Fire Resistance of Load-Bearing Masonry Walls

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A comprehensive theory is being developed to predict the behavior of load-bearing masonry walls subjected to fire on one side.

THE PERFORMANCE of load-bearing masonry exposed to fire on one side is being studied at the Experimental Building Station, Sydney, Australia. The object is to develop a theory of behavior related to basic properties readily determined from small specimens. The behavior of full-scale specimens is being related to thermal diffusivity, thermal expansion, thickness, height, and load conditions.

Thermal diffusivity in combination with thickness determined the shape of the thermal gradient and, therefore, the thermal rating of the wall. In combination with thermal expansion, it determines the curvature of the wall. Curvature in combination with height determines the vulnerability of the wall to loading.

This paper discusses that part of the research program dealing with load conditions and height.

EXPERIMENTAL PROCEDURE

The test apparatus[1] accommodates specimens 3 m square and maintains a uniform distribution of load throughout the test. The platens are restrained against lateral and rotational movement.

Fourteen tests were carried out in this part of the research program. In all tests, the specimens were built with the same type of extruded clay brick and the same mortar proportions. The bricks had manufacturing dimensions of 290 mm by 90 mm by 90 mm. The walls were unrendered and nominally 90 mm thick by 3 m wide. Four different heights were tested — 3.0 m, 2.7 m, 2.4 m, and 2.1 m. Six walls were built in each of the 3.0-m and 2.4-m heights and tested at different loads (Table 1). The loads are expressed as percentages of the permissible design load at mid-height in accordance with Australian Standard 1640–1974.[2] The tests were conducted in accordance with AS 1530, Part 4–1975.[3]

TABLE 1. *Specimen Details and Test Results*

Test number	Nominal height of wall (mm)	Nominal slenderness ratio	Stress at mid-height of wall (MPa)	Applied ÷ permissible load (%)	Time to failure: Average temperature (min)	Time to failure: Maximum temperature (min)	Time to failure: Structural collapse (min)	Maximum central deflection: Reading (mm)	Maximum central deflection: Time (min)
LB25A	3000	25.0	1.09	125	—	—	27	78	27
LB25B	3000	25.0	0.87	100	—	—	31	81	31
LB25C	3000	25.0	0.66	75	—	—	34	88	33
LB25D	3000	25.0	0.44	50	—	—	29	81	28
LB25E	3000	25.0	0.22	25	—	—	35	97	35
LB25F	3000	25.0	0.15	17.4	—	—	39	106	39
LB26A	2400	20.0	1.48	125	67	72	191	64	191
LB26B	2400	20.0	1.19	100	67	73	164	73	164
LB26C	2400	20.0	0.89	75	68	76	136	73	135
LB26D	2400	20.0	0.59	50	64	74	104	75	103
LB26E	2400	20.0	0.30	25	65	72	131	80	130
LB26F	2400	20.0	0.15	12.5	62	68	171	93	170
LB28	2100	17.5	0.65	50	68	75	220	66	219
LB29	2700	22.5	0.50	50	—	—	65	79	64

TEST RESULTS

Table 1 lists the failure times for each test and the deflection at the center of the wall just before collapse. Figures 1 through 4 show the central deflection during the test for the four different wall heights. Figure 5 shows the variation of central deflection at collapse with applied load for the 3.0-m and 2.4-m walls. Figures 6 and 7 illustrate the effect of applied load and slenderness ratio, respectively, on the collapse time.

EFFECT OF APPLIED LOAD

Collapse times for the six walls in LB25 did not vary greatly. But there was a slight tendency for the time at collapse to be greater for walls with lower loads than those with higher loads (Figure 6).

On the other hand, there were significant differences between the collapse times for the six walls in LB26. Not only was the longest collapse time almost double the shortest, but also the difference between collapse times of successive tests was about 30 min. The curves in Figure 6 show that a

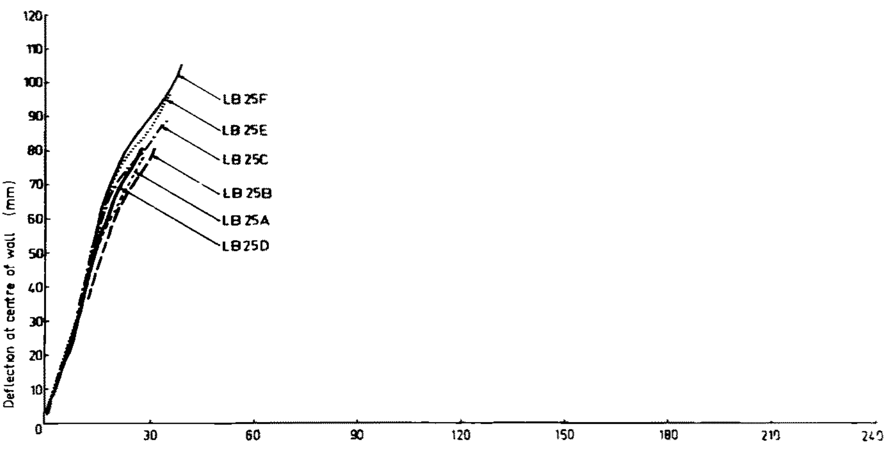

Figure 1. Variation of central deflection with time for walls LB25.

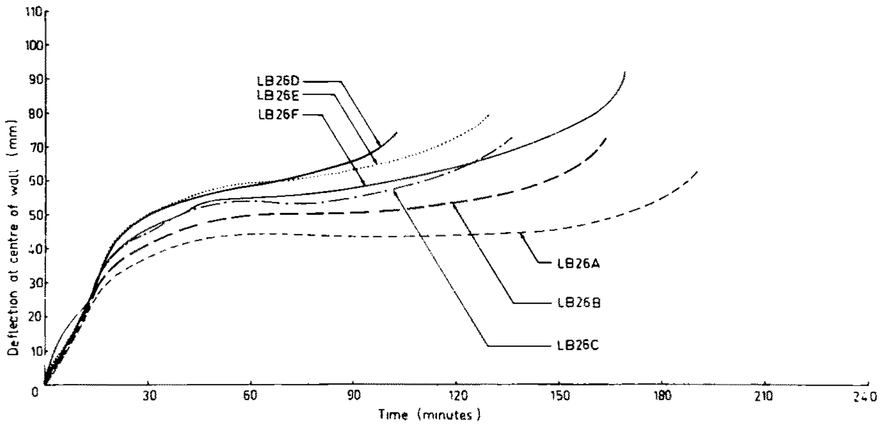

Figure 2. Variation of central deflection with time for walls LB26.

minimum collapse time occurred when the applied load was approximately 50 percent of the permissible load. On both sides of this minimum point, collapse times increased rapidly.

The curves in Figure 6 can be explained in terms of the combination of the applied load and bowing due to thermal effects. Before the fire starts, the vertical load acts down the center line of the wall. As the wall bows toward the fire as a result of thermal effects, the point of application of the vertical load moves towards the fire (Figure 8). Initially, the load will tend to counteract the bowing caused by thermal effects, i.e., the load will inhibit the deflection of the wall. But as the wall deflects further, a stage is reached beyond which the vertical load tends to increase the deflection until the wall collapses.

The variation in central deflection during a test can be idealized as a three-phase curve:

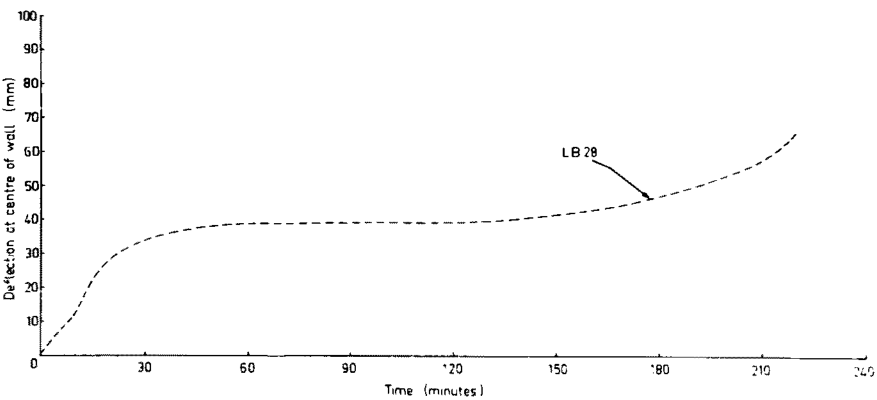

Figure 3. Variation of central deflection with time for wall LB28.

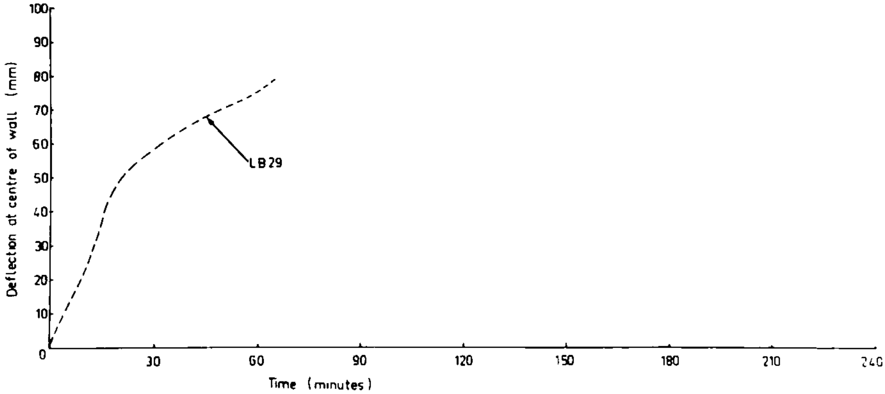

Figure 4. Variation of central deflection with time for wall LB29.

- Phase 1 — a rapid increase in deflection;
- Phase 2 — no increase in deflection (plateau); and
- Phase 3 — a further increase in deflection (tail).

The length of each phase has been found to depend on the slenderness ratio and the applied load.

The initial phase is the result of thermal bowing with a steep thermal gradient and is largely independent of the load. During the second phase, the thermal gradient is flatter and the load inhibits further deflection. The length of the plateau depends on the magnitude of the load. For example, in LB26, the plateau is the longest for the most heavily loaded wall (BS26A) and decreases for lower loads until, for LB26D, LB26E, and LB26F, it has almost disappeared. The third phase starts when the strength of the wall adjacent to the fire deteriorates and the load tends to accelerate deflection. The tail is longer for more lightly loaded walls (Figure 2) because the load is not great enough to cause rapid deflection.

The magnitude of the load also affects the central deflection at collapse. The curves in Figure 5 indicate that there is a tendency for the central deflection just before collapse to be larger for more lightly loaded walls. A heavy load tends to cause the wall to collapse at a lower deflection, whereas a more lightly loaded wall deflects more before the load causes the wall to collapse.

EFFECT OF SLENDERNESS RATIO

Figure 6 shows that collapse times for the 2.4-m walls (LB26) were much higher than for the 3.0-m walls (LB25). Collapse time for the 2.1-m wall (LB28) was higher again, whereas collapse time for the 2.7-m wall (LB29) fell mid-way between those for the 2.4-m and 3.0-m walls.

Figure 9 shows the steepness of the curve relating collapse times for the four walls of various heights tested at 50 percent of their permissible loads; a difference of only 300 mm in height had a dramatic effect.

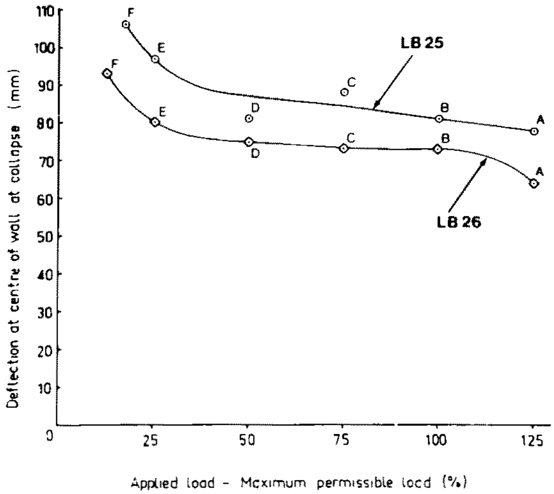

Figure 5. Relationship between central deflection at collapse and applied load for walls LB25 and LB26.

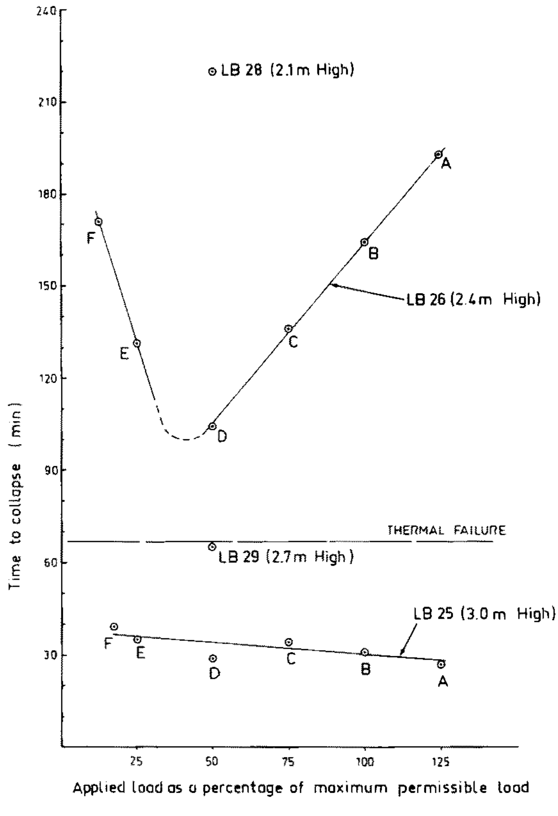

Figure 6. Relationship between collapse time and applied load.

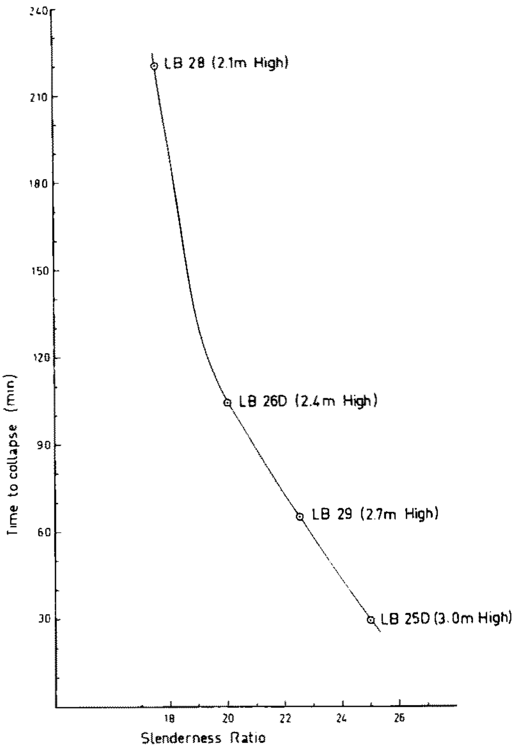

Figure 7. Relationship between collapse time and slenderness ratio.

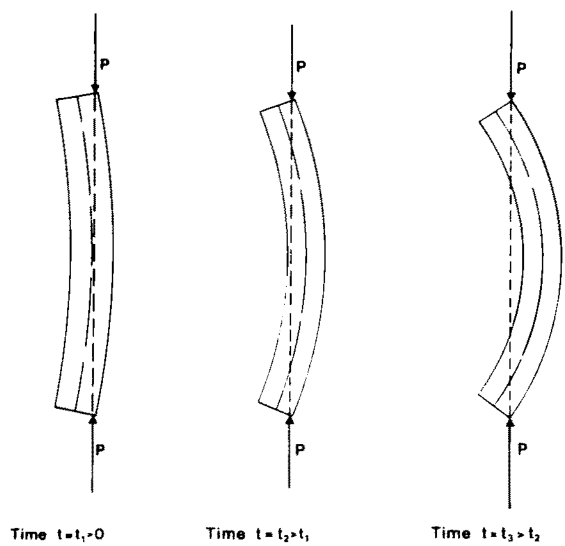

Figure 8. Diagram showing deflected shape at various times during test.

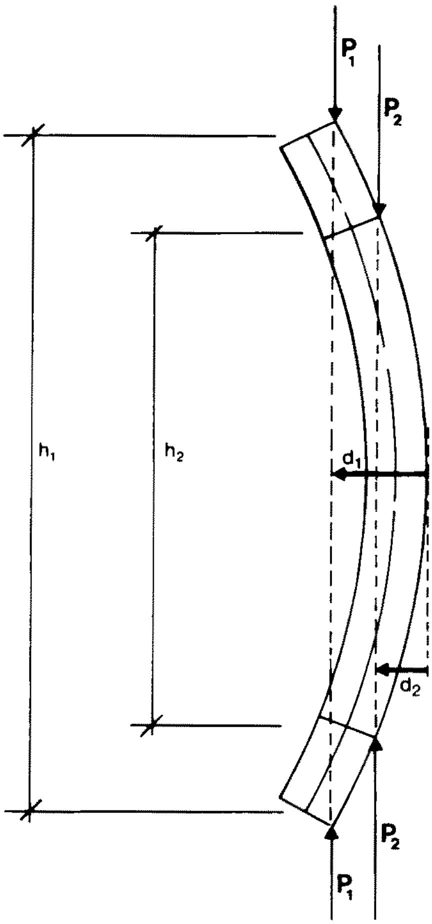

Figure 9. Diagram comparing deflections of short and tall walls.

If we neglect the effect of the applied load, the curvature of walls made from a particular brick would be independent of their heights provided heating conditions were constant (Figure 9). Each wall would collapse when the central deflection was about equal to the thickness. Therefore, the taller wall would collapse first, because it would reach the critical deflection earlier than the shorter wall.

As previously discussed, the variation of central deflection during a test can be idealized as a three-phase curve. For the 3.0-m walls (LB25), the second and third phases did not exist, whereas for the shorter walls (LB26, LB28, and LB29), the second and third phases were present but their lengths varied (Figures 1-4). It appears that the taller walls were so slender that the deflection due to thermal effects quickly increased to the critical deflection at which collapse occurred. For the less slender walls, critical deflection was not reached so rapidly, and there was a period for which the applied load decreased the rate of deflection.

The difference in the shape of these curves explains the difference in the shape of the curves in Figure 6. There was little difference in collapse times for the 3.0-m walls (LB25), but collapse times for the 2.4-m walls (LB26) varied as the lengths of the plateau and tail in the deflection curves responded to the intensity of the loads.

Furthermore, the central deflection at collapse, the critical deflection, varied with the height of the wall (Figure 5). Critical deflection was larger for the walls in LB25 than the corresponding walls in LB26. This difference can be explained in terms of the tensile strength of the brickwork. Walls that are slow to deflect suffer a greater loss of tensile strength because of longer exposure to the fire and, therefore, collapse at smaller deflections.

FIRE RESISTANCE RATING

The average time to failure was 66 min by the criterion of average temperature rise[3] and 73 min by the criterion of maximum temperature rise. Whenever thermal failure occurred before structural failure, the thermal failure time exceeded 60 min. Therefore, the fire resistance rating for the walls tested was in excess of 1 hr, provided we chose a combination of applied load and slenderness ratio that prevented structural collapse before 1 hr. Collapse times for the 2.4-m walls (LB26) were well in excess of 1 hr. Therefore, we can safely say that a wall built from the same materials as the walls tested and with a slenderness ratio of 20 or less will achieve a 1-hr fire resistance rating for any practical applied load. The 3-m walls all collapsed before the thermal rating (66 min) was achieved.

SUMMARY

A series of fourteen full-scale fire resistance tests were carried out on single-leaf load-bearing brick walls in accordance with Australian Standard 1530, Part 4–1975.[3] The walls were constructed with a particular extruded clay brick nominally 290 mm by 90 mm by 90 mm. The conclusions from these tests were as follows:

- The magnitude of the applied load and the slenderness ratio both had a significant effect on the structural performance of the wall.
- For a wall with a high slenderness ratio, the time to structural collapse tended to be slightly greater for a more lightly loaded specimen.
- For a wall with a low slenderness ratio, the time of structural collapse was a minimum when the applied load was approximately 50 percent of the permissible design load. The time for structural collapse increased rapidly as the applied load either increased or decreased with respect to this applied load.
- A small increase in slenderness ratio resulted in a marked reduction in collapse time.
- Those walls having a slenderness ratio of 20 or less achieved a 1-hr fire resistance rating for any practical load.

REFERENCES

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[2] *Brickwork in Buildings (AS 1640–1974)*, Standards Association of Australia, Sydney, 1975.

[3] *Method for Fire Tests on Building Materials and Structures; Part 4 — Fire Resistance Test of Structures (AS 1530, Part 4–1975)*, Standards Association of Australia, Sydney, 1975.

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