DEFORMATION MEASUREMENTS ON A LOADBEARING MASONRY HIGHRISE STRUCTURE IN CANADA

H. Keller
Principal
Suter Keller Inc.
Ottawa, Canada

G. T. Suter
Professor
Carleton University
Ottawa, Canada

ABSTRACT

The use of brick masonry as a cladding material has been widely accepted in North America and elsewhere in the world. However, structural framing systems today are more flexible than those designed during the first half of this century. This development has led to numerous brick veneer cracking problems which have recently resulted in expensive repairs and costly litigation. The cracking problems are caused primarily by differential movements between veneer and loadbearing structure, movements which are even today not well known and which are based almost exclusively on laboratory studies. To aid the designer in estimating more accurately differential deformations between veneer and loadbearing structure, measurements on actual structures are required.

The paper describes field instrumentation carried out on an 11-storey loadbearing masonry apartment building located in Mississauga, Ontario. The exterior wall sections consist of 78 mm clay brick veneer, 19 mm cavity, and 190 mm and 240 mm loadbearing concrete block masonry. Measurements were taken during construction and for a period of approximately one year after the building's completion.

The field measurement results are compared to values obtained from a computer program which was developed to predict differential deformations due to elastic, creep, moisture and thermal effects at any time during the building's life. The differential movements at the top of the structure were found to be much smaller than predicted by the analysis program under unrestrained conditions and amounted to only about 1 mm. While this finding is rather surprising, it seems to indicate that a significant amount of interaction exists between veneer and loadbearing masonry for a structure with a narrow cavity.

1. INTRODUCTION

The history of modern loadbearing masonry structures in Canada and the rest of the world is short. In Canada it dates from 1965 when the engineered design of masonry was first introduced in our design code. Over the past nineteen years about 300 medium to highrise loadbearing masonry structures have been built in this country and it is the deformations of these structures which are the basis of this paper.

The typical modern masonry highrise structure employs a loadbearing inner wythe of concrete masonry which may be highly stressed and therefore is subject to elastic and creep deformations as well as to shrinkage and possible thermal movements. The outer wythe of brick masonry generally is not loadbearing and is separated from the inner wythe by a cavity which typically varies in width from about 25 to 100 mm. The outer wythe or veneer represents a structure's skin and hence must be durable, be resistant to water penetration, possess

reasonable thermal insulating properties and be attractive. Typically the veneer on a loadbearing masonry structure is vertically continuous from the foundation to the roof and is tied back to the inner wythe by means of connectors. The function of the connectors is both to provide lateral stability to the veneer and to transmit lateral forces from the veneer to the loadbearing inner wythe. Since the veneer is not loadbearing, its vertical deformations are partly due to the elastic and creep strains resulting from selfweight and partly due to thermal movements, shrinkage (concrete brick only) and moisture expansion (clay brick only). Because selfweight stresses even for a 10 or 15 storey structure are relatively small, elastic and creep movements are also small and major deformations of the veneer will be due to thermal effects and shrinkage or moisture expansion.

This paper represents an attempt to answer the following pertinent questions: What are the overall deformations of the veneer and of the loadbearing inner wythe, i.e. what are the differential movements between the veneer and the highly stressed shear walls? What is the magnitude and frequency of movements to which connectors are exposed?

During the past decade an increasing number of brick veneer cracking problems have occurred and these have led to personal injury, expensive repairs and costly litigation. While the majority of veneer distress problems to date are associated with reinforced concrete structures, experience with loadbearing masonry highrise structures indicates that veneer cracking problems also exist here, however, to a lesser degree. Since the Canadian history of modern masonry structures is brief, more problems are likely to surface in the future. To overcome these important problems concerning veneer safety and serviceability, one must know more accurately the differential deformations between veneer and loadbearing masonry. World-wide evidence in this area is very scanty and the purpose of this paper is to furnish a first set of differential deformation results which reflect the Canadian conditions. The key results indicate that relative movement between loadbearing masonry and veneer are much smaller than predicted by conventional analysis based on unrestrained conditions. This would indicate interaction of the two wythes and hence that unrestrained movement between veneer and loadbearing masonry does not exist.

2. THE STRUCTURE

The 11-storey, 148 unit apartment building, seen in Fig. 1, is located in Mississauga (Toronto) Canada. A typical floor plan is shown in Fig. 2. The walls are built in typical masonry cavity wall construction, as seen in Fig. 3, with an inner loadbearing wythe of 190 mm and 240 mm concrete masonry and a non-loadbearing outer 78 mm clay brick veneer. The veneer is supported directly on the concrete foundation and is continuous over the whole building height. A relatively narrow cavity of 19 mm is bridged by metal connectors which tie the veneer to the loadbearing structure. Special connectors, as seen in Figs. 3 and 4, had to be developed to accommodate coursing differences between brick and block masonry which resulted from the use of metric block and imperial sized bricks. The coursing pattern employed in this structure is depicted in Fig. 5. Insulation consisted of 100 mm fibreglass bats placed between steel studs on the interior face of the concrete block masonry. A typical exterior wall cross section is shown in Fig. 6. As a result of poor soil conditions no basement was provided and both exterior and interior shear walls are supported on strip footings. Floors and roof consist of a Hambro composite steel joist/concrete slab system spanning in the north-south direction.

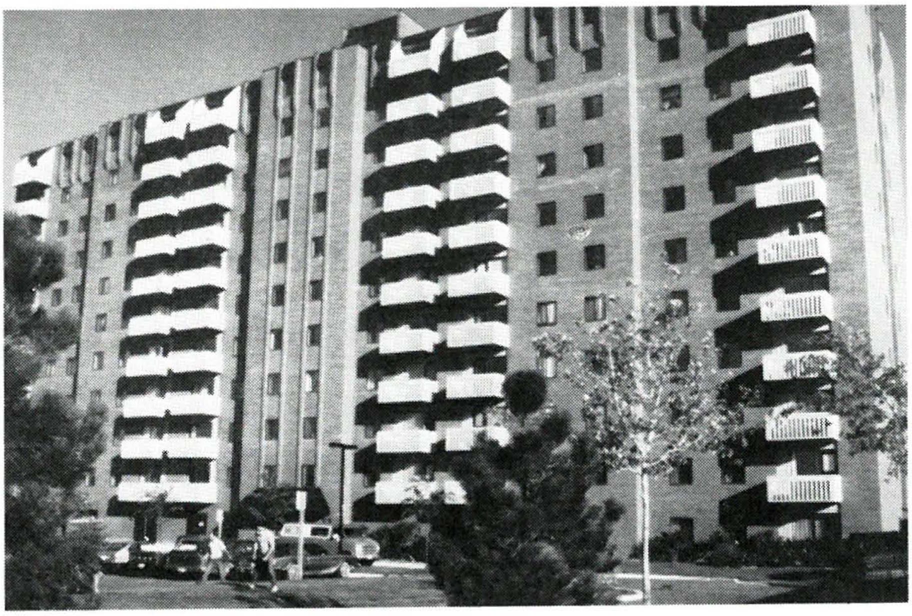

Fig. 1   General view of building

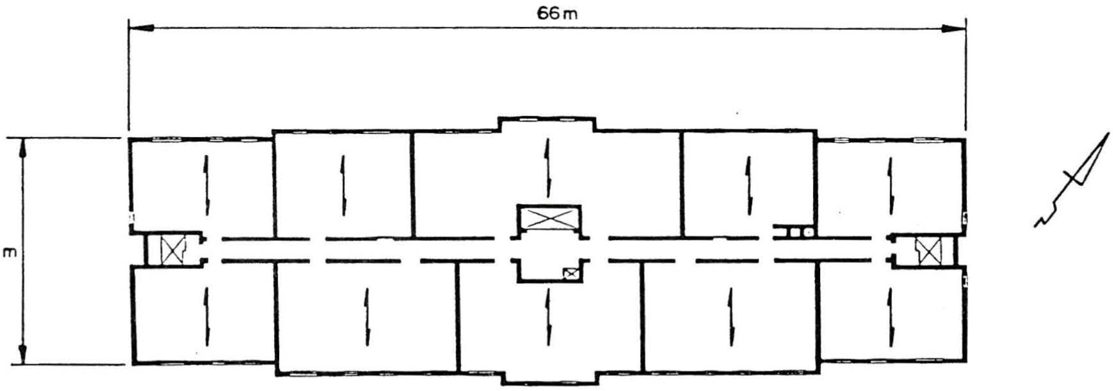

Fig. 2   Typical floor plan

The building's precast concrete balconies are supported on the loadbearing inner wythe only and are cast-in with the floor slab to form an integral unit. Precast concrete lintels are typically used to span window and door openings. Footings were placed in the fall of 1981. Construction resumed in the spring of 1982 and the roof was cast in July 1982. The building was ready for occupancy in the fall of 1982.

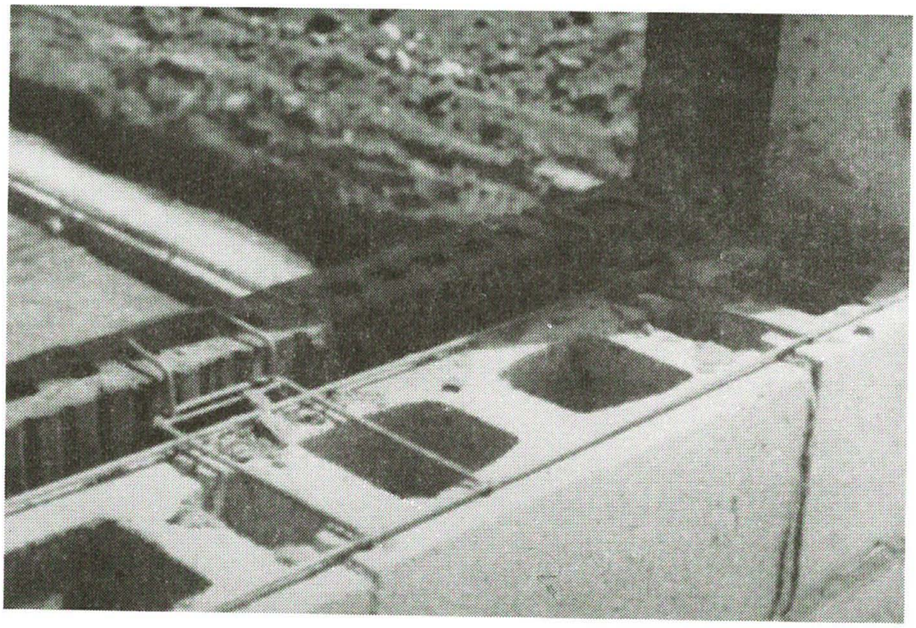

Fig. 3 Typical cavity wall construction showing metal connectors

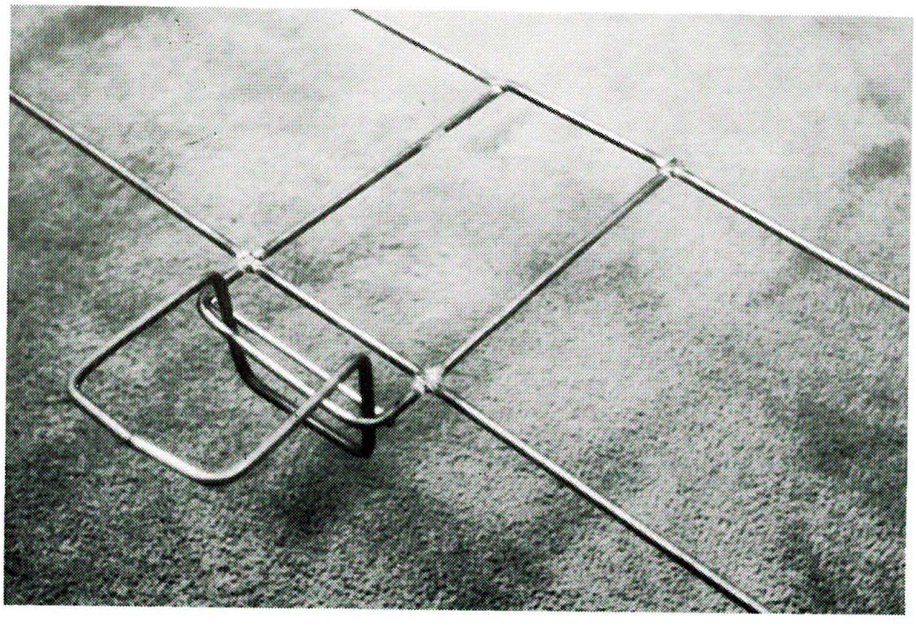

Fig. 4 Adjustable veneer connections developed to accommodate coursing differences

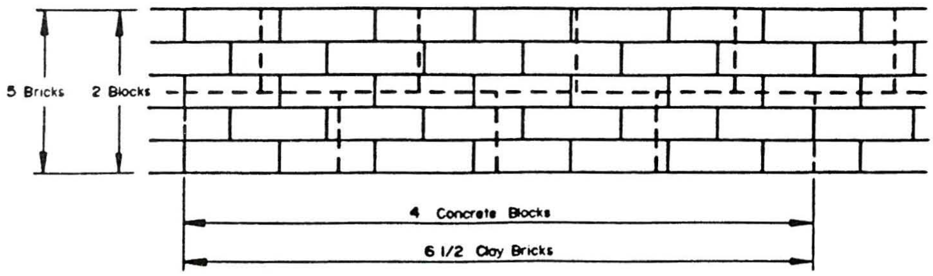

Fig. 5 Typical coursing pattern used for metric block and imperial brick

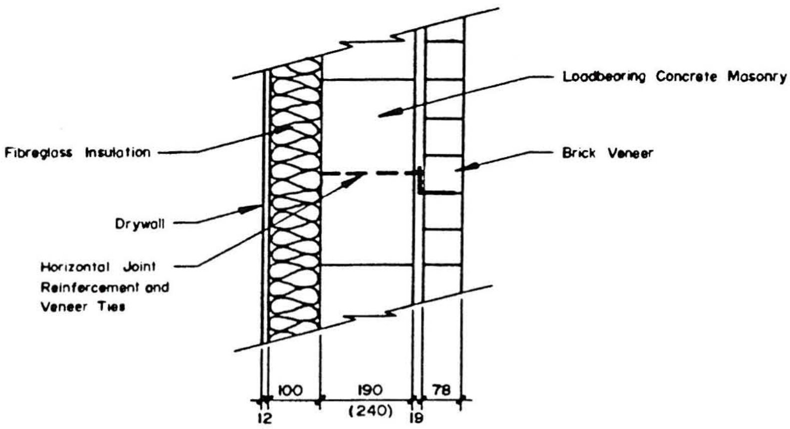

Fig. 6 Typical exterior wall cross section

3. FIELD MEASUREMENTS

3.1 General

Field measurements consisted typically of the following:

a) During Construction

- Strain readings at ground floor level
  - exterior face of veneer
  - interior face of loadbearing wall
- Temperature recordings at ground floor level
  - exterior face of veneer
  - interior face of loadbearing wall
  - air temperature
    - exterior
    - cavity
    - interior

b) In Service

- Strain readings at ground floor level
  - exterior face of veneer
  - interior face of loadbearing wall
- Relative displacement measurements between veneer and loadbearing wall at roof level
- Temperature recordings
  - exterior face of veneer at ground floor
  - interior face of loadbearing wall at ground floor level
  - air temp.
    - exterior
      - ground level
      - roof level
    - cavity — ground level
    - interior — ground level
- Overall vertical measurements on veneer

Strain readings were taken by means of a 610 mm Demec mechanical extensometer and displacement measurements were obtained with dial gauges as shown in Fig. 7. Standard spring loaded Starrett gauges were used and modified to include a friction grip on the plunger. This feature would ensure that maximum relative movements would be retained on the gauge dial until the next observation. Temperatures were measured with a hand held thermocouple and an electronic thermometer. Overall vertical veneer movements were measured with a steel tape. The tape was attached to a stainless steel pin which was epoxied into the veneer at roof level. The locations of instrumentation installation are shown in Fig. 8.

Starting in April 1982, measurements were taken every two weeks during the construction process. Once the structure was completed, measurements continued at monthly intervals for the first half year and three-month intervals until December 1983.

3.2 Control Specimens

A total of 89 control specimens were manufactured on site, field cured and tested in the Structures Laboratory at Carleton University. The test specimens are part of a standard materials testing procedure adapted for masonry construction. The specimens were tested for compressive strength and the results were intended for use in establishing the deformation components contributing to the overall differential movements measured in the field. Typically the following specimens were tested:

Specimen	Type
Mortar	50 x 50 x 50 mm
Grout	100 x 100 x 200 mm
Concrete Block	½ Block
Grouted Concrete Masonry	3-Stack Prism
Plain Concrete Masonry	3-Stack Prism
Clay Brick	½ Brick
Clay Brick	Full Brick

4. DISCUSSION OF RESULTS

4.1 Ground Level Strain Measurements

Strain measurement results obtained at ground level for the four walls N, E, S and W are presented in Table 1 and Fig. 9. Note that all gauge points installed on the concrete masonry walls were replaced on June 25, 1982. This change was required as workmen, unaware of the significance of the gauge points, parged the inside face of all exterior concrete masonry walls in accordance with a local by-law. Readings on these walls were then continued with the newly installed gauge points. As the relationship between readings taken prior to and after June 25, 1982 are not known, the following assumption was made to tie together the two sets of readings: in view of the fact that the relation of strain vs. time for brick and block were observed to be very similar, it was assumed that

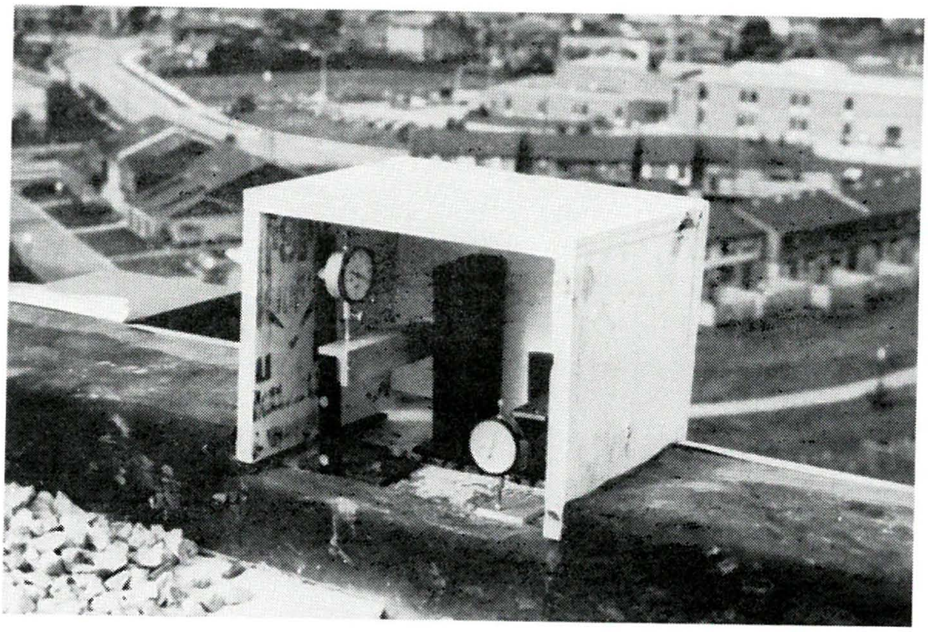

Fig. 7 Dial gauge installation at roof level

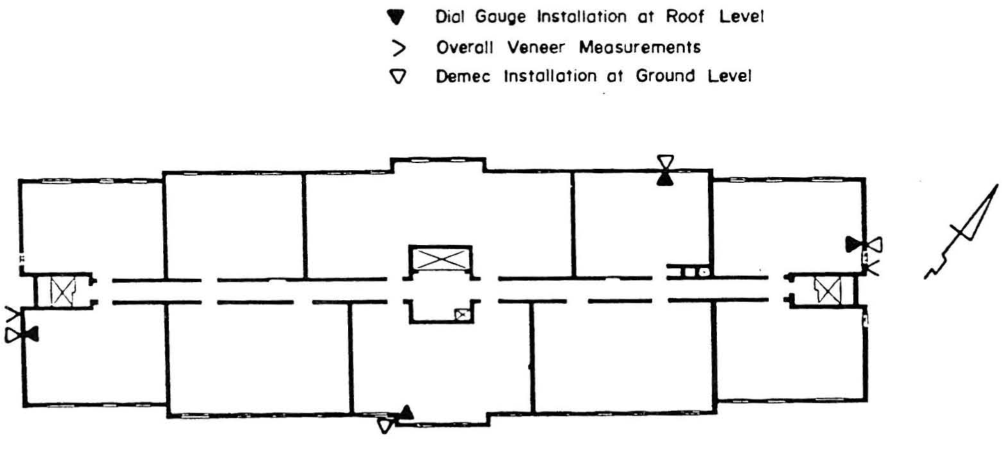

Fig. 8 Location of instrumentation

the slope of the curves for brick and block was identical during the period from June 10 to June 25, 1982. The block strains have thus been adjusted in Fig. 9.

General observations based on Fig. 9 are as follows:

- brick and block strains appear to be similar. This result is surprising and seems to indicate that considerable interaction exists between veneer and loadbearing masonry walls
- strains in the N and S walls are higher than those in the E and W walls. Larger strains in the N and S walls are to be expected as these walls are part of the primary loadbearing elements of the building.

Table 1 Ground Level Temperatures and Strains

Wall	Date	Brickwork			Blockwork			Elapsed Time
		Temp. (°C)	Reading*	Strain (mm/m)	Temp. (°C)	Reading*	Strain (mm/m)	(Days)
North	82 04 28	9.0	628	0.0	9.0	1338	0.0	0
	82 05 11	18.0	627	-2.7	16.5	1332	-16.2	13
	82 05 25	15.5	625	-8.1	14.0	1327	-29.7	27
	82 06 10	18.0	628	0.0	17.5	1330	-21.6	43
	82 06 25	25.0	615	-35.1	19.5	-238**	0.0	58
	82 07 13	22.0	587	-110.7	22.0	-263	-67.5	76
	82 07 14	21.0	591	-99.9	21.0	-260	-59.4	77
	82 07 23	24.0	585	-116.1	24.0	-261	-62.1	86
	82 10 21	9.8	540	-237.6	12.0	-285	-126.9	176
	82 11 08	12.5	542	-232.2	12.0	-288	-135.0	194
	82 12 13	-1.0	519	-294.3	0.0	-312	-199.8	229
	83 01 13	-1.5	522	-286.2	6.0	-307	-186.3	260
	83 02 23	4.5	530	-264.6	18.0	-315	-207.9	301
	83 03 23	-5.0	507	-326.7	10.0	-330	-248.4	330
	83 04 25	2.5	521	-288.9	11.0	-325	-234.9	363
	83 08 10	18.0	524	-280.8	23.0	-305	-180.9	470
	83 12 30	-9.5	467	-434.7	-	-	-	612
East	82 04 28	10.0	588	0.0	8.0	1345	0.0	0
	82 05 11	21.0	608	54.0	16.5	1352	18.9	13
	82 05 25	16.4	604	43.2	13.5	1347	5.4	27
	82 06 10	18.5	614	70.2	17.5	1360	40.5	43
	82 06 25	20.0	610	59.4	19.5	1012	0.0**	58
	82 07 13	23.5	610	59.4	21.5	1000	-32.4	76
	82 07 14	26.0	611	62.1	21.0	1000	-32.4	77
	82 07 23	25.0	606	48.6	24.0	1000	-32.4	86
	82 10 21	11.0	585	-8.1	12.5	977	-94.5	176
	82 11 08	13.0	582	-16.2	13.5	976	-97.2	194
	82 12 13	-1.5	565	-62.1	0.5	952	-162.0	229
	83 01 13	-1.0	562	-70.2	4.0	934	-210.6	260
	83 02 23	11.0	577	-29.7	15.0	953	-159.3	301
	83 03 23	3.0	567	-56.7	5.5	941	-191.7	330
	83 04 25	8.5	577	-29.7	14.5	956	-151.2	363
	83 08 10	16.5	588	0.0	-	-	-	470
	83 12 30	-7.5	555	-89.1	-	-	-	612
South	82 04 28	11.0	317	0.0	9.0	970	0.0	0
	82 05 11	20.0	313	-10.8	19.0	960	-27.0	13
	82 05 25	15.4	290	-72.9	14.3	931	-105.3	27
	82 06 10	17.5	296	-56.7	17.5	934	-97.2	43
	82 06 25	20.0	287	-81.0	20.0	421**	0.0	58
	82 07 13	25.3	279	-102.6	23.5	399	-59.4	76
	82 07 14	22.5	278	-105.3	22.5	398	-62.1	77
	82 07 23	26.3	277	-108.0	25.5	395	-70.2	86
	82 10 21	10.0	227	-243.0	-	-	-	176
	82 11 08	18.0	226	-245.7	-	-	-	194
	82 12 13	-1.0	186	-353.7	-	-	-	229
	83 01 13	-2.5	188	-348.3	-	-	-	260
	83 02 23	19.0	214	-278.1	-	-	-	301
	83 03 23	2.0	179	-372.6	-	-	-	330
	83 04 25	4.0	203	-307.8	-	-	-	363
	83 08 10	17.5	215	-275.4	-	-	-	470
	83 12 30	-3.0	159	-426.6	-	-	-	612
West	82 04 28	20.0	-416	0.0	11.0	1716	0.0	0
	82 05 11	25.5	-406	27.0	17.5	1716	0.0	13
	82 05 25	16.6	-412	10.8	14.0	1708	-21.6	27
	82 06 10	18.0	-407	24.3	17.5	1717	2.7	43
	82 06 25	20.3	-413	8.1	20.0	1455	0.0**	58
	82 07 13	27.5	-416	0.0	23.5	1430	-67.5	76
	82 07 14	22.5	-413	8.1	22.0	1434	-56.7	77
	82 07 23	31.8	-413	8.1	25.0	1429	-70.2	86
	82 10 21	11.3	-440	-64.8	14.5	1396	-159.3	176
	82 11 08	20.5	-419	-8.1	17.5	1401	-145.8	194
	82 12 13	-1.0	-450	-91.8	1.0	1369	-232.2	229
	83 01 13	0.3	-449	-89.1	8.0	1373	-221.4	260
	83 02 23	13.0	-427	-29.7	12.5	1396	-159.3	301
	83 03 23	2.0	-445	-78.3	7.0	1352	-278.1	330
	83 04 25	11.0	-435	-51.3	14.0	1365	-243.0	363
	83 08 10	18.8	-420	-10.8	23.0	1388	-180.9	470
	83 12 30	5.5	-433	-45.9	15.0	1337	-318.9	612

* Adjusted for Invar

** New targets installed

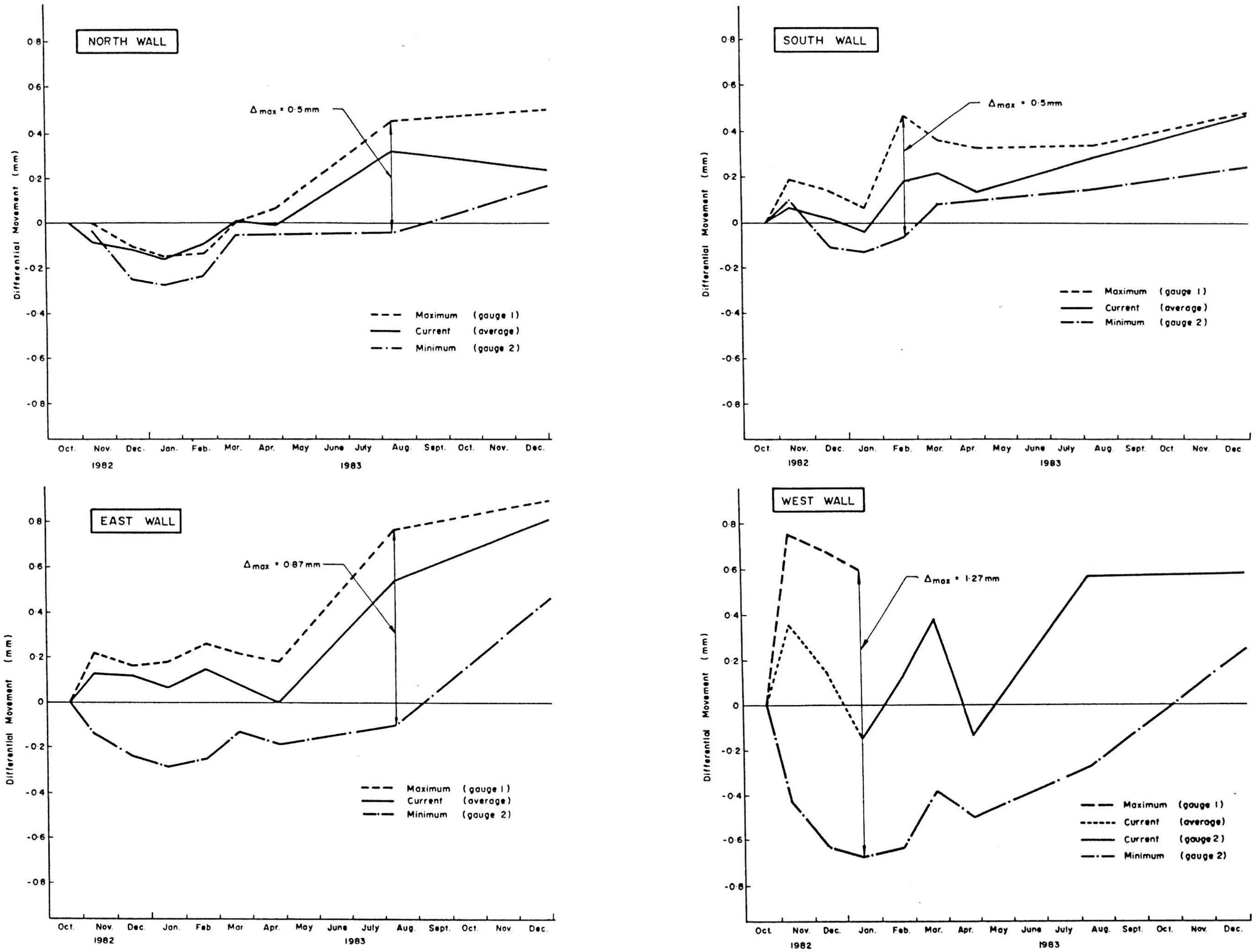

Fig. 9 Observed Ground Level Strain

4.2 Differential Movements at Roof Level

Maximum, minimum and current relative displacements between brick and block were recorded at roof level. While the current readings represent the relative position of brick and block at the time of reading, the maximum and minimum would have occurred at some time during the previous reading interval. Differential movements between the two wythes are summarized in Table 2 and Fig. 10. A common datum was established at the time of the dial gauge installation on October 21, 1982 and the values presented in Table 2 give the brick position relative to the block position. For example the current value of +0.24 for the N wall (83 12 30) implies that the brick veneer has moved up by 0.24 mm relative to the block wall at the time of reading. Similarly, a minimum value of -0.63 for the N wall (82 11 08) indicates that at some time during the previous time interval the brick veneer had moved down relative to the block wall by as much as 0.63 mm. Note that ideally the current readings of gauges 1 and 2 should be identical. Observations show, however, that slight differences in the order of 0.15 mm did occur. The discrepancy is likely due to support bracket flexibility. The large difference of more than 1 mm which occurred in the W wall after January 13, 1983 is believed to have been caused by malfunctioning of dial gauge 1 due to freezing conditions. Dial gauge 1 results for the W wall are thus considered unreliable after January 13, 1983.

Maximum and minimum positions recorded during any time interval ideally should form a band within which the current position should lie. As seen in Fig. 10 this is generally true except for the W wall where the current position

Table 2 Differential Movements at Roof Level

Wall	Date	Position at Time of Reading (mm)			Max. Pos. During Interval (mm)	Min. Pos. During Interval (mm)
		Gauge 1	Gauge 2	Average	(Gauge 1)	(Gauge 2)
North	82 10 21	0.00	0.00	0.00	-	-
	82 11 08	-0.12	-0.04	-0.08	0.00	-0.04*
	82 12 13	-0.17	-0.07	-0.12	-0.10	-0.25
	83 01 13	-0.21	-0.11	-0.16	-0.15	-0.27
	83 02 23	-0.13	-0.03	-0.08	-0.13	-0.23
	83 03 23	-0.04	0.07	0.02	0.01	-0.05
	83 04 25	-0.06	0.05	-0.01	0.07	-0.05
	83 08 10	0.29	0.34	0.32	0.45	-0.04
	83 12 30	0.26	0.22	0.24	0.50	0.22
East	82 10 21	0.00	0.00	0.00	-	-
	82 11 08	0.21	0.05	0.13	0.22	-0.14
	82 12 13	0.16	0.08	0.12	0.16	-0.24
	83 01 13	0.11	0.02	0.07	0.17	-0.28
	83 02 23	0.20	0.09	0.15	0.26	-0.25
	83 03 23	0.11	0.04	0.08	0.22	-0.13
	83 04 25	0.04	-0.04	0.00	0.18	-0.18
	83 08 10	0.59	0.49	0.54	0.76	-0.10
	83 12 30	0.84	0.78	0.81	0.89	0.46
South	82 10 21	0.00	0.00	0.00	-	-
	82 11 08	0.04	0.10	0.07	0.19	0.10*
	82 12 13	-0.02	0.06	0.02	0.14	-0.11
	83 01 13	-0.07	0.00	-0.04	0.07	-0.13
	83 02 23	0.17	0.18	0.18	0.47	-0.06
	83 03 23	0.21	0.23	0.22	0.37	0.08
	83 04 25	0.13	0.15	0.14	0.33	0.10
	83 08 10	0.29	0.26	0.28	0.34	0.15
	83 12 30	0.48	0.46	0.47	0.48	0.25
West	82 10 21	0.00	0.00	0.00	-	-
	82 11 08	0.40	0.29	0.35	0.75	-0.43
	82 12 13	0.19	0.09	0.14	0.67	-0.63
	83 01 13	-0.09	-0.21	-0.15	0.59	-0.67
	83 02 23	-0.43**	0.12	-0.16**	0.06**	-0.63
	83 03 23	-1.15**	0.38	-0.39**	-0.56**	-0.38
	83 04 25	-1.63**	-0.14	-0.89**	-0.45**	-0.50
	83 08 10	-0.85**	0.56	-0.15**	-0.28**	-0.27
	83 12 30	0.21**	0.57	0.39**	0.43**	0.24

* should be less than the average current position

** results questionable due to malfunctioning of gauge 1

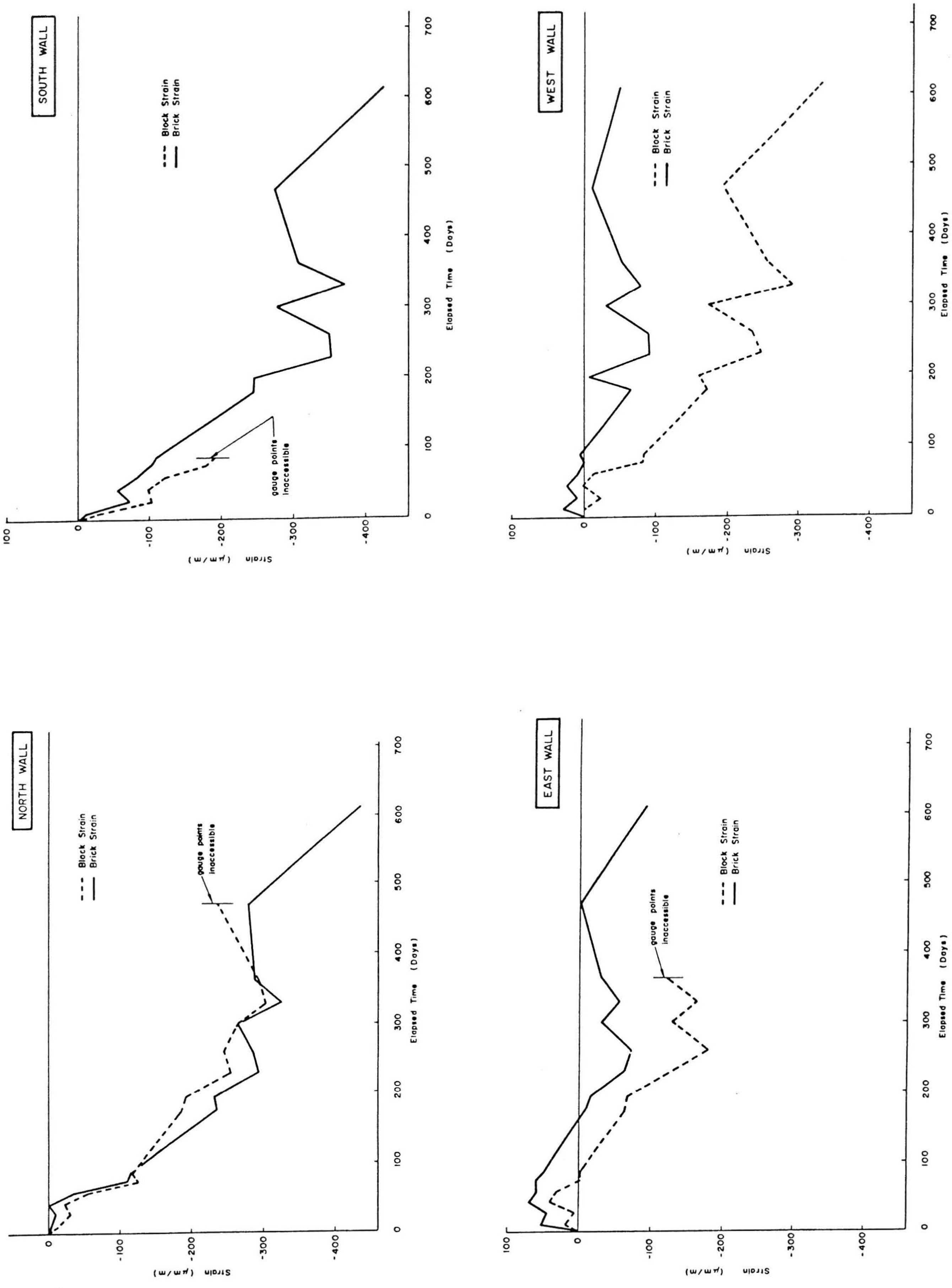

Fig. 10 Differential movement between brick and blockwork at roof level

lies outside the max/min band width. This is obviously incorrect and the problem is thought to be related to the malfunctioning of gauge 1. Also in cases where relative movements are very small (less than the measurement error of 0.15 mm between gauges 1 and 2), the difference between current position given by the two gauges yields an average which is outside the max/min positions dictated by each gauge.

Although Fig. 10 indicates a general trend of relative increase in brickwork height versus blockwork height, as one would expect, the magnitude of the differential movements is very small with a maximum of 1.27 mm for the W wall. This amount is far less than the theoretical predictions of 5 to 10 mm after 1 year for unrestrained conditions. These differential measurements, however, are in line with strain measurements at ground level and seem to indicate considerable interaction between the two wythes.

4.3 Control Specimen Test Results

Control specimen test results in Table 3 are included here for general information. The control specimen test results have been used to determine the masonry properties for analysis and use in the computer program of the paper

Table 3 Control Specimen Test Results

Control Specimen Test Result Set #1 (Applicable to floors 1 and 2)

Specimen Type	No. of Specimens	Compressive Strength (MPa) x_{min}	$\bar{x}$	x_{max}	V(%)
Mortar cube	6	12.8	13.2	14.1	3.4
Grout prism	4	31.7	35.7	40.1	10.5
Concrete block	5	21.5	22.7	23.5	3.4
Clay brick	5	73.5	83.4	90.4	8.5
Plain 3-stack masonry prism	3	12.7	15.1	16.5	-
Grouted 3-stack masonry prism	3	11.4	13.2	14.5	-

Age at testing: 33-38 days

Control Specimen Test Result Set #2 (Applicable to floors 3 to 8)

Specimen Type	No. of Specimens	Compressive Strength (MPa) x_{min}	$\bar{x}$	x_{max}	V(%)
Mortar cube	6	11.2	12.1	12.7	4.2
Grout prism	6	30.2	34.0	38.7	9.0
Concrete block	6	14.2	16.3	18.6	10.0
Clay brick	6	65.4	70.3	74.5	4.7
Plain 3-stack masonry prism	3	8.8	12.1	14.2	-
Grouted 3-stack masonry prism	3	10.7	12.4	14.7	-

Age at testing: 34-35 days

Control Specimen Test Result Set #3 (Applicable to floors 9 to 11)

Specimen Type	No. of Specimens	Compressive Strength (MPa) x_{min}	$\bar{x}$	x_{max}	V(%)
Mortar cube	6	12.6	13.0	13.9	3.9
Grout prism	6	11.6	13.4	14.6	8.9
Concrete block	6	11.0	12.2	13.2	7.4
4-stack clay brick masonry prism	3	23.0	28.2	35.0	-
Plain 3-stack masonry prism	3	12.0	13.7	15.9	-
Grouted 3-stack masonry prism	3	6.0	8.2	10.5	-

Age at testing: 33-35 days

entitled "Differential Movement Between Clay Brick Veneer and Concrete Block in Loadbearing Masonry Highrise Structures" which is also presented at this conference[1].

As the results in Table 3 are self evident, no further discussion of control specimen test results will be included in this paper.

4.4 Correlation of Results

Results of the computer analysis[1] indicate that under unrestrained conditions, differential movements at roof level are of the order of 14 mm in the West wall. If it is assumed that the adjustable ties are not free to slide, the computer program predicts a differential movement of about 10 mm. Our field measurements show, however, a maximum differential movement of only 1.27 mm in the West wall. This can be predicted with the computer program by assuming that restraint is provided not only by the ties but also by other factors such as the presence of mortar in the cavity. A value of about 0.3 mm was predicted assuming that about 5% of the veneer surface area is rigidly connected to the concrete masonry with mortar. Clearly the actual situation lies somewhere between these extremes. In the absence of more detailed field measurements, the authors are, however, unable to accurately assess the true restraint between the two wythes.

5. CONCLUSIONS

The current study has been an attempt to record on an actual building the differential movements between loadbearing masonry and veneer. Measurements were carried out during construction and for a period of about one year past the building's completion date.

The key conclusions are as follows:

- relative movements between loadbearing masonry and veneer are very small with a maximum of 1.27 mm on the W wall
- strain measurements at the ground level both for the veneer and the loadbearing masonry are similar indicating that the two wythes are not acting independently
- computer analysis work shows that considerable restraint must exist between the two wythes to predict differential movements at the roof level which are in agreement with field measurement results.

In summary, the key conclusion is that unrestrained movement between loadbearing masonry and brick veneer does not exist as is normally assumed in the design. Reasons for the interaction between wythes in this structure are thought to be as follows:

- the use of a narrow cavity of only 19 mm tends to provide a stiff connection between wythes
- the presence of mortar droppings in the cavity (in some areas the cavity was observed to be virtually solidly filled) provides a partially rigid connection between the two wythes.

Under the conditions of a narrow cavity, stiff metal connectors and extensive mortar droppings in the cavity, the exterior walls are no longer able to act independent of each other.

ACKNOWLEDGEMENTS

The project has been made possible through Supply and Services Canada, Contract No. SR81-00073. The cooperation and interest in this study by the following individuals is kindly acknowledged: Mr. Bill Ellerington, Mastercraft Development Corporation (Developer/Contractor), Mr. A. J. Garwood, P.Eng., Garwood Leclair Inc. (Structural Consulting Engineers), Dr. A. H. P. Maurenbrecher, DBR/NRC (Technical Advisor).

REFERENCES

1. Fenton, G. A. and Suter, G. T., "Differential Movement Between Clay Brick Veneer and Concrete Block in Loadbearing Masonry Highrise Structures" 7th IBMC, Melbourne, Australia, February,1985.