IV–40. Edge Restraint Provided by Continuity of Panel Walls

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ABSTRACT

The steel frames used for the extensive lateral loading research programme, which has been previously described, are known to give intermediate edge restraint and were deliberately chosen thus to simulate to some extent the inevitable variation in practice. In-plane forces are thought to contribute to lateral resistance, and it was considered that such support might be achieved in bays of a long wall if continuity could be developed. This paper describes the results of a limited number of experiments to test this hypothesis.

Les adres en acier employés pour le vaste programme de recherche sur les charges latérales, qui a été décrit précédemment, sont connus comme donnant une contrainte intermédiaire sur les bords et furent choisis à dessein pour simuler ainsi jusqu'à un certain point les variations inévitables das la pratique. Il est supposé que les forces dans le plan contribuent à la résistance latérale, et il fut considéré qu'un tel support pourrait être obtenu dans les travées d'un mur long si la continuité pouvait être développée.

Ce document décrit les résultats d'un nombre limité d'expériences effectuées pour mettre cette hypothèse à l'épreuve.

Die in dem ausgedehnten Untersuchungsprogramm über Querbelastung verwendeten Stahlrahmen ergeben wie schon früher beschrieben eine indirekte Kantenunterstützung und wurden absichtlich gewählt, um die in der Praxis unvermeidlichen Unterschiede zu simulieren. Es wird angenommen, daß in der Fläche auftretende Kräfte die Querfestigkeit erhöhen und da_ eine derartige Unterstützung in Abschnitten einer langen Wand erreicht werden kann, wenn eine Kontinuität entwickelt wird. Dieser Artikel beschreibt die Ergebnisse einer eingeschränkten Anzahl von Experimenten, welche zur Prüfung dieser Annahme durchgeführt wurden.

Le intelaiature d'acciaio, usate per il vasto programma di ricerca sulle sollecitazioni laterali che è stato descritto precedentemente, danno un supporto intermedio di bordo e sono state scelte espressamente per riprodurre come meglio possibile le inevitabili variazioni che si hanno in pratica. Le forze complanari probabilmente contribuiscono alla resistenza laterale e quindi si è considerato che supporto di questo tipo può essere ottenuto in campate di un muro lungo se si può ottenere continuità. Questo articolo descrive i risultati di un numero limitato di esperimenti effettuati per provare questa ipotesi.

INTRODUCTION

A programme of exprimental tests on full-scale walls carried out at the British Ceramic Research Association was sponsored by the Building Research Establishment to provide a basis for a method of design for laterally loaded panel walls. The Code of Practice being drafted at that time has been published as BS 5628:Pt. 1, 'The structural use of masonry'[1] and now includes guidance on this subject. In this context laterally loaded panels comprise walls carrying mainly loads normal to the plane of the wall although limited vertical loads in addition to self-weight may be considered. Such panels may be supported on 2, 3 or 4 edges.

In comparing theoretical predictions with experimental results it is desirable that the actual conditions, particularly the boundary conditions or edge restraints, should represent as accurately as possible the idealised conditions assumed in theory. Although the experimental attainment of simple support is relatively straightforward it was necessary to examine closely means of achieving full edge continuity, that is full restraint to rotation. The additional restraint of zero in-plane translation is necessary for in-plane arching to develop.

Walls tested previously at BCRA[2] usually had the upper edge free and the vertical edges tied to a steel frame. Although this form of edge restraint may be reasonably representative of some forms of construction the magnitude of the restraint is somewhat indeterminate between simple and full support, even though the moment resistance of the ties in brickwork was determined separately.

The trench facility at BCRA used for tests on horizontal arching provided a maximum wall length of 2.72 m. In view of its fixed span and limited availability, and in an attempt to avoid the expense and inconvenience of providing a substantial independent steel or concrete reaction frame to afford full resistance to rotation and translation, a number of 'continuous' walls were tested. This paper describes the tests and discusses the results.

EXPERIMENTAL RESULTS

The identification of the walls is given in Table 1 which shows diagrammatically the geometry and edge restraints together with the brick/mortar combinations and the experimental failing pressures. Table 2 gives the compressive strength of bricks and mortar, water absorption of bricks and flexural strength of brickwork. Lateral load was applied using the air-bag method,[2] loading at a rate of 0.14 kN/m²/min. The details of the individual tests follow.

Walls 1110, 1119

These two walls were similar apart from the brick and mortar. Each wall was 2.54 m high and 8.2 m long with 1 m long bonded returns at each end. They contained a bituminous damp-proof course (dpc) between the first and second brick courses. The central portion of the wall, 2.72 m long, was loaded, two vertical steel channels being positioned behind and in contact with the wall at each end of this portion to simulate prototype columns. The channels were bolted to the laboratory floor and braced at the top to the reaction boards of the air-bags. The maximum load was attained when the first visible crack appeared. This was accompanied by a lateral displacement of about 5 mm in the centre of the loaded area. Prior to vertical cracking opposite the vertical channels the adjacent wing panels moved about 1 mm, shearing having occurred at dpc in both wings and their returns.

Walls 935–938, 979, 980

These tests have been reported already,[3] the restraint to the vertical edges representing the ultimate in rigid supports provided that the walls are mortared solidly against the supports. Because of the restriction of in-plane extension, initial cracking does not correspond to ultimate failure although it may represent a serviceability limit state. The failure loads given correspond to the first crack and to ultimate failure.

Walls 966, 968, 990/1

These tests were included in the trench programme,[3] the walls being built within and mortared up to a steel frame along their vertical edges, so that some rotational resistance was provided. The top edges were free.

Walls 993, 994, 1005, 1008

These walls were built within frames[3] so that only simple support was provided at the vertical edges.

Wall 1136

This test was similar to wall 1119 except that the lateral load was applied to all three panels simultaneously. Failure occurred by shear at the dpc along one wing wall and its return and vertically along the steel support. The remaining apparently uncracked two panels were reloaded and the panel supported by the two channels failed by cracking in the pattern of an inverted 'Y.' There were signs of incipient shear at the dpc of the adjacent panel. This mainly 'undamaged" panel was then reloaded but the course above the dpc was strutted to resist movement so that effectively undisturbed brickwork was tested. The three stages or failure of the wall are shown in Fig. 1 in which the fracture lines have been exaggerated for clarity.

Wall 1198

In view of the substantial resistance to rotation apparently provided by the wing walls and returns to an adjacent panel the effect of a lesser length of wing wall was investigated in this test. The central section and supports were as for wall 1136 but the wings were only 0.9 m long, without returns. The whole face of the wall was loaded, a typical inverted 'Y' crack pattern occurring at failure.

DISCUSSION

Walls numbered between 935 and 1119 form sets of four types of vertical edge restraint applied to two types of masonry, that is brick and mortar combinations AX and BY (Table 2). Simple support, that is purely resistance to displacement normal to the wall, is a lower limit achieved by walls 993/1008 and 994/1005. At the other extreme full restraint (rotational and in-plane translational) is provided by walls 935–8, 979, 980. The appropriate relation for walls in frames 966/991 and 968/990, and for continuous walls 1100 and 1119, between the limits of simple and full support is indeterminate: indeed the objective is to assess their relationship to the limiting conditions.

The results for walls 966, 968, 990/1 contained within a steel frame suggest that the edge restraining moments in those particular cases lie between 30 and 50% of the moment required to prevent rotation completely.

Tests on walls 1136 and 1198 have explored the more practical conditions, in which the whole length of a continuous wall is loaded, to determine the minimum conditions under which full edge continuity may be assumed in design.

BS 5628 includes an approximate method of calculation, based on reference 3, for walls able to arch between rigid supports. If this method is used for walls 2.72 m long the relevant ultimate pressures are 22.5 kN/m² for AX and 9.2 kN/m² for BY. By comparison with the trench walls, the method is conservative, but the results are nevertheless much higher than for the multi-bay walls 1119 and 1136. For these higher pressures to be achieved in practice in-plane forces must be able to develop and for walls such as 1119 and 1136 they must be resisted by shear on the dpc in the side bays of the walls. The shear stresses required to achieve a lateral pressure of 22.5 kN/m² and 9.2 kN/m² in walls 1119 and 1136 are 2.2 Nmm² and 0.9 N/mm² respectively. No characteristic shear figures are yet available for dpc's under the self weight of one storey height of wall, but the characteristic values for brickwork are approximately 0.38 N/mm². Even if this is conservative it is considerably lower than the figure necessary to restrain in-plane forces, and it is, therefore, not surprising that the failure pressures of walls 1119 and 1136 were so much less than their equivalent walls in the trench.

In Table 2, the flexural strengths of the brick mortar combinations AX and BY for the interlocking strong direction are given. Similar, but characteristic figures, are given in BS 5628; both sets of strengths are repeated in Table 3 which compares the known flexural strength with one calculated from the failure pressures of walls 1100 onwards. The BS 5628 method of using bending moments has been used for the appropriate support conditions and patterns of failure.

It can be seen that the calculated flexural strengths are about three-quarters of those obtained from small specimens, in other words, either the calculation method underestimates the failure pressure or the full potential of the flexural strength from the small specimens has not been realised in the walls. On the other hand, the code characteristic values are a lot lower than those from the experimental small specimens. In any event, it does not appear that the continuity of walls past supports allows any significant in-plane actions to develop, though the continuity in itself allows extra lateral pressure to be carried by virtue of the distribution of bending moments.

The tests on wall 1136 and its remaining parts provide qualitative support for the main conclusion. The returns clearly do not provide full rotational restraint because failure in one wing panel occurred at a load much closer to the simply supported than the fully supported case, even though one end is effectively restrained by continuity past the support. This point is emphasised by the second and third tests. Although the length of returns (0.9 m) is marginally less than the minimum of ten times the thickness of the supported wall recommended in BS 5628[1] for full resistance to rotation, it is clearly the shear resistance at the dpc which is the critical factor rather than the shear strength of the masonry in the return and of its bond to the loaded wall. Therefore the justification for assuming full restraint at a bonded junction with a short return in the presence of a dpc should be considered carefully in design.

In wall 1198 the wing panels extended only a short distance (0.84 m) beyond the vertical supports but the failure load was comparable to that of wall 1119 which was much longer but loaded only at the centre. Sensibly full restraint appears to be provided by short extensions which is a valuable consideration in the design of laterally loaded panel walls.

CONCLUSIONS

From this limited series of tests it appears that a valuable contribution to lateral load resistance is provided by continuity of walls over supports, even when the extension is less than ten times the wall thickness. However, the benefit of such continuity does not extend to enabling significant in-plane forces to develop, because of the lack of shear resistance at the dpc. As a result walls of this type do not resist such high lateral loads as those fully restrained against rigid abutments.

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REFERENCES

1. British Standards Institution. BS 5628: Part 1: 1978. The Structural Use of Masonry: Part 1: Unreinforced Masonry. British Standards Institution, London 1978.
2. West H.W.H., Hodgkinson H.R., and Webb W.F. Lateral Loading Tests on Walls With Different Boundary Conditions. Proc. 3rd Int. Brick Masonry Conf. Ed. L. Foertig and K. Göbel, Bonn. Bundesverband der Deutschen Ziegelindustrie, 1975.
3. Hodgkinson H.R., West H.W.H., and Haseltine B.A. Preliminary Tests on the Effect of Arching in Laterally Loaded Walls. Proc. 4th Int. Brick Masonry Conf., Bruges. Groupement National de l'Industrie de la Terre Cuite, 1976.

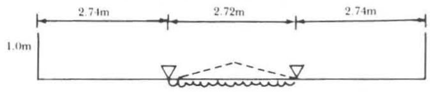
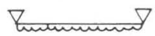
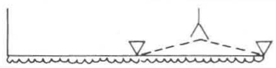
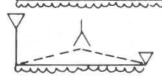
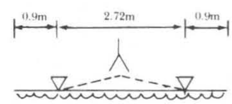
TABLE 3—Comparison of calculated flexural stress with experimental

Wall no.	Brick/ Mortar	Ultimate pressure kN/m²	Flexural stress N/mm² Exp (Table 2)	Calculated from wall test	BS 5628 characteristic	Remarks on calculated stress
1100	AX	10.1	2.7	2.0	2.0	Ignores in-plane forces from side bays
1119	BY	7.4	1.7	1.3	0.9	
1136 (1)	BY	4.1	1.7	1.1	0.9	Flexural stress up to 1.7 based on vertical crack alone
(2)		4.4	1.7	1.2	0.9	
(3)		3.8	1.7	1.4	0.9	
1198	BY	7.1	1.7	1.4	0.9	Assumes wing walls provide continuity

TABLE 2—Materials Data

Brick designation	Compressive strength N/mm²	Water absorption %	Mortar designation and mix	Flexural strength of masonry N/mm²
A	54.4	4.7	X=1:¼:3	2.7
B	24.2	22.1	Y=1:1:6	1.7

TABLE 1—Wall Data and Strengths

Wall No.	Wall Layout and Failure Pattern	Brick/ Mortar	Pressure at First Crack kN/m^2	Ultimate Failure Pressure kN/m^2
1100		AX	10.1	10.1
993 1008		AX	5.1 (4.8, 5.4)	5.1
966 991		AX	5.0 (4.4, 5.5)	7.2
935 936 979 980	 Arching pressure calc. BS 5628 =22.5 kN/m²	AX	9.0 (7.4, 10.7)	>31
1119		BY	7.4	7.4
994 1005		BY	3.7	3.7
968 990		BY	3.5 (3.3, 3.6)	4.9
937 938	 Arching pressure calc. BS 5628 =9.2 kN/m²	BY	7.9	21.0
1136 (1)		BY	4.1	4.1
(2)		BY	4.4	4.4
(3)		BY	3.8	3.8
1198		BY	7.1	7.1

Note: All walls 34 courses, 2.54m high except 979 and 980 which were 22 courses, 1.64m high. All walls 102.5mm thick.

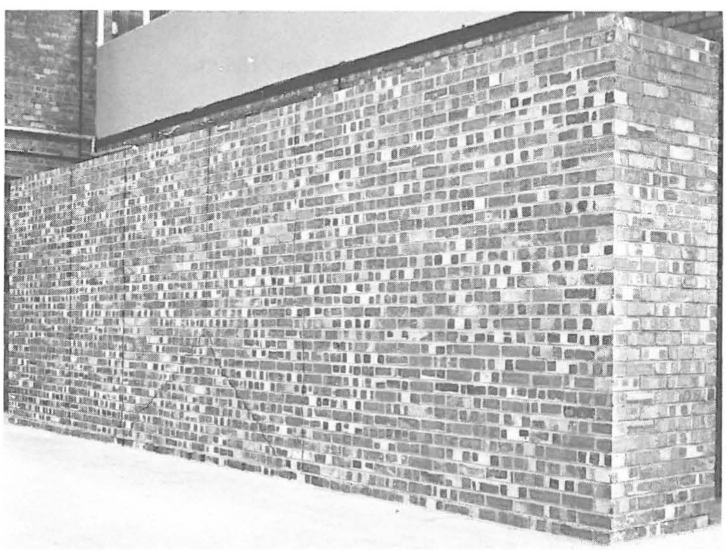


Figure 1.