IV–5. Compressive Strength of Axially Loaded Brick Walls Stiffened Along Their Vertical Edges

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ABSTRACT

The paper summarises comparative tests carried out to determine the load carrying capacity of axially loaded brick walls unstiffened and stiffened along their vertical edges, and of various slenderness and aspect ratios. It appears that such walls (stiffened along the vertical edges by return walls) behave like stiffened plates until the appearance of vertical cracks between the returns and the main wall. These cracks neutralise the effect of stiffening, and, as a result, the ultimate strength of the wall is similar to that of an unstiffened or strip wall. This behaviour has been confirmed up to the slenderness ($^h/_t$) ratio of 32. Design codes, as for example BS 5628 (1978) allow higher stresses in walls stiffened along their vertical edges compared to an unstiffened or strip wall, but this is not substantiated by these experiments, at least for axially loaded walls having slenderness ratios up to 32.

INTRODUCTION

The walls in any load-bearing masonry structure may be of two types: i) Unstiffened at the vertical edges; (ii) Stiffened at one or both vertical edges by a return wall. The strength of walls of the first category has been the subject of systematic investigation with a view to establishing the permissible or characteristic strength for the design; no comprehensive tests have ever been carried out on walls of the second category. Although, there is complete lack of data, various codes[1,2,3] have attempted to utilize the stiffening effect of such walls placed at right angles, by allowing heavier loading compared to an unstiffened wall. To remedy this situation, an extensive programme of comparative testing to determine the load-carrying capacity of unstiffened or strip walls and walls stiffened on two vertical edges has been undertaken. The walls were of different slenderness (8 to 32) and aspect ratios and subjected to various loading conditions as shown in Table 1.

MATERIALS

Bricks

Full-scale bricks of 34.3 N/mm², ½-scale bricks of 31.9 N/mm² and ⅓-scale bricks of 30.7 N/mm² compressive strengths were used for the construction of walls.

Mortar

1:¼:3 (cement:lime:sand) Mortar was used for the construction of all the test walls. 100-mm cubes were made for full-scale wall. The average strength of mortar cubes for the full-scale walls were 19.6 N/mm² with a coefficient of variation of 20%. The strength of 70-mm cubes for ½-scale walls were 15.3 N/mm² and the coefficient of variation was 9.5%. 25.4-mm cubes were used for ⅓-scale wall. Their average strength was 27.0 N/mm² and the coefficient of variation was also 20%. All the mortar cubes were tested on the same day as the corresponding test walls.

TEST ARRANGEMENTS

Full and ⅓-scale walls were tested in specially designed test rigs. The distributed load was applied by several hydraulic jacks operated by a single pump. The load was measured by load cells connected to a digital voltmeter and pen-chart recorder. In a few full-scale walls the unloaded flanges of the I-sections were supported at the bottom on a number of load cells to measure the transfer of load from the loaded webs.

Half-scale walls were tested in an "Avery" Universal (Fig. 1) testing machine. The load from the machine was distributed through 152mm armour plate to the web and flanges of the stiffened wall—I in section. Care was taken to see that the load was applied axially as far as possible.

The deflections of the walls were measured by 0.002mm dial gauges. A "Demec" gauge was used to measure the strain.

In some cases, as shown in Table 1, only the main wall, stiffened at both vertical edges, was loaded. In the others both flanges and web were axially loaded, Table 1, equally at all stages till failure.

DISCUSSION OF TEST RESULTS

Wall Strengths

The test results, which are summarized in Table 1, indicate that in both the loading cases the walls with returns do not show increased strength as compared to strip walls. Initially, walls stiffened along the vertical edges by return walls behave like stiffened plates and as a result bend on both axes until the appearance of vertical cracks between the returns (flanges) and the main walls (webs).

In cases where the main wall or the web only was loaded, the cracks appear at the intersection of the flanges (returns) and the main wall (web) as can be seen in Fig. 2. In walls in which both the flanges and web were equally loaded, the cracks appeared in both flanges on either side of the web, thus dividing it into two sections as in Fig. 3. With increased loading, these cracks extended throughout the height of the test wall, thus neutralising the effect of stiffening, and as a result, the ultimate load-carrying capacity of these walls is similar to that of an unstiffened or strip wall.

Deflection

Typical central deflection results for very slender strip walls and walls with returns are given in Fig. 4. The deflection of the wall with returns prior to cracking of the returns was much smaller than in the case of the corresponding strip walls. This indicates that the stiffening effect was evident before onset of the cracks separating the returns with main wall. Also, it can be seen from Fig. 4, that as the distance between the returns increases, i.e. with the increases in aspect ratio, the central deflection also increases. In other words, before cracking the stiffening effect decreases with the increasing aspect ratio.

Strains

Fig. 5 gives the typical strains in the central cross-section of a very slender wall with returns and the corresponding strip wall. The stress-strain curve was linear up to 90% of the failure load. The strains in the wall with returns were smaller than those in a similar strip wall, which confirms the evidence of initial stiffening effect before cracking. Again, the effect is much less with increase in the aspect ratio.

Although great care was taken to apply axial loading, it appears from the strain readings on both faces of the mid cross-section of the strip wall that this was not fully achieved. However, the resulting eccentricity due to deflection and other causes was equal to 0.04 t (t - thickness) or 0.0013 1_e (height) at 88% of the ultimate load; which is minimal. Both faces of walls with returns showed very nearly the same strain, thus indicating that the loading was axial.

Load Distribution and Vertical Shear Stress

In case of walls with returns, where only the web was loaded, some load was transferred to the flanges or returns. It appears that 5.8 to 6.7% of the total applied load was carried by each of the returns before its separation from the web. The average ultimate vertical shear stress which destroyed the bond completely was in the order of 0.345 N/mm^2 to 0.68 N/mm^2 (calculated on an area equal to the height × thickness of the main wall). In these tests returns were bonded to the main wall by alternate brick courses, for any other bonding arrangement the ultimate vertical shear stress may be different.

Effect of Slenderness Ratio

Table 2 shows a summary of capacity reduction factors found for the various walls, taking as a datum the average strength of walls having a slenderness ratio of 8. The corresponding reduction factors given in BS 5628:1978 are shown for comparison. It will be noted that there is no practical difference as between walls with and without returns and that the strength reduction with increasing slenderness ratio is very much less than suggested by the British Code.

The upper slenderness limit of the tests was, however, just about the point at which buckling failure of axially loaded walls would be expected and it is possible that with very slender walls the stiffening effect of returns, which the deflection measurements reveal at lower loads, would prevent buckling failure at a load corresponding to the overall height/thickness ratio. This is now being investigated experimentally.

CONCLUSIONS

1. Walls stiffened along their vertical edges by returns did now show increased strength as compared with strip walls up to a slenderness ratio of 32. It would appear therefore, that up to this limit, no increase in the bearing capacity of axially loaded walls should be made on account of their edges being stiffened by bonded returns. This conclusion holds whether or not the returns are loaded to the same extent as the main wall.
2. Before cracking and separation of returns, the central deflections of walls with returns are smaller than those of corresponding strip walls which indicates effective stiffening up to this point. This stiffening effect decreases with increasing aspect ratio.
3. As returns provide effective stiffening at low axial loads, they may be effective in increasing the strength of very slender walls which may be expected to show buckling rather than strength failures. Further research is proceeding on this aspect.

ACKNOWLEDGEMENT

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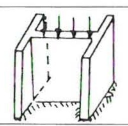
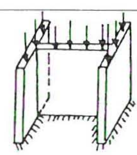
TABLE 1—Test Results of Axially Loaded Strip Walls and Walls Stiffened Along Their Vertical Edges by Way of Returns

Test No.	Ht/Length $L_{e/a}$	S.R. $l_{e/te}$	(a) Failure stress for strip wall N/mm²		(b) Failure stress for walls with returns N/mm²	Strength of walls with returns / Strength of strip walls $^{b}/_{a}$
1	1.3	24	10.8	9.2	9.9	1.1
2	1.3	24	7.65		10.9	1.2
3	1.0	24	8.13		8.86	1.08
4	1.0	24			8.86	1.0
5	1.4	8	10.84	11.12	10.24	0.91
6	1.4	8	11.55		9.8	0.87
7	0.8	8	11.2		11.0	0.98
8	$c10.8	8			10.56	0.94
9	2.8	16	11.15	11.15	10.7	0.96
10	2.8	16	11.15		10.7	0.96
11	1.6	16	11.15		9.30	0.83
12	1.6	16			9.72	0.87
13	5.6	32	9.07	9.35	9.89	1.05
14	5.6	32	9.62		8.50	0.91
15	3.12	32	9.35		7.9	0.85
16	3.12	32			9.2	0.98
17	2.06	32	9.35		7.24	0.77
18	2.06	32			9.08	0.97
19	1.3	24	12.0	14.5	10.6	0.73
20	1.3	24	17.0		9.4	0.65
21	1.0	24			10.0	0.60
22	1.0	24	20.3	16.6	15.0	0.90
23	1.0	24	12.94		11.8	0.71
24	1.0	24			17.7	1.10
25	1.0	24			15.0	0.90

Note 1 to 4 Walls built with ⅓rd scale brick
17 to 18 Walls built with ½ scale brick
19 to 23 Full scale wall



5 to 16 Wall built with ½ scale brick
24 to 25 Full scale wall



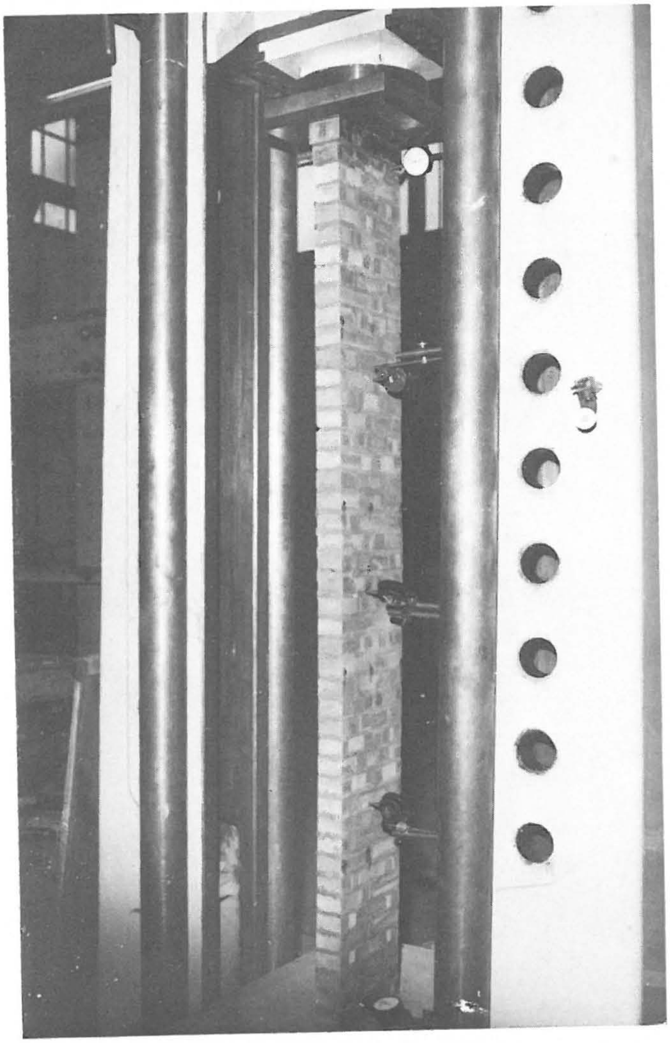


Figure 1. Wall test arrangement

Figure 2. Showing the cracks at the intersection of main wall and return.

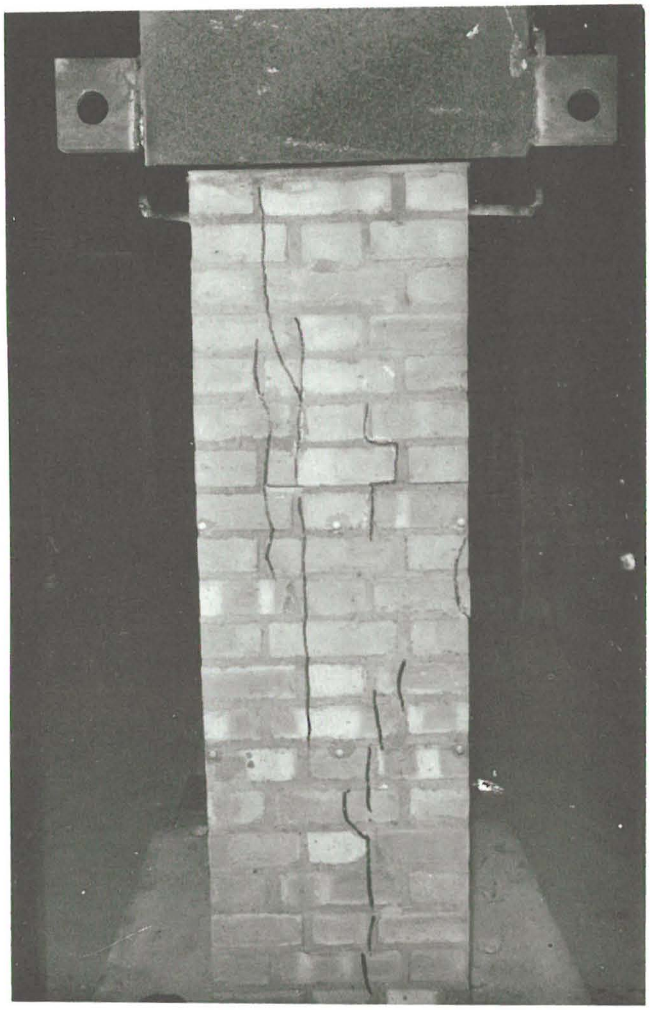


Figure 3. Showing the cracks in the flange on either side of the web.

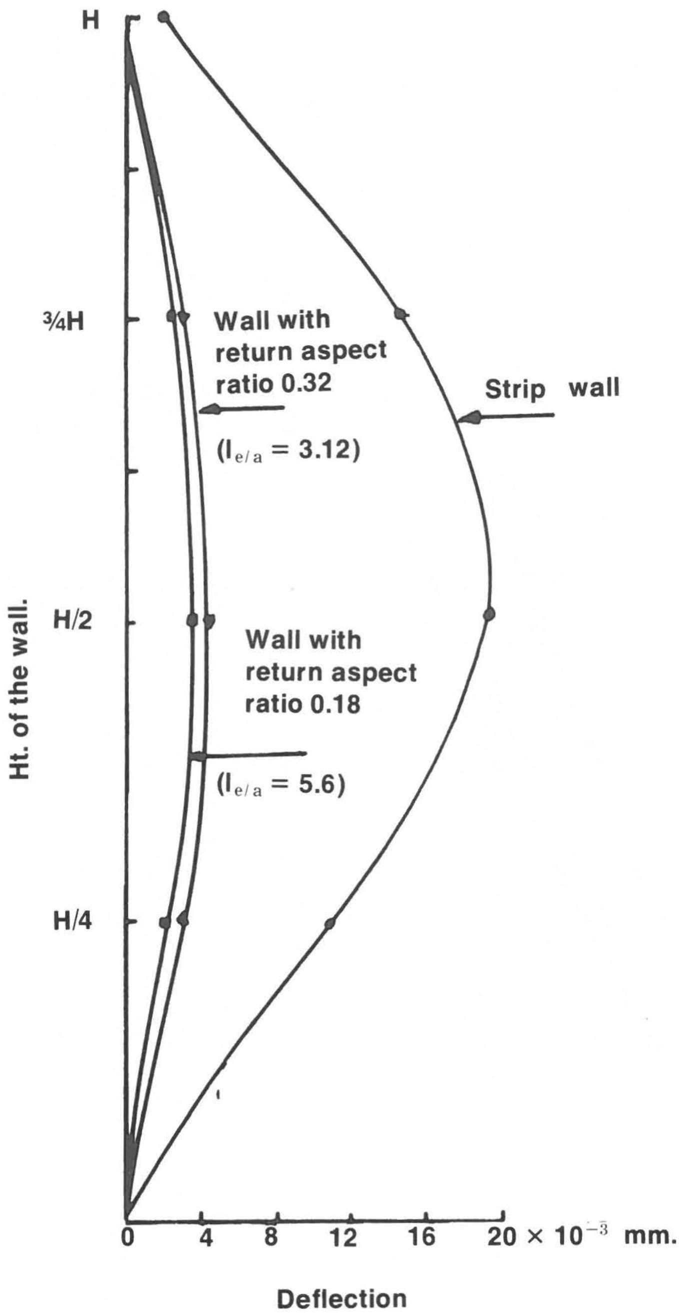


Figure 4. Deflection of walls (S/R = 32) at 6.75 N/mm^2 stress.

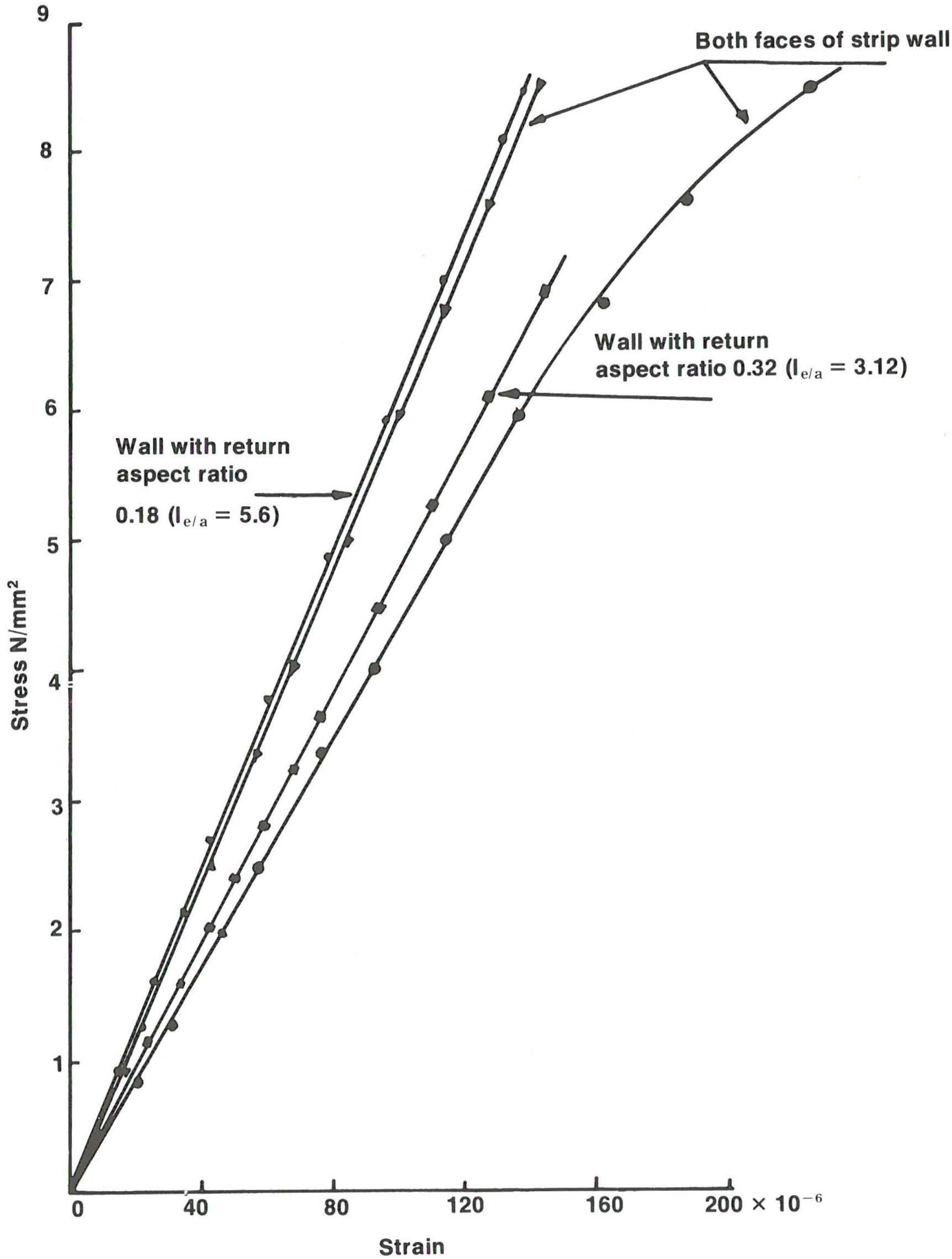


Figure 5. Showing stress-strain relationship

TABLE 2—Capacity Reduction Factor for Slenderness Ratio

$l_{e/t}$	strip walls	Walls with two returns	Capacity Reduction factor BS 5628
8	1	1	1
16	0,99	0.97	0.83
32	0.83	0.83	0.4 (for 27) (32 Not Permitted)