IV–24. The Lateral Resistance of Walls with One Free Vertical Edge

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ABSTRACT

Most of the walls tested in the British Ceramic Research Association's research programme on laterally loaded walls have either been restrained on two sides, or on three sides (i.e. two sides and bottom). In buildings there are many more conditions of peripheral restraint and these include walls with door and window openings. This often gives rise to walls with three sided restraint, where the supports are on one side, the bottom and the top. This paper is concerned with a limited programme of tests on walls with this type of restraint.

La plupart des murs essayés dans le programme de recherche de la B Ceram RA sur des murs chargés latéralement, étaient contraints soit sur deux côtés, soit sur trois côtés (c'est à dire, deux côtés et la base). Dans les batiments, beaucoup plus de conditions de contrainte périphérique se trouvent et celles-ci comprennent les murs avec des baies de portes et de fenêtres. Ceci donne souvent lieu à des murs avec une contrainte sur trois côtés, lorsque les supports sont sur un côté, la base et le faîte. Cette Note est intéressée par un programme d'essais limité sur des murs avec ce type de contrainte.

Die meisten der im Rahmen des Forschungsprogramms der B Ceram RA auf Querbelastung geprüften Wände wurden entweder auf zwei oder drei Seiten zurückgehalten (d.h. zwei Seiten und Grundfläche). In Gebäuden kommen viele andere Arten der Zurückhaltung am Umfang vor, dazu gehören Wände mit Tür- und Fensteröffnungen. Dadurch entstehen Wände mit dreiseitiger Zurückhaltung, in welchem Fall die Unterstützungen auf einer Seite, unten und oben liegen. Diese Notiz erfaßt ein eingeschränktes Prüfprogramm für Wände dieser Art.

Nel programma di ricerca sui muri soggetti a sollecitazioni laterali, effettuato dalla B Ceram RA, la maggior parte dei muri soggetti a prove erano trattenuti o su due lati o su tre lati (cioè i due fianchi e la parte inferiore). Nelle costruzioni ci sono molte altre forme di contenimento periferico, tra cui muri con aperture per porte e finestre. Spesso questo produce muri con contenimento su tre lati, in cui i supporti sono lungo un fianco, in basso ed in alto. Questa Nota Tecnica si riferisce ad un limitato programma di prove su muri con questo tipo di supporti.

INTRODUCTION

Most of the walls tested in the British Ceramic Research Association's research programme on laterally loaded walls have either been restrained on two sides, or on three sides (i.e. two sides and bottom).[1] This work has been extensively reported. In buildings there are many more conditions of peripheral restraint and these include walls with door and window openings; a limited number of early tests on such walls were previously reported.[2] The presence of door and window openings often gives rise to walls with three sided restraint, where the supports are on one side, the bottom and the top, (the so-called C-shaped wall). This paper gives the results of a modest programme of work on walls of this configuration, and compares the experimentally determined lateral resistances with those predicted by calculation according to the new U.K. limit state Code of Practice.[3]

EXPERIMENTAL

The test walls are built into steel channel frames which represent one bay of a multi-bay steel or reinforced concrete frame structure. A uniformly distributed pressure is applied, at a steady rate, over the whole face of the wall through a number of lightweight inflatable air-bags.[2] The reaction from the air-bags is transmitted to a steel frame clad in plywood, which is clamped back to the main frame containing the test wall. A number of linear transducers are mounted in salient positions to measure the lateral deflection of the walls. These transducers are connected to a data logger, the punched tape output of which is fed to a computer with plotter to produce curves of applied pressure versus deflection.

All the walls were built on a damp-proof course laid on a bed of mortar on a course of bricks which was clamped to the bottom member of the frame, so that the restraint

to the bottom of the wall is provided solely by the shear resistance of the d.p.c. Restraint at the side is provided by ties built into the mortar bed joints and attached to the metal frame.

Test walls have been built with two types of brick, a wire-cut multi-perforated facing (Type A) and a deep-frogged semi-dry pressed common (Type B), and with an aerated concrete block (AAC). All the walls were tested after being cured for 28 days. Brick B, which had an initial suction rate in excess of 2 $kg/m^2/min$ was immersed in water for a few seconds before laying to adjust the suction rate to approximately 1 $kg/m^2/min$.

The flexural strength of the brickwork and the blockwork was determined by wallette tests, as specified in Appendix A3 of BS 5628.[3]

RESULTS AND DISCUSSION

The physical properties of the bricks and blocks are given in Table 1. A typical pressure versus deflection plot is shown in Figure 1. The curves are delineated by capital letters which indicate the position of the transducers on the wall as indicated in the inset. The flexural strengths of the wallettes are given in Table 2 and in Table 3 the dimensions of the panels, type of brick or block, mortar strength and actual failure load. Figure 3 shows a typical failure pattern.

In a previous paper[1] several design theories were examined, but it was concluded that, although strictly not applicable to a brittle material like masonry, the yield line theory (used in reinforced concrete design) gave reasonable results for the type of wall most tested i.e. supported on the bottom and two sides. Figure 2 is repeated from the paper[1] and shows good agreement with experimental results in the practical range, though it over estimates the higher failure pressures. It is necessary in masonry design under lateral loading to be able to allow for the different flexural strengths in the two orthogonal directions and this is possible with yield line theory. The flexural strengths given in Table 2 were used in conjunction with the same theory from which the predicted pressures in Figure 2 were obtained, to arrive at the predicted failure loads in Tables 3 and 4. The actual and predicted failure loads from Table 3 have been used to plot Figure 4; it can be seen that the fit to the "exact" line is better particularly at the high values, that is the walls of smaller length. This is reasonable, as one would expect the longer panels to tend towards pure vertical spanning at their free edges. This explains the first crack pressure for wall 1151, the predicted value being calculated as if the wall spans vertically. The reason that only the brick/mortar combination BY exhibited this effect could be that this combination had the lowest failure strength on the bed joint of those tested.

The A.A.C. walls are more sensitive to differences in predicted and actual failure pressures because the failure pressures are low in comparison to the others. It is worth noting here that the value of the restraint assumed at the vertical edge of the panels is based upon extrapolation of the values obtained from tests on brickwork wallettes tied to and cantilevering from their vertical supporting members. The conclusion from these tests was that the restraint value of the ties was independent of the type of brick, being mainly related to the grade of mortar used. Whilst this may be appropriate for other brick mortar combinations, it may not be justifiable to extrapolate these values to blockwork walls.

Only three cavity walls of the C configuration have been tested, so to draw firm conclusions would be premature. It can be seen, however, from Table 4 that the sums of both the actual and predicted failure pressures for single leaf walls of the same masonry are similar to or less than the actual failure pressures of the three cavity walls tested. Thus the three walls bear out the earlier findings[1] that cavity walls subjected to lateral loading may safely be designed on the assumption that their strength is equal to the sum of the strengths of the individual leaves.

Figure 5 shows calculated pressures using the design method given in BS 5628 plotted against the actual failing pressures. Line (E), representing the lowest global safety factor ($\gamma m \times \gamma f = 2.5 \times 1.2 = 3.0$), shows that all the test walls would have had an adequate factor of safety when calculated in the way outlined. All the experimental results, including the C-shaped walls, now lie above the exact prediction line A. One obvious reason is that the partial continuity of the test frames has been ignored when designing to the Code but a more important reason is that the flexural strengths have been smoothed out by use of a characteristic value.

CONCLUSIONS

This short paper describes a series of walls supported top and bottom and on one vertical edge tested under lateral loading to determine whether or not they fall within the general design theory proposed earlier on the basis of an extensive series of tests on walls supported at the bottom and on two vertical edges. The results confirm that the method may be used and is, if anything, somewhat more accurate for this C-shape of wall.

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REFERENCES

1. WEST. H.W.H., HODGKINSON, H.R., HASELTINE, B.A. and TUTT, J.N. The Resistance of Brickwork to Lateral Loading, J.I. Struct.E. Vol. 55 No. 10, Oct. 1977.
2. WEST, H.W.H., HODGKINSON, H.R. and WEBB, W.F. Lateral Loading Tests on Walls with Different Boundary Conditions, Proc. FIBMAC, Essen, April, 1973.
3. BRITISH STANDARDS INSTITUTION. Code of Practice for Structural Use of Masonry, BS 5628: Part 1: 1978. Unreinforced Masonry.

TABLE 1—Physical Properties of Bricks and Blocks

Unit	Mean Crushing Strength N/mm²	Mean Water Absorption %	Density kg/m³
Brick A	63.1	6.4	N.A.
Brick B	27.9	22.2	N.A.
Block AAC	4.1	N.A.	700

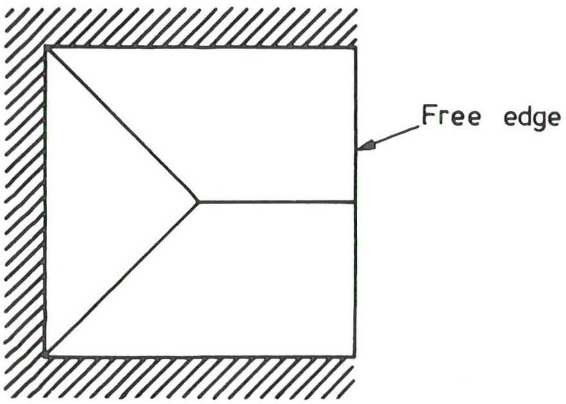

Figure 3. Idealised Failure Pattern of Walls (Yield Line Theory)

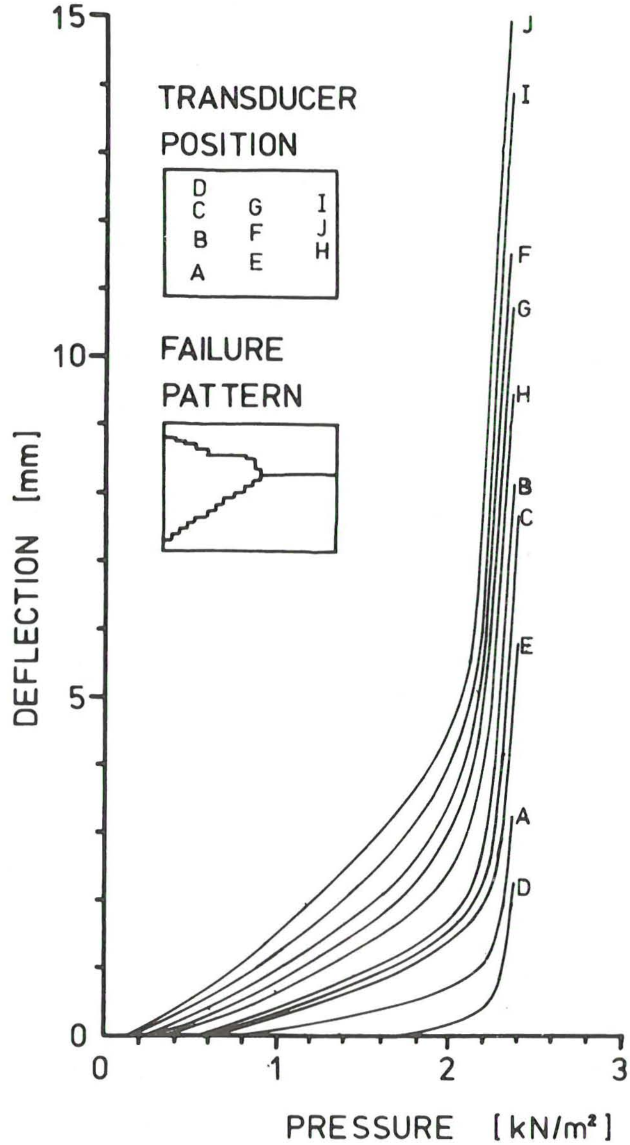

Figure 1. Typical Pressure/Deflection Plot

TABLE 2—Flexural Strength of Wallettes

Brick or Block	Normal to Bed Joint: Mean Flexural Stress (N/mm²)	S.D. (N/mm²)	C.V. (%)	Parallel to Bed Joint: Mean Flexural Stress (N/mm²)	S.D. (N/mm²)	C.V. (%)	Orthogonal Ratio	Mortar
A	2.44	0.25	10.3	0.92	0.17	18.8	2.6	X
B	1.19	0.19	15.9	0.32	0.06	19.3	3.7	Y
A.A.C.	0.62	0.06	9.5	0.41	0.05	11.5	1.5	Y

TABLE 3—Lateral Strengths of Single Leaf Walls Restrained on Three Edges (Top, Bottom and One Side)

Wall No	Brick & Block	Mortar	Mortar Strength (N/mm²)	Panel Height m	Panel Length m	Actual Failure Load (kN/m²)	Predicted Failure Load (kN/m²)
1271	A.A.C. Block	Y	4.3	2.6	5.5	0.7	1.27
1272	A.A.C. Block	Y	3.8	2.6	3.6	1.0	1.57
1273	A.A.C. Block	Y	3.8	2.6	2.4	1.7	2.17
1151	B	Y	4.5	2.6	5.5	0.6 (1st crack) 1.5	0.7 (1st crack) 1.3
1290	B	Y	4.1	2.6	3.6	2.4	1.84
1154	B	Y	5.0	2.6	2.4	3.6	2.80
1274	A	X	14.8	2.6	5.5	2.7	3.17
1288	A	X	15.5	2.6	3.6	3.8	4.34
1156	A	X	17.0	2.6	2.4	6.0	6.14

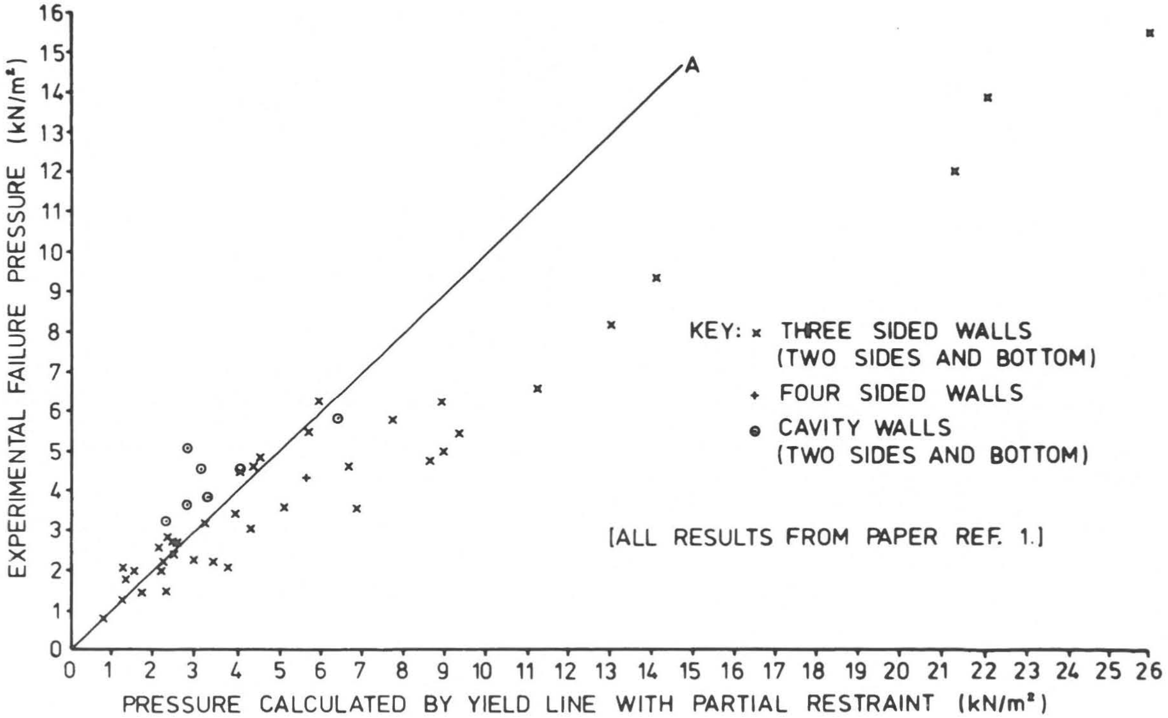

Figure 2. Calculated Pressure Versus Experimental Pressure

TABLE 4—Lateral Strengths of Cavity Walls Restrained on Three Edges (Top, Bottom and One Side)

Wall No	Brick & Block	Mortar	Mortar Strength (N/mm²)	Panel Height	Panel Length	Failure Pressure of Single Leaf Walls of Same Bricks		Arithmetic Sums of the Two Loads	Failure Load (kN/m²)	Arithmetic Sums of the Predicted Failure Loads for the Individual Leaves (kN/m²)
						Loaded	Unloaded			
1287	B+Block	Y	3.9	2.6	5.5	1.5	0.7	2.2	2.4	2.57
1299	B+Block	Y	4.2	2.6	3.6	2.4	1.0	3.4	3.4	3.41
1279	B+Block	Y	4.0	2.6	2.4	3.6	1.7	5.3	8.0	4.97

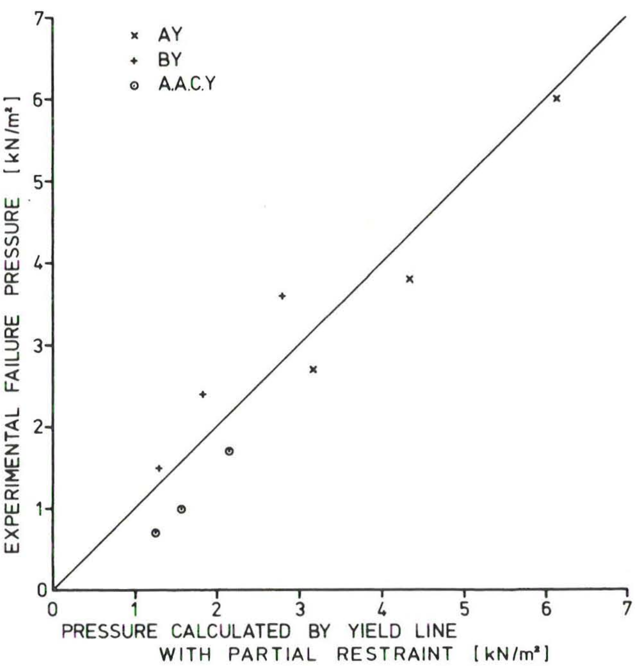

Figure 4. Calculated Pressure Versus Experimental Pressure

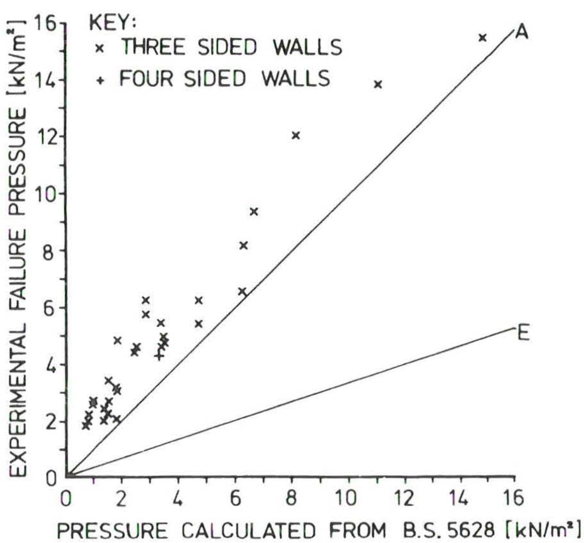

Figure 5. Design Pressure Versus Experimental Pressure for 102.5 mm Walls