DIFFERENTIAL MOVEMENT BETWEEN CLAY BRICK VENEER AND CONCRETE BLOCK IN LOADBEARING MASONRY HIGHRISE STRUCTURES

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ABSTRACT

Loadbearing masonry highrise construction in North America typically employs concrete block as the loadbearing material and clay brick as the veneer. The two wythes are commonly separated by an air cavity of at least 25 mm width and the insulation may be placed in the cavity or on the inside face of the concrete block masonry. The veneer typically is tied to its backup by means of continuous horizontal joint reinforcement. To ensure a safe and serviceable building enclosure, differential movements between the two wythes must be considered in design and construction. Failure to do so may lead to problems such as masonry cracking, caulking deterioration, moisture penetration, and tie distress.

The paper outlines the deformations affecting clay brick and concrete block masonry. A computer program was developed to predict deformations due to elastic, creep, moisture, and thermal effects at any time during a building's life. The program finally arrives at differential movements between the two wythes. An overview of the capabilities and limitations of the program is presented by the authors. The analysis program is applied to an example building and the paper discusses the predicted differential movement results as affected by restraint between the two wythes.

1. INTRODUCTION

Although clay brick has been very popular as a veneer for many years, it was only recently that designers began to recognize the sometimes marked difference in the deformational properties of brick and concrete. For example, the phenomenum of moisture expansion of clay brick was first reported in 1931 by L. A. Palmer[1] but even today it is not well understood by most designers. Since concrete generally shrinks with time, this aspect alone can lead to significant differential movement between a brick panel and its backup concrete block masonry. Further differential movement will arise as a result of thermal, elastic and creep effects in the veneer and its backup.

Under normal construction rates, the total differential movement between brick veneer and concrete block masonry, on a storey by storey basis, usually amounts to less than 3 mm. However, the veneer on most loadbearing masonry structures runs uninterrupted from the ground to the roof resulting in differential movements which are cumulative over the height of the building. Failure to take these movements into account in design may lead to problems such as masonry cracking, caulking deterioration, moisture penetration, and tie distress, particularly at the upper levels of the structure.

To predict the magnitude of these differential movements, a computer program was developed, firstly to calculate the absolute unrestrained movement in each material, secondly to compare these movements, and thirdly to arrive at a

restrained differential movement[2]. In the case of most loadbearing masonry structures, restraint between the two wythes is provided by masonry ties and mortar droppings.

This paper first outlines the various sources of long term and instantaneous movements arising in the structural materials and presents the relationships which were used to predict their magnitudes. Then the capabilities and limitations of the computer program are discussed particularly with reference to the treatment of restraint between the veneer and the structure. Finally the computer program is applied to an example building investigating the effects of various restraint conditions between the veneer and structure on the differential movement at the roof level. The example building models an 11 storey loadbearing masonry structure located in Toronto, Canada, which was instrumented to measure differential movements, overall movements and strains. The results of the field measurements are presented in another paper entitled "Deformation Measurements on a Loadbearing Masonry Highrise Structure in Canada"[3] also presented at this conference.

2. DEFORMATIONS

2.1 Elastic

The elastic modulus of both clay brick and concrete block masonry has been found by most researchers to increase with time. For the clay brick masonry of our example building, the program makes use of a relationship derived from work by Grimm[4]

$$E_{mbr}(t_i) = E_{mbr}(28) + 7.957 \times 10^3 \, [\ln\{31 + \ln(t_i)\} - 3.536] \quad \text{(MPa)} \qquad (1)$$

where the 28 day elastic modulus, $E_{mbr}(28)$, is given by Grimm as

$$E_{mbr}(28) = 7.957 \times 10^3 \, [\ln(f'_m) - 1.12] \quad \text{(MPa)} \qquad (2)$$

The elastic shortening of the brick panel can be calculated from

$$\delta_{br_{\ell,i}} = \delta_{br_{\ell,i-1}} + (V_{\ell,i} - V_{\ell,i-1}) \left[\frac{H_\ell}{A_{br_\ell} \cdot E_{mbr}(t_i)} \right] \qquad (3)$$

where $V_{\ell,i}$ is the total load applied to the top of the brick panel at level ℓ at the beginning of time interval i. Note the assumption that the elastic deformation remains constant under constant load, despite the changing elastic modulus, but the response to an incremental load varies.

The elastic modulus of ungrouted concrete block masonry was derived from tests performed on block prisms obtained from the building discussed in the following paper [3]. The effect of grout on the net elastic modulus of the concrete masonry is expressed by Sturgeon [5] as

$$E_{mbl} = \frac{[0.56 E_{gbl}(\alpha)(1-\psi)] + \psi E_{ubl}}{\alpha(1-\psi) + \psi} \qquad (4)$$

and the variation of elasticity with time was derived from work by C.E.B.[6] on concrete as follows

$$E_{mbl}(t_i) = E_{mbl}(28)\sqrt[3]{0.3103\ln(1.1631t_i) - 0.3073\ln(1 + \frac{t_i}{93.09})} \qquad (5)$$

The elastic shortening of the frame at level ℓ will be

$$\delta fr_{\ell,i} = \delta fr_{\ell,i-1} + \left[(P - V)_{\ell,i} - (P - V)_{\ell,i-1}\right]\left[\frac{H_\ell}{A_{bl_\ell} \cdot E_{mbl}(t_i) + A_{s_\ell} \cdot E_s}\right] \qquad (6)$$

Note that the force applied to the top of the brick veneer, $V_{\ell,i}$, acts on the structure in opposition to the applied building load $P_{\ell,i}$. Equation (6) gives the elastic deformation of the structure due to the building loads and the forces transmitted to the veneer. However there will be some additional secondary elastic strains arising from the difference between the unrestrained thermal, creep, and shrinkage deformations of the block and its reinforcement. In general these movements result in a gradual transfer of stress from the block to the reinforcement and while they are treated in the program, the reader is referred to Ref. 2 for additional details.

2.2 Creep

The creep of both clay brick and concrete block masonry has been found to be affected not only by the magnitude of the applied stress but by the age of material at the time of loading. Thus as the load changes, the calculation of creep must take an incremental form with an appropriate adjustment for the age at which the incremental load is applied.

The relationship proposed by Poljakov[7] gives creep strains which are in relatively poor agreement with observations by Warren and Lenczner[8]. However Poljakov gives an age-at-loading correction factor which appears to be quite reasonable. Warren and Lenczner conducted an intensive study into the relationship between creep and time for brick masonry loaded at an age of 28 days, from which the following hyperbolic relationship was derived

$$\varepsilon_{crbr} = \sigma_{br} \times 10^{-5}\left[\frac{t_i - 28}{a + b(t_i - 28)}\right] \qquad (7)$$

The coefficients a and b are determined for various conditions and brick strengths in Ref. 8 . The computer program combines Poljakov's correction factor with Warren and Lenczner's relationship which, employing the principle of superposition, yields the incremental relationship

$$\varepsilon_{crbr}(t_i) = \sum_{j=1}^{i-1} (k_j)(\sigma_{br_j} - \sigma_{br_{j-1}})(10^{-5})\left[\frac{t_i - t_j}{a + b(t_i - t_j)}\right](0.1 + 1.82e^{-0.3\sqrt[4]{t_j}}) \qquad (8)$$

The calculation of creep strains occurring in concrete block masonry follows the guidelines developed for concrete by C.E.B.[9].

$$\varepsilon_{crbl}(t_i) = \sum_{j=1}^{i-1} k_j \left(\sigma_{bl_j} - \sigma_{bl_{j-1}}\right) \phi_{bl}(t_i, t_j) \qquad (9)$$

where $\phi_{bl}(t_i, t_j)$ is the block masonry creep function giving the specific creep at the time of interest, t_i, due to the stress increment applied at the beginning of interval j[2].

2.3 Moisture

The response of clay brick to the environment after being fired is radically different from that of concrete block. As noted earlier, L.A. Palmer[1] was the first to experimentally verify the fact that clay brick gradually expands with exposure to the atmosphere, whereas concrete usually shrinks. Although it is generally agreed that the moisture expansion of clay varies with the logarithm of time, its ultimate magnitude is highly variable — dependent not only on the composition of the clay but also on the firing temperature and the environmental conditions. The computer program makes use of the following relationship derived from work by Grimm[4].

$$\varepsilon_{bm}(t_i) = \varepsilon_{bmt}\left[\frac{3.12\,\{\log(t_i + 2.3) - \log(t_p + 2.3)\}}{3.12\,\log(t_t + 2.3) - 1}\right] \qquad (10)$$

Equation 10 depends on either a delayed moisture expansion test, as described by Grimm, or an estimated moisture expansion value for ε_{bmt}. Moisture expansion of the brick used in the example building was in fact monitored for a period of 29 months and so Eq. (10) was employed to predict the brick unit expansion at times of interest. To calculate the net expansion of the brick masonry, it is necessary to include the effect of mortar shrinkage, i.e.

$$\varepsilon_m(t_i) = R_{br}\varepsilon_{bm}(t_i) + (1 - R_{br})\varepsilon_{ms}(t_i) \qquad (11)$$

where the shrinkage strain of the mortar, ε_{ms}, can be found in Ref. 2.

The ultimate shrinkage of concrete block masonry depends largely on the aggregate type and the relative humidity of the environment. Curves proposed by C.E.B.[9] show very good agreement with the average of test results presented by NCMA[10] on the shrinkage of concrete block units. Thus the ultimate shrinkage of both the grout and the block unit is predicted by the following relationship derived from C.E.B.

$$\varepsilon_{grsu} = \varepsilon_{blsu} = -\left[7.7206 \times 10^{-4}\left(1 - \frac{RH}{100}\right)^{0.7737}\right]\left[0.6 + \sqrt{\frac{18}{d_m}}\right] \qquad (12)$$

The shrinkage strain of grout at the time of interest can be found from

$$\varepsilon_{grs}(t_i) = \varepsilon_{grsu} \cdot \beta_s(t_i) \tag{13}$$

The function β_s is derived from C.E.B. curves and governs the rate of progression of the shrinkage. Because of its complexity, the interested reader is again referred to Ref. 2 for details.

Since HHFA[11] found that rewetting concrete block results in an expansion of about ¼ of the shrinkage which had already occurred, it is desirable to make an adjustment for the wetting effect of grout by means of the relation

$$\varepsilon_{bls}(t_i,t_p) = \varepsilon_{blsu}[\beta_s(t_i) - (1 - 0.25\alpha)\beta_s(t_p)] \tag{14}$$

where the assumption is that the degree of wetting is directly proportional to the fraction of cores grouted.

Finally the net shrinkage of the concrete block masonry can be found from

$$\varepsilon_{sh}(t_i) = \left[\frac{\alpha(1 - \psi)}{\alpha(1 - \psi) + \psi}\right] \varepsilon_{grs}(t_i) + \left[\frac{\psi}{\alpha(1 - \psi) + \psi}\right]\left[R_{bl}\varepsilon_{bls}(t_i,t_p) + (1 - R_{bl})\varepsilon_{ms}(t_i)\right] \tag{15}$$

where the mortar shrinkage, $\varepsilon_{ms}(t_i)$, is given in Ref. 2.

2.4 Thermal

The thermal strain in each of the building elements is relatively easy to determine from

$$\varepsilon_{th} = \alpha_{th}(T_i - T_p) \tag{16}$$

where T_p is the temperature of the element at the time of its placement. T_p is assumed to be equal to the mean ambient air temperature with a lower bound of -5°C since some heating is generally provided during the winter months. The determination of the element temperatures, T_i, at the time of interest is carried out in two ways:

1) for average temperatures, which contribute to creep stresses, and for the minimum winter temperatures,a one-dimensional steady-state heat flow analysis is applied to the exterior wall sandwich. The wall sandwich is composed of up to 8 layers including air cavity, the thickness, density, thermal conductivity, specific heat, emissivity, and absorptivity of each layer being specified by the program user or calculated internally depending on material type.

2) For extreme summer conditions, a one dimensional transient heat flow analysis is performed on the exterior wall sandwich over a 24 hour period. The transient analysis allows the effect of

solar radiation on the veneer and interior layers to be included. The program automatically selects the temperature set with the greatest temperature differential between the veneer and frame — due to thermal mass and phase lag, this will not necessarily coincide with the maximum veneer temperature.

2.5 Freezing

When clay brick freezes, it usually undergoes a certain amount of expansion. Tests performed by Davison[12] indicated a large variability in the magnitude of this expansion, either upon first freezing or in the permanent strain which exists after rethawing. Temporary freezing expansion strains of between 0.03 and 1.19 mm/m were observed with an average of 0.44 mm/m; permanent strains ranged from 0 to 0.56 mm/m with an average of 0.16 mm/m. It should be noted that in all cases the brick was saturated prior to freezing and so the freezing expansion of bricks on site would be expected to be somewhat lower. The program assumes that freezing expansion only occurs if the mean ambient temperature drops below that required for freezing and if the bricks do not undergo freezing prior to construction, i.e. while stacked on site.

3. COMPUTER PROGRAM

The computer program was developed to study the interaction between a veneer and its supporting structure, particularly with regards to the stresses arising in each structural element and differential movements. The program has the following capabilities and limitations:

- reinforced concrete, structural steel, and loadbearing masonry structures can be modelled
- veneer can be connected to the frame by masonry ties alone, or by ties and shelf angles at single or multiple floor spacing and with various expansion gaps
- yield and stiffness properties of the ties and/or shelf angles are considered in the analysis. Ties are assumed to act as if lumped at each floor level.
- up to 8 different 'times of interest' can be specified after construction is completed
- the veneer must be present on at least one level of the building and must be of clay brick
- the maximum number of storeys, including basements, is 25.
- all forces are assumed to act concentrically and all materials, except ties and shelf angles, are assumed to be linearly elastic.

4. EXAMPLE BUILDING

The example building modelled for this paper is an 11 storey loadbearing masonry apartment building constructed near Toronto in Mississauga, Canada. Construction was completed by August 1982 and subsequent times of interest correspond to 6 of the dates on which measurements were actually taken, i.e., October 21, 1982, November 8, 1982, January 13, 1983, March 23, 1983, August 10, 1983 and finally December 30, 1983.

Fig. 1 shows a plan of the structure highlighting the wall section on the southwest face which has been modelled in the computer program. Due to the orientation of the floor joist system, the tributary area acting on the 7.23 m wall section is about 12.8m². Dead loads are about 2.6 kN/m² and 20% of the live loads of 1.9 kN/m² are assumed to act on a permanent basis. The maximum summer afternoon and minimum winter air temperature are 35 and -25°C respectively. Interior air temperature is maintained at 21°C.

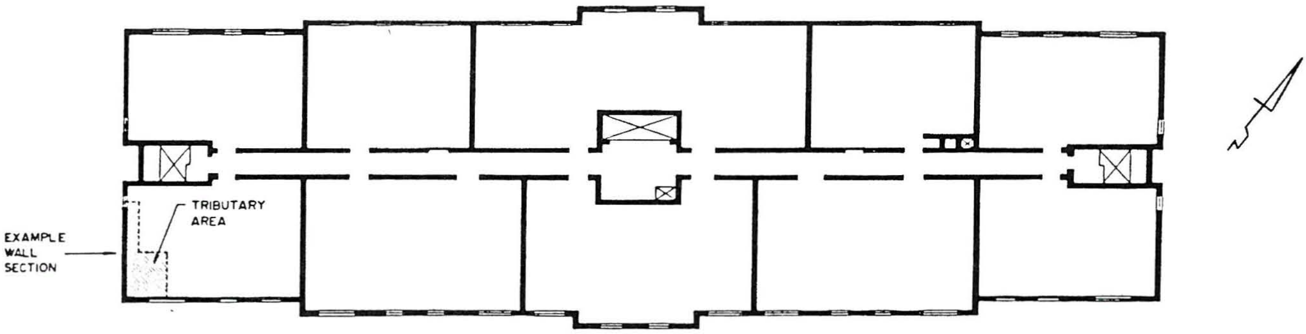

Fig. 1 Typical floor plan view of example building with modelled wall section shown.

The brick masonry veneer was assumed to have a coefficient of thermal expansion in the vertical direction of 6.9 µm/m/°C; a moisture expansion of about 0.25 mm/m was measured after 29 months. Mortar shrinkage was assumed to reach an ultimate value of 0.4 mm/m. Average compressive strengths of the brick masonry and mortar were found to be 28 MPa and 13 MPa respectively. Freezing expansion was assumed to occur at temperatures less than -7°C with a temporary value of 0.15 mm/m and a permanent set of 0.10 mm/m.

The loadbearing wall consisted of 190 mm thick concrete block units, 78% solid with 39% to 47% of the cores grouted. A coefficient of thermal expansion of 9.2 µm/m/°C was used and the ultimate shrinkage strain of the concrete masonry was assumed to be 0.23 mm/m. The elastic modulus of the masonry was determined from prism tests to be 16 300 MPa in the first and second floors and 11 700 MPa at upper levels. Within the tributary area, the cross-sectional area of the vertical reinforcement was 2200 mm² for the first two levels and 1800 mm² at higher levels.

Insulation consisting of 100 mm fibreglass batting was placed on the interior face of the block masonry. The location of the insulation has a large influence on the potential differential movement arising from thermal effects. With insulation placed on the interior face of the concrete masonry, annual thermal differential movement will be small. However, if the insulation is placed between the brick and block, cyclic differential movements of about 0.9 mm per storey can be expected on an annual basis.

To accommodate construction tolerances, the masonry ties were of the adjustable type as shown in the following paper[3]. With the brick veneer running uninterrupted from the ground floor to the roof, a considerable accumulation of mortar

droppings in the 19 mm air cavity must be expected. If the ties were prevented from sliding in their brackets by this mortar, each would develop a stiffness of about 18 kN/mm against vertical differential movement and would yield under a vertical force of about 0.9 kN. The ties were spaced at 400 mm centres both horizontally and vertically. Thus at each storey the total tie stiffness per metre width of wall is about 320 kN/mm and yield takes place under a load of about 16 kN.

The potential restraint offered by the mortar is less easily quantified. For a cavity width of only 19 mm, it is not unreasonable to expect some 40 to 50% of the interior veneer surface area to have mortar against it. Even if only 10% of this is sufficiently wedged between the two wythes to develop a shear capacity of 2.5 MPa[13], a shear resistance of about 300 kN per metre width of wall per storey can result. Note that the stiffness of such a system prior to shear failure, would be in excess of 1000 kN/mm/m.

Results presented in the paper "Deformation Measurements on a Loadbearing Masonry Highrise Structure in Canada" indicate that a significant degree of restraint must exist between the two wythes[3]. This field result then justifies the range of restraint considered here.

5. ANALYSIS RESULTS

The structure was modelled with varying degrees of restraint between the veneer and the structure; stiffnesses between 0 and 1000 kN/mm/m width of wall and yield or shear capacities between 0 and 300 kN/m at each floor level were assumed. Fig. 2 shows graphically the predicted roof level differential movement between veneer and structure at the various times of interest. In general, the differential movement increases rapidly up to January 1983, by which time the clay brick freezing expansion has occurred, decreases slightly until March 1983 while the freezing expansion reverts to its lesser 'permanent' value, and then follows a gradually increasing sinusoidal pattern. Under any restraint condition, the maximum differential movement is expected to occur in August 1983 with a wide range of values — from 13.9 mm with no restraint between the two wythes to 0.23 mm with a connection stiffness of 1000 kN/mm/m and a yield or shear strength of 300 kN/m. At yield or shear strengths less than about 50 kN/m, the differential movement is largely independent of the connection stiffness. However, for yield or shear strengths greater than about 100 kN/m, differential movement is primarily dependent on the connection stiffness. Thus if ties alone are providing the restraint between wythes, differential movements of up to 10 mm can be expected despite their relatively high stiffness. On the other hand if 4 to 5% of the surface area between wythes is connected by mortar, differential movements will not likely exceed 0.23 mm. This condition appears to be advantageous until it is remembered that the presence of mortar between wythes defeats the rainscreen principle.

A further disadvantage to limiting differential movements in this fashion arises from the fact that the unreinforced veneer becomes the major loadbearing element. Fig. 3 shows the veneer, concrete block, and reinforcement stresses at the ground level. If the restraint between wythes is assumed to be provided by mortar droppings, then the axial veneer stress is predicted to reach a maximum value of 5.7 MPa in compression. This does not appear to be a major problem since the ultimate compressive strength of the brick masonry is about 28 MPa and some lateral support is provided every 400 mm. However under these conditions the concrete block masonry reaches a stress of about 1.2 MPa in tension at the ground level and up to 1.6 MPa in tension at higher levels. Hamid[14] found the tensile strength of grouted concrete masonry to be

generally less than 1.0 MPa and so it is likely that cracking of the concrete masonry will occur. Once cracking has occurred the entire load, transferred to the reinforcement, is sufficient to yield the steel in tension and further open the cracks. These cracks could lead to moisture penetration, corrosion of the vertical steel and reduction in wall stability. The stress in the vertical reinforcement is largely governed by thermal effects. At colder temperatures the steel contracts more than the surrounding masonry and so its stress tends to decrease during the winter and, conversely, increase during the summer. This pattern is shifted down with increasing restraint between the veneer and structure, that is for yield and shear strengths greater than 50 kN/m the reinforcement is seen to go into tension during the winter. In general, for the range of connection stiffnesses considered here, the ground level stresses are primarily governed by the yield or shear strengths acting between the veneer and structure.

The question can be asked if the restrained analysis results which predict significant compression in the veneer and even tensile stresses in the so called loadbearing concrete masonry can be realistic? The authors really do not know. Differential measurement results presented in Reference 3 for the same structure analyzed as part of this paper are of the same order of magnitude as those predicted here assuming the degree of restraint and material properties given in this paper. Strain results presented in Reference 3 indicate that the block masonry is actually shortening, however what stress level can be associated with the shortening is not known and is dependent on the actual restraint and material properties. Only additional field measurements on more structures in combination with realistic laboratory tests can lead to reliable prediction of stress levels and differential movements. The authors currently are part of a team involved in the field measurement of movements of a second highrise loadbearing masonry structure.

6. CONCLUSIONS

The computer program developed to model the long term and instantaneous action of the exterior masonry walls of high rise structures indicates considerable potential for differential movement between a veneer and its supporting structure. It should be pointed out at this point however that although the elastic, creep, moisture, freezing and thermal effects are based on laboratory test results, it is only assumed that laboratory conditions reflect full scale field conditions. For example the magnitude of shrinkage of concrete block masonry observed on a small assemblage under controlled conditions may be considerably different than that arising in the field of an existing building.

Based on the computer simulation, the following conclusions can be drawn concerning the magnitude of differential movement between the veneer and structure at the roof level of the 11 storey example building:

- If the ties are free to slide in their brackets and no other source of restraint exists between the veneer and structure, a differential movement of about 14 mm can be expected within the first 2 years. If this situation is realistic, the movement must be accounted for by the designer in the detailing of window openings, balconies and parapets.
- If the ties are unable to slide freely, restraint between the two wythes is governed by the flexural yielding of the ties and differential movement can be expected to decrease slightly to about 10 mm within the first 2 years. Subsequent cyclic thermal movement may result in fatigue failure of the ties.

· If only 4 to 5% of the veneer surface area is rigidly connected to the supporting concrete masonry with mortar, the expected differential movement is drastically reduced to less than 0.3 mm in the first 2 years. Although this alleviates the detailing problems mentioned above, it can result in the unreinforced brick veneer carrying major building loads and may lead to cracking of the concrete block masonry. Subsequent moisture penetration and corrosion problems may ensue.

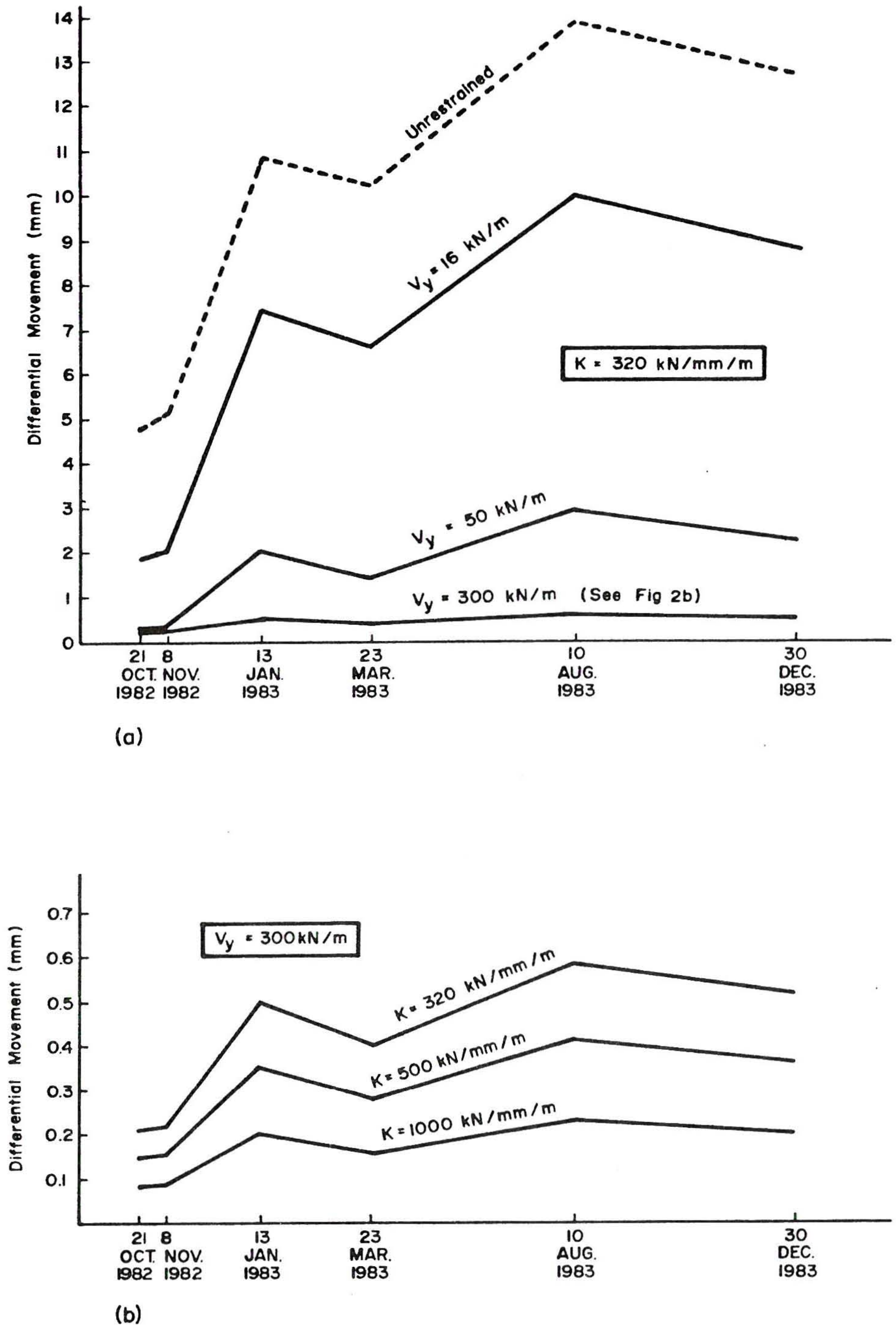

Fig. 2 Predicted differential movement between veneer and structure at the roof level for various stiffnesses, K, and yield or shear strengths, V_y.

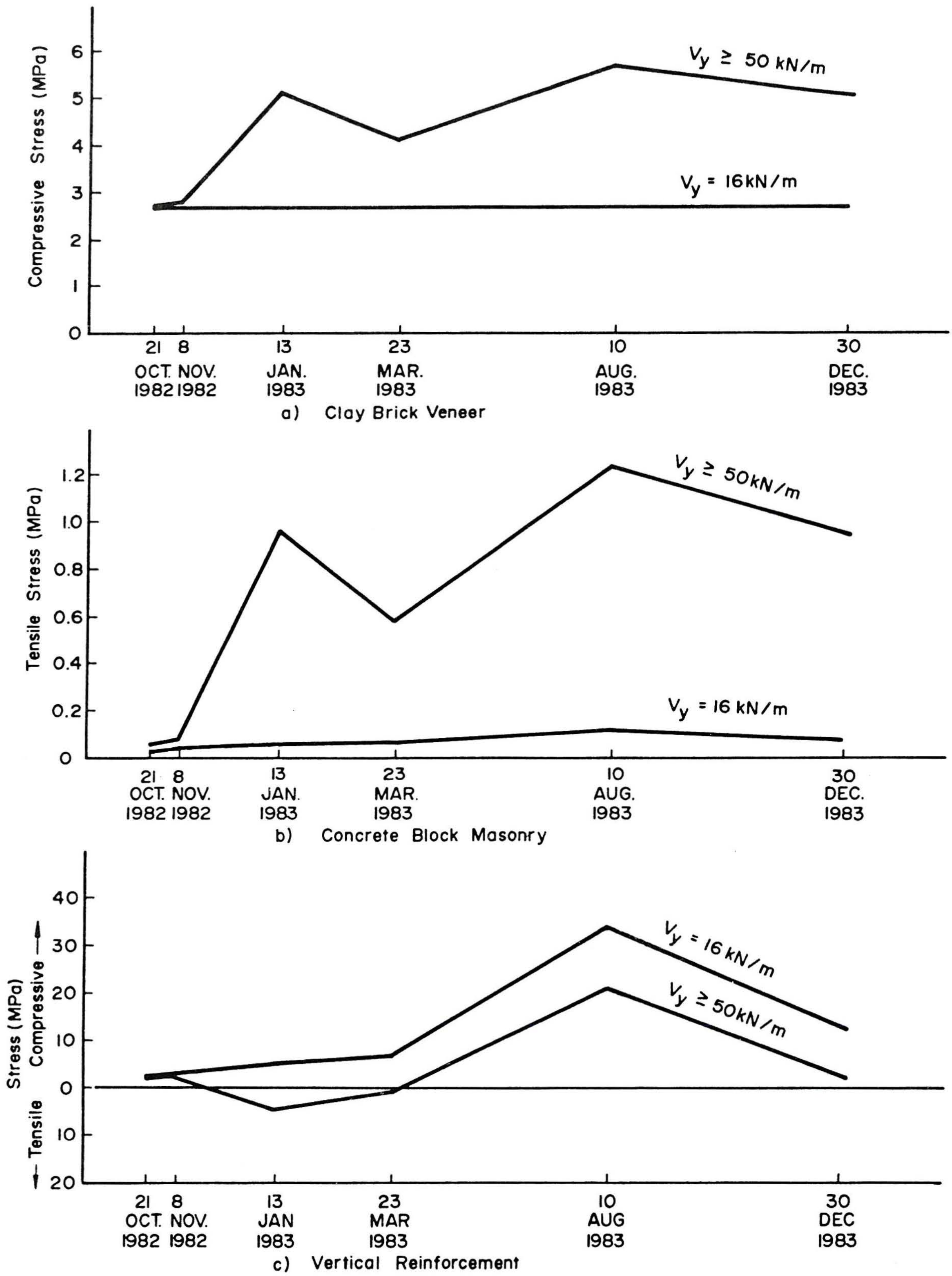

Fig. 3 Predicted ground level axial stresses for a) clay brick veneer, b) concrete block masonry, and c) vertical reinforcement at various times of interest.

ACKNOWLEDGEMENTS

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NOTATION

A_{bl} net cross-sectional area of the concrete block masonry within the tributary area neglecting reinforcement area, mm²

A_{br} net cross-sectional area of the brick veneer within the tributary area, mm²

A_s cross-sectional area of the vertical reinforcement, mm²

E_{gbl} elastic modulus of fully grouted concrete masonry, MPa

E_{mbl} net elastic modulus of concrete masonry, MPa

E_{mbr} elastic modulus of clay brick masonry, MPa

E_s elastic modulus of reinforcing steel, MPa

E_{ubl} elastic modulus of ungrouted concrete masonry, MPa

f'_m compressive strength of masonry, MPa

H storey height, mm

k correction factor to account for the overestimation of creep recovery by the principle of superposition

p total building load acting at the top of a concrete masonry panel, N

R_{bl} ratio of modular to nominal vertical concrete block dimensions, dimensionless

R_{br} ratio of modular to nominal vertical brick dimensions, dimensionless

RH relative humidity of environment, %

t_i age of the element in question at the time of interest, days (months in Eq. 10)

t_j age of the element in question at the beginning of time interval j, days

t_ℓ age of the element in question at the time it was loaded, days

t_p age of brick unit at the time of placement in the wall, days (months in Eq. 10)

t_t age of the brick unit at the time of delayed moisture expansion test, months

T_i element temperature at time of interest, °C

T_p temperature of the element in question at the time of its placement, °C

α fraction of concrete block cores grouted, dimensionless

α_{th} coefficient of vertical thermal expansion of the element in question, mm/mm°C

δ_{br} vertical elastic deformation of brick veneer panel, mm

δ_{fr} vertical elastic deformation of a structure panel, mm

ε_{bls} shrinkage strain of the concrete block unit since its placement, mm/mm

ε_{blsu} ultimate shrinkage strain of the concrete block unit, mm/mm

ε_{bm} moisture expansion strain of the clay brick unit since its placement, mm/mm

ε_{bmt} moisture expansion strain of the clay brick unit derived from a 4 hour accelerated steam test or a delayed expansion test, mm/mm

ε_{crbl} creep strain of concrete masonry, mm/mm

ε_{crbr} creep strain of clay brick masonry, mm/mm

ε_{grs} shrinkage strain of grout, mm/mm

ε_{grsu} ultimate shrinkage strain of grout, mm/mm

ε_m net moisture expansion strain of clay brick masonry, mm/mm

ε_{ms} shrinkage strain of mortar, mm/mm

ε_{sh} net shrinkage strain of concrere masonry, mm/mm

ε_{th} thermal expansion strain, mm/mm

σ_{bl} uniform vertical stress acting on the concrete masonry, MPa

σ_{br} uniform vertical stress acting on the clay brick masonry, MPa

ϕ_{bl} creep function giving the specific creep of concrete masonry, mm/mm/MPa

ψ ratio of net to gross concrete block unit area, dimensionless

Moisture Expansion: Update and Review.

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Summary.

Since my report to the 9th. Australian Ceramic Conference in August 1980 we have continued to measure bricks undergoing natural expansion as well as using the Brick Development Research Institute accelerated weathering test.

The 5 year natural exposure results have confirmed my 1980 prediction of a 50% decrease in brick moisture expansion.

Test results from the late 1960s indicated that some of the bricks produced by the Company I represent had relatively high moisture expansion, - greater than 1mm/m at 5 years ex-kiln. A reduction in the values was sought as a means to improve product quality.

In order to show any reduction achieved, the ranking of each brick type, categorised by colour, had first to be established. A 5 brick sample was selected which represented the range of firing typical of production for that day. The bricks were steam treated to the Brick Development Research Institute accelerated weathering test as described in Australian Standard AS 1226.5 - 1984.[1] After measurement of the expansion resulting from the steam treatment, the predicted long term (5 year) expansion, e mm/m was calculated as described in reference 1 above. Table 1 details this information.

Table 1. Predicted long term (5 year) expansion of bricks, e mm/m. Sample 4753.

Colour	Cream	Pink	Red	Grey	Brown Light	Brown Medium	Brown Dark
Date.							
1969	1.71	1.70	1.22	1.21	1.13	1.35	0.71
70	1.75	1.72	1.26	1.36	1.03	1.31	0.66
71	1.78	1.82	1.34	1.46	1.37	1.34	0.65
72	1.98	1.63	1.39	1.23	1.04	1.01	0.53
73	1.54	1.32	1.30	1.03	0.90	0.90	0.47
74	1.49	1.11	1.03	0.97	1.04	0.76	0.46
75	1.44	1.35	1.13	0.93	0.88	0.92	0.52
76	1.43	-	0.84	0.95	1.42	0.92	-
77	1.48	1.30	1.01	1.21	1.06	0.92	-
78	1.05	-	0.60	0.75	0.39	0.62	-
79	1.01	0.67	-	1.03	-	0.48	-
80	1.09	0.70	0.59	0.82	0.72	0.56	-
81	1.19	0.65	0.63	0.87	-	0.49	-
82	1.14	1.03	0.65	0.79	0.51	0.72	-
83	1.03	0.85	0.61	0.80	0.58	0.55	-
1984	1.08	0.95	0.57	0.71	-	0.49	-

To confirm the predicted values, natural expansion, on bricks not subjected to the steam treatment, has been measured over a period of years, as shown in Table 2.

Table 2. Measured brick expansion mm/m on 1969 production. Sample 40.

Colour	Cream	Pink	Red	Grey	Light	Brown Medium	Dark
Time Ex-Kiln							
5 Years	1.89	1.84	1.52	1.19	1.33	1.32	0.80
10 "	2.05	1.98	1.77	1.47	1.63	1.57	1.05
15 "	2.19	2.08	1.94	1.65	1.83	1.61	1.12

Table 3 details a comparison of the predicted and measured expansions at 5 years on 1969 production. The predicted values are 80% to 100% of the measured values, with a 91.2% average over the whole brick colour range. The measured values average 0.14 mm/m greater than the predicted values.

Table 3. Comparison of Predicted and Measured expansion at 5 years mm/m

Colour	Cream	Pink	Red	Grey	Light	Brown Medium	Dark.
Predicted	1.71	1.70	1.22	1.21	1.13	1.35	0.71
Measured	1.89	1.84	1.52	1.19	1.37	1.32	0.80
Ratio%	90.5	92.4	80.3	101.7	82.5	102.3	88.8
Diff.mm/m	0.18	0.14	0.30	0.02	0.24	0.03	0.09

The measured expansions detailed in Table 2 show continued growth for all brick colours from 5 to 10 and 10 to 15 years. The magnitude of expansion tends to be less for bricks with higher 5 year values. The "dark brown" appears somewhat as an exception. These bricks are hard fired and fluxed to a greater extent than all of the other colours.

A general reduction in the predicted expansion of day-old bricks during the period 1969 to 1979 was achieved[2] , (refer also Table 1.) Having established the close relationship between the predicted and measured 5 year values of 1969 production, it was expected that the lower predicted values from the steam test 1979 onwards, would give correspondingly lower 5 year measured results .

Once again, matched sets of 5 bricks were sampled. One set to be steamed, the other measured under natural exposure conditions. The sample size for the Cream brick was 2 lots of matched sets, ie. 20 bricks. For the Red brick, 3 lots of matched sets were taken.

On the Cream brick, the predicted value was 1.12 mm/m at 5 years, whilst the measured expansion at 5 years was 1.20 mm/m. The Red brick also gave a close result in that the predicted value was 0.60 mm/m at 5 years and the measured expansion was 0.55 mm/m. Both results being within 0.1 mm/m/5 years compares favourably with the 1969 production comparison of an average difference of o.14 mm/m/5 years.

The lower predicted moisture expansion values of 1979 onwards have thus been validated. The sought after brick quality improvement has been realised.

References.

1. Standards Association of Australia. AS 1226.5 - 1984 Method for determining characteristic expansion.

2. W. Goldfinch (1980) Proceedings 9th. Australian Ceramic Conference, Sydney. PP 159-62.