansion is typically accommodated by incorporating horizontal and vertical control (expansion) joints.

The authors contend that the bulk of the differential movement between exterior brick wythes and interior support elements is not dominated by brick expansion. Other factors, such as creep and shrinkage of interior concrete block wythes and/or other structural support elements, are deemed to be the dominant sources of this differential movement.

To investigate this claim, a permanent structure was required for long-term field observations. Initially, a simple tower located at an industrial site was envisioned; however, this concept soon evolved into an eye-catching clock tower at a prominent location in the city of St. Albert, just north of Edmonton, Alberta, Canada. Elwi et al. (1995) provide a detailed description of this structure, the Perron Tower, and the construction phases. Both concrete block and clay brick specimens were taken from the clock tower site to the CMRI laboratory for monitoring purposes.

The database has been updated from 631 days of monitoring, as previously reported (Elwi and Hatzinikolas, 1998), to 1322 days. In addition, more rigorous quality control measures were applied to the data sets and the analysis was modified. Previous results have been reinterpreted as stable and recognizable trends in the extended database have been observed.

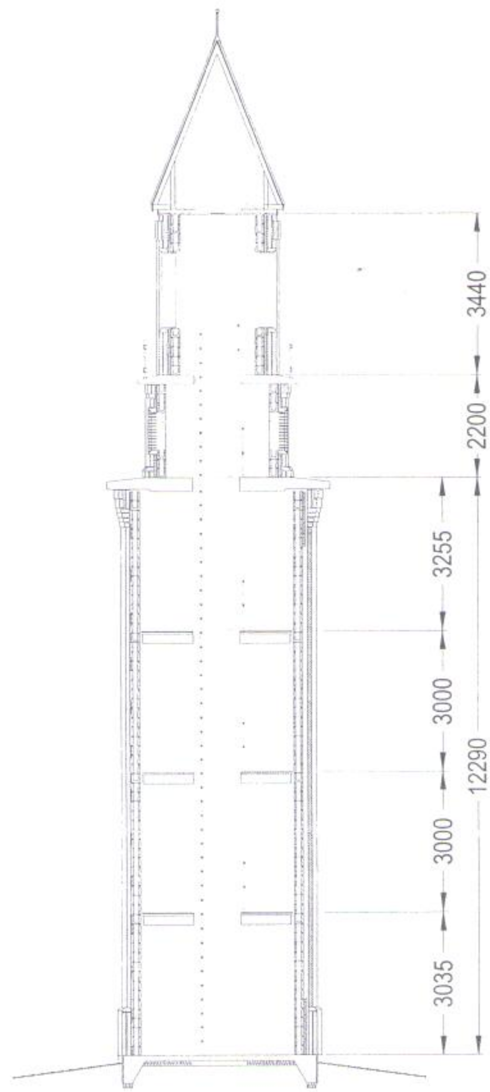


Figure 1 – Elevation of Perron Clock Tower

Experimental Program

Structural System of Experimental Tower

The Perron Clock Tower, shown in figure 1, stands 21 m in elevation and changes cross-sectional dimensions twice. Elevation 0 mm references the top of the structural slab-on-grade which all the vertical components share. The lower cross-section shown in figure 2, elevation 0 to 12045 mm, served as the research portion of the structure. This cross-section consists of four corner pilasters constructed from 300 mm concrete masonry units and four insulated cavity walls utilizing a 200 mm concrete block wythe and a burned clay unit wythe. The pilasters are fully reinforced and grouted; whereas, the walls are neither reinforced nor have any grouted cores. A concrete structural slab placed at elevation 12045 mm transfers all the lateral and vertical loads above this point to the four pilasters. Each cavity wall stands independent from the corner pilasters and thus only resists lateral loads and self-weight. The 12.5 mm vertical control joints between each pilaster and the adjacent walls were filled with a foam rod and flexible caulking. A freestanding steel braced-frame located inside the structure provides lateral bracing to each cavity wall at 3 m vertical increments. Slotted connections were utilized in the vertical direction of the lateral bracing system between the steel braced-frame and the block wythe to prevent any restraint in this direction. Two types of masonry connectors (Wang et al., 1997) were used between the clay brick and concrete block wythes for lateral load transfer. The east, south, and west wall wythes were connected with shear transfer ties and the north wall wythes were connected with vertically slotted ties which provide lateral restraint only. In addition to the use of different masonry ties, the spacing and amount of rigid insulation was varied between wythes (see figure 2) to observe any load transfer effects.

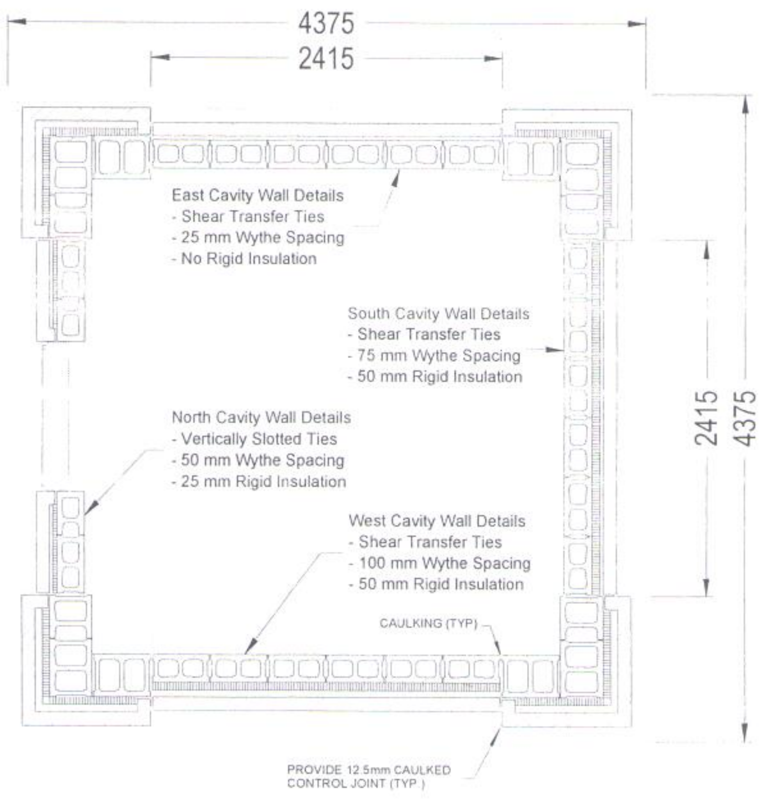


Figure 2 – Cross Section of Instrumented Region of Tower (Elev. 0 – 12040 mm)

Field Instrumentation

Due to the long duration of the testing program, only mechanical measuring devices were fixed to the structure. One steel survey tape was hung from the center of each block wythe at elevation 11500 mm and remained under constant tension from a 1.36 kg (3 lb) mass suspended in a container of motor oil at elevation 0 mm. A series of vernier scales, accurate to 0.1 mm, were permanently fixed to each block wythe along the survey tape to provide the block wythe movement data. A similar survey tape and vernier arrangement were also placed on each pilaster. To measure the differential movements between the block and brick wythes, an arrangement with DEMEC™ points was used where the top demec point was mounted to the exterior brick wythe via a horizontal bar and the lower demec point was mounted directly to the interior block wythe. The top demec point was located at elevation 11600 mm and the lower demec point was positioned 200 mm below at time of installation. A portable DEMEC™ mechanical strain gauge, accurate to 0.000008 strain, was used to measure the differential movement of each wall. A hand-held Fluke™ 51 electronic thermometer was used to measure brick, block, survey tape, and air temperatures at various locations. The steel survey tapes and demec points were installed on July 21, 1995.

Laboratory Monitoring of Units

In parallel with the field monitoring program, both concrete block and clay brick specimens were removed from the lots used to construct the tower to conduct a laboratory monitoring program. Three series of masonry units were monitored in the lab: burned clay units, 200 mm concrete block, and 300 mm concrete block. The 300 mm concrete blocks were used to construct the pilasters and were approximately 5 years old at the time of construction. Although these aged units were monitored both in the laboratory and in the field, none of this data is presented in the analysis. The purpose for monitoring the pilasters was to ensure that the structural system performed as it was intended; in that, no vertical load interaction existed between the cavity walls and the pilasters. Observations from both the burned clay units and the 200 mm concrete units are discussed as these components formed the cavity walls.

Again, mechanical devices were used to monitor the laboratory masonry units. The test setup was similar to that performed by Drysdale et al. (1995). Each 200 mm and 300 mm concrete masonry unit was fitted with demec points initially spaced at 200 mm. A 200 mm demec gauge was used to measure dimensional changes. The burned clay units were fitted with demec points initially spaced at 50.8 mm (2 inches) and the respective demec gauge was used to monitor the dimensional changes. The same electronic thermometer used in the clock tower was used to measure the temperature of the laboratory units.

Upon delivery to the site, five 200 mm concrete masonry blocks were taken to the Canadian Masonry Research Institute (CMRI) laboratory on June 15, 1995 for monitoring. The blocks were manufactured on June 8, 1995 in accordance with CSA Standard A371. Figure 3 shows the block shrinkage versus time along with the maximum CSA S304.1-94 code provision plotted for comparison. The final data reading was taken on day 1310 which refers to days from manufacturing of the block (i.e. day 0 is June 8, 1995). Both this set of data points and the data from day 631 have an average shrinkage of 0.8 mm/m which coincides with the maximum value suggested in the code. This large value of shrinkage should not be alarming due to the ambient conditions at the CMRI laboratory located in Edmonton, Alberta. Having a relatively constant room temperature of 22 °C and very low relative humidity, no

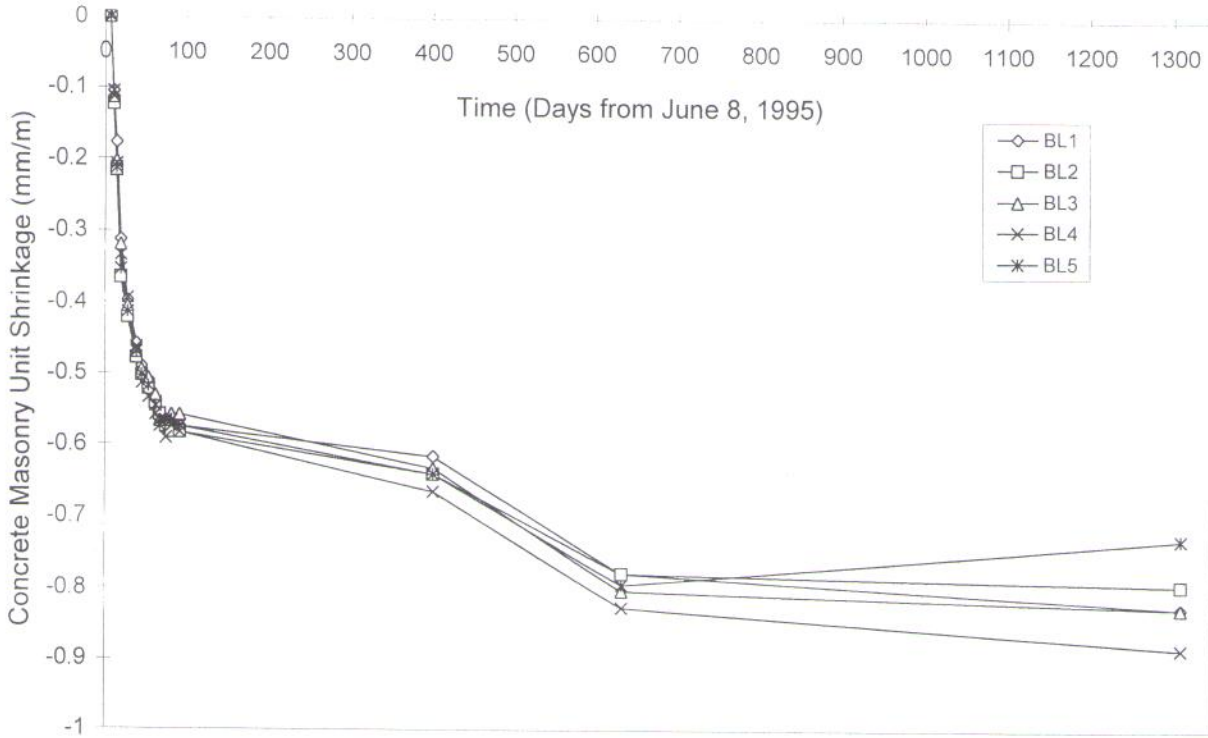


Figure 3 – Laboratory Concrete Block Movement

indoor humidifier is installed, the lab environment provides ideal conditions for maximum drying shrinkage.

The burned clay bricks were manufactured on June 8, 1995 and arrived to the site on June 19, 1995. Ten brick samples were immediately taken to the CMRI laboratory for monitoring purposes. The clay brick units were manufactured in accordance with CSA Standard A82.1 and were fired at 1188 °C (2170 °F). Preliminary results for the laboratory brick expansion published at the 8^{TH} Canadian Masonry Symposium (Hatzinikolas and Elwi, 1998) were reviewed. The review revealed that the initial standard bar readings were not incorporated in the analysis. This error produced a trend showing the bricks stopped expanding around day 50. In this paper, the corrected analysis shows significantly different laboratory brick movement than previously shown. Figure 4 presents the clay brick expansion versus time with the maximum CSA S304.1-94 code provision for brick expansion included for comparison. The maximum expansion values occur at day 1310 which again corresponds to days from manufacturing. Although, the data appears to be segregated with eight specimens grouped around 0.8 mm/m and two specimens grouped around 1.2 mm/m, all 10 specimens at day 1310 are within two standard deviations of the mean. If the arithmetic mean is calculated at day 1310 using all 10 specimens, the brick expansion is 0.86 mm/m. If the mean is recomputed using only the data within one standard deviation, an expansion value of 0.79 mm/m is found. Note that specimens Br3, Br7, and Br10 were not within one standard deviation of the mean. Regardless, these values fall within the recommended provision published in the code.

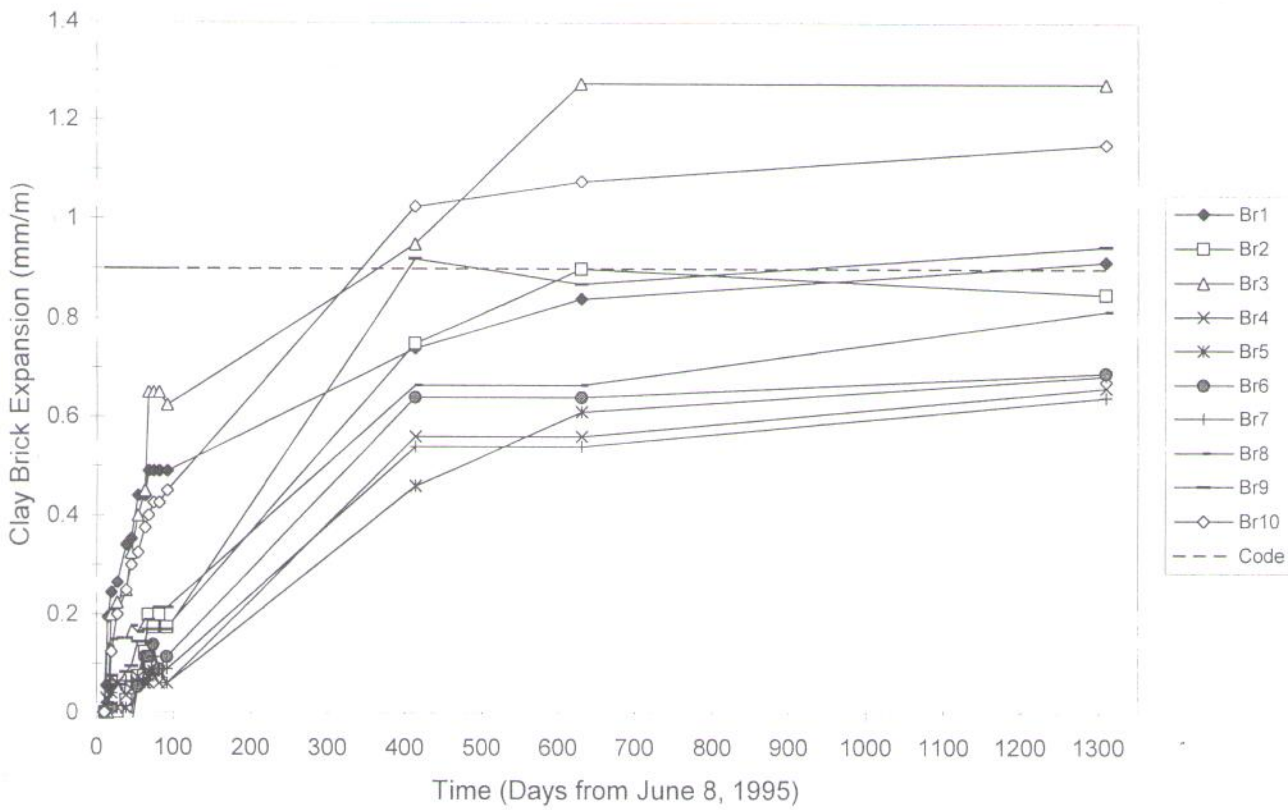


Figure 4 – Laboratory Clay Brick Movement

Results

Five sets of data were available to the investigators. These consisted of: laboratory block movement, laboratory brick movement, comprehensive field temperature readings, field block wythe vertical movement, and field differential movement between the block and brick wythes.

Temperature Compensation

Temperature readings were necessary to correct both the demec and survey tape field readings for comparison to the laboratory units, as well as to separate this temporary effect from the permanent movement of the walls. The annual air temperature in Edmonton, Alberta typically fluctuates between –40 ^{o}C (-40 ^{o}F) and +40 ^{o}C (+104 ^{o}F). A reference temperature of 22 ^{o}C was used to evaluate and then remove any thermal movements. This temperature conveniently coincided with both the mean laboratory temperature and the mean temperature on July 21, 1995, day 0. The coefficient of thermal expansion for the 200 mm concrete block (α_{BL}) was determined by linear regression analysis from two independent sets of data. On both June 22 and July 14, 1996, vertical block wythe movement versus temperature readings were recorded throughout each day. Figures 5a and 5b show the block wythe movement versus change in block temperature for each day. The slopes from each set of linear regression equations were averaged and then divided by the control distance of 11000 mm to yield a value for α_{BL} of 11.5×10^{-06} mm/mm/°C. This value is within the typical range of $6 - 13 \times 10^{-06}$ published in the literature (Jessop, 1980). Note, the east slope from the July 14 data was found to be an outlier and thus was not included. Type S mortar was used in proportions of: 1 part normal cement, $^1/_2$ part hydrated lime, and 4 parts sand. Jessop (1980) states a typical coefficient of thermal expansion for a 1 part cement and 3 part sand mortar of 13×10^{-06}. Hence, this value was used in the analysis. The vertical coefficient of thermal expansion for the clay brick (α_{Br}) was taken as 8×10^{-06} mm/mm/ °C which is the mean value reported in CSA S304.1-94. For the Luffkin ™ steel survey tapes used, the manufacturer reported a value of 11.7×10^{-06} mm/mm/°C for α_{Tape}.

Figure 5a - Thermal Block Wythe Movement on 22 June 1996

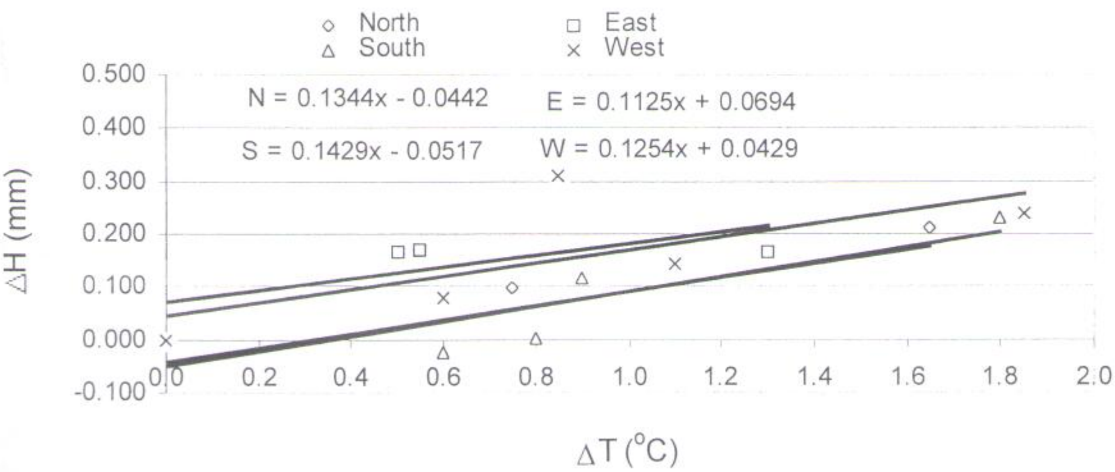
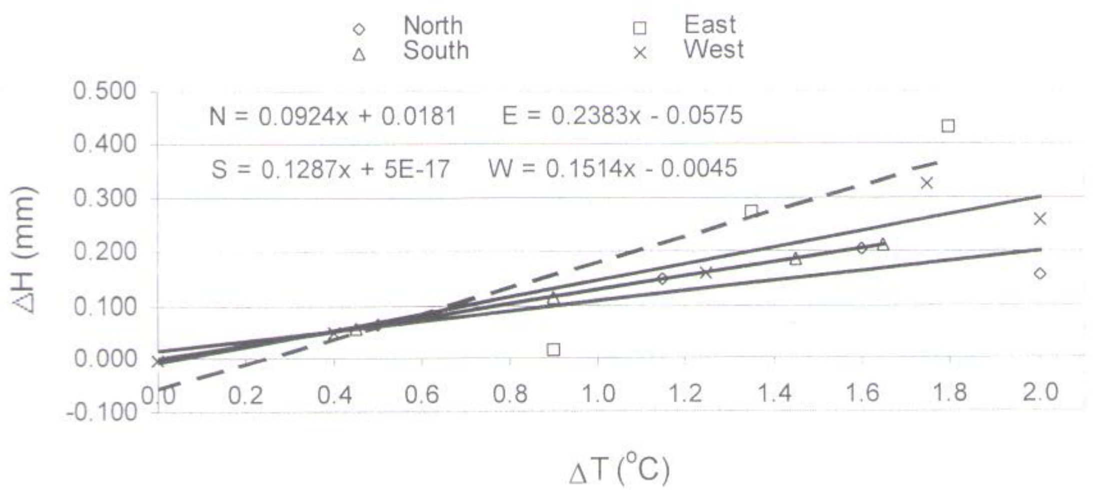


Figure 5b - Thermal Block Wythe Movement on 14 July 1996



Long-term Differential Movements in the Tower

Brick and block wythe movement data was collected over a period of 1279 days from the Perron clock tower. Two completely independent data collecting techniques, steel survey tape and demec gauge, were used to asses the results presented in figures 6, 7, 8 and 9. These figures show the brick, block, and differential wythe movements for the north, east, south and west cavity walls respectively. Each figure is presented with the thermal movements removed from each series of data.

The block wall movement was directly measured with the steel survey tape and the laboratory block movement was measured with a demec gauge. Figures 6 through 9 clearly indicate that the block wythes in each of the four cavity walls behave similarly to the predicted wythe movements calculated from the laboratory block movement. The predicted laboratory shrinkage values were computed by multiplying the mean unit shrinkage by the control height of 11000 mm. In this calculation, the mortar joints are assumed to shrink at the same rate as the blocks.

The differential movement between the block and brick wythes was measured directly with a demec gauge. This is included in figures 6 through 9. Positive changes in the differential movements represent opposite movements between the block and brick wythes. The trends show a permanent positive differential change in height for each of the four cavity walls. Also, the magnitude of the differential change is approximately equal for all four walls.

To asses the brick wythe movements, the block wythe movements were algebraically added to the differential movements. Positive changes indicate brick wythe vertical expansion and negative changes indicated vertical shrinkage. The predicted laboratory brick expansion values were calculated by multiplying the mean unit expansion by 9348 mm. This distance corresponds to the brick unit dimension of 57 mm multiplied by 164 courses in the 11 m control height. Thus, the movement effects due to the mortar joints are not included. As seen in figures 6 through 9, each brick wythe undergoes very little vertical movement.

Figure 6 - North Cavity Wall Wythe Movement with Thermal Movements Removed
(Cavity wall details: Slotted ties, 50 mm wythe spacing, 25 mm rigid insulation)

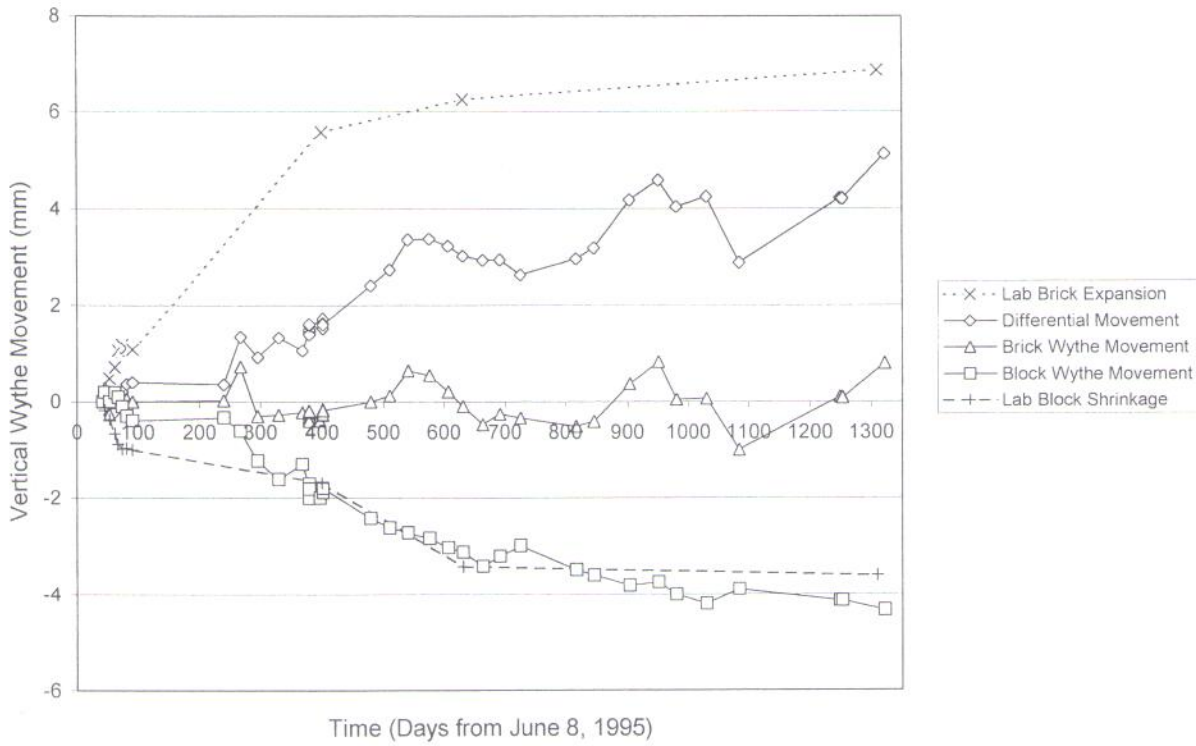


Figure 7 - East Cavity Wall Wythe Movement with Thermal Movements Removed
(Cavity wall details: Shear transfer ties, 25 mm wythe spacing, no rigid insulation)

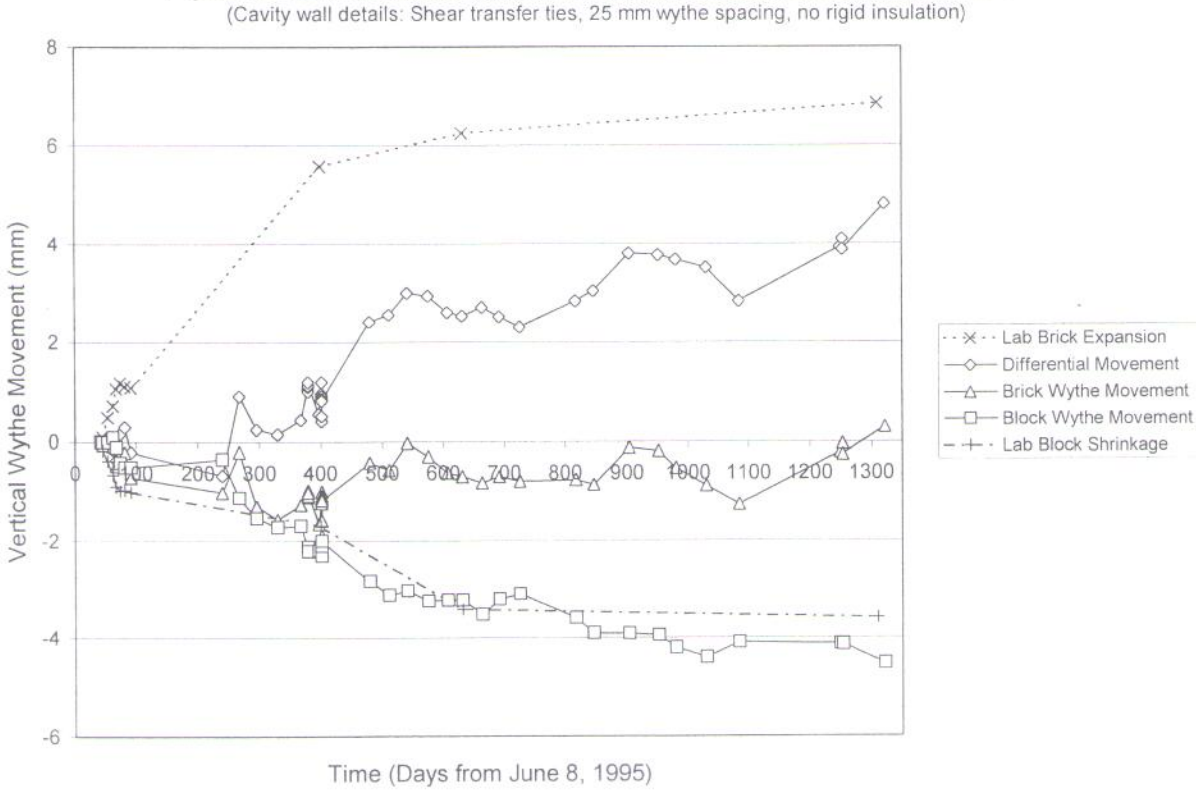


Figure 8 - South Cavity Wall Wythe Movement with Thermal Movements Removed
(Cavity wall details: Shear transfer ties, 75 mm wythe spacing, 50 mm rigid insulation)

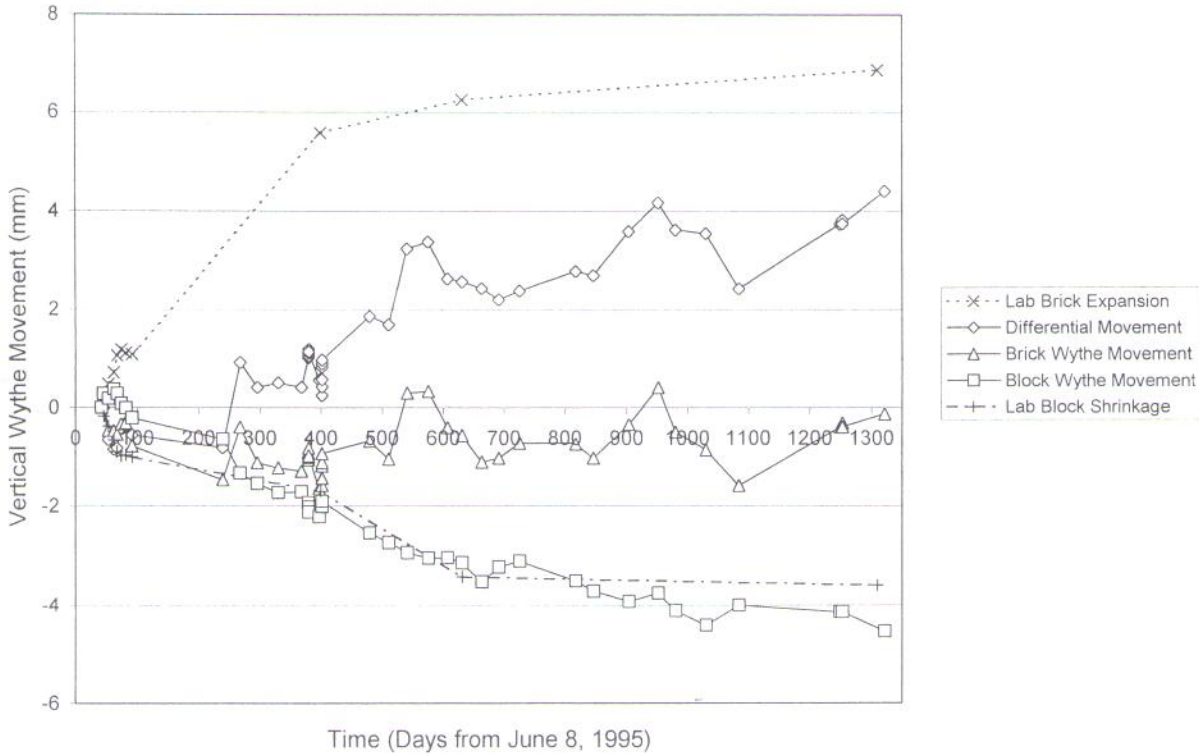


Figure 9 - West Cavity Wall Wythe Movement with Thermal Movements Removed
(Cavity wall details: Shear transfer ties, 100 mm wythe spacing, 50 mm rigid insulation)

Conclusions

Both the brick expansion and block shrinkage trends from the laboratory specimens are consistent with the CSA S304.1-94 code provisions. The block wythe shrinkage in all four cavity walls is in good agreement with the expected block shrinkage determined from the laboratory specimens. However, the brick wythe expansion in the tower varies drastically from that predicted by the laboratory specimens. The figures presented within clearly show that the brick wythes, as complete assemblies, do not expand in the vertical direction. Rather, movement in the brick wythes is governed by seasonal variations in humidity only. The block movement is also influenced by seasonal variations in humidity levels but is dominated by permanent moisture shrinkage. Differential movement is also independent of the type of masonry tie used. Both the shear and non-shear connected wythes perform the same. As these are non-load bearing walls, creep effects in the block are considered as negligible.

Current thinking that many envelope failures are a result of excessive brick wythe expansion is based on laboratory monitoring of clay units and is not supported by the field behavior of brick wythes observed in this study. Any brick expansion is counteracted by creep and shrinkage mechanisms in the mortar joints themselves. Thus, the field observed differential movements between clay brick and concrete block wythes are entirely governed by the long-term movement of the concrete block wythe, with slight movements induced by changes in seasonal humidity levels.

The authors recommend that greater emphasis be placed on determining the permanent movement of vertical load carrying structural components in buildings. Specifically, building code provisions relating to the size and location of control joints should be based solely on long-term building component "Creep" and "Shrinkage" movements.

Acknowledgements

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