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LATERAL LOAD RESISTANCE OF DRY-STACK MASONRY WITHOUT INFILL

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ABSTRACT

A series of deformation controlled tests on laterally loaded dry-stack walls without infill is described. Contrary to some expectations, the walls resisted substantial loads, and returned almost to their original position on unloading. Individual block movements in x, y and z directions were measured to an accuracy of around 0.2 mm. The observed local behaviour is described and some possible approaches for analysis are outlined. It is concluded that dry-stack masonry without infill can be used in structural applications. An indication is given of the further research and development work required to achieve that objective.

INTRODUCTION

Laying concrete masonry blocks is a heavy manual task which must be done with great care for an effective and attractive result to be obtained. The skills required are similar to those required in assembly tasks in manufacturing industry, where conditions of work and rates of pay are often superior. A shortage of craftsmen can arise, particularly when there is a boom in construction, and this in turn leads on to increased costs and delays.

In response to this, over the last ten to fifteen years, manufacturers in the UK and in other countries have produced hollow concrete masonry units to accurate vertical tolerances (commonly less than 1 mm). Walls up to five metres high can be erected by simply laying or 'stacking' such blocks one on top of the other. The verticality of the walls can be better than that achieved by craftsmen laying blocks with mortar joints. It is usual to insert rebars running both horizontally and vertically, following which the cores in the blocks are then filled with concrete.

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The product used in our tests was developed by David W Gordon & Sons of Aberdeen, Scotland and is 290 mm thick. Figure 1 shows the shapes of the various units and how they bond together to form a wall and return. A sizeable market has been developed for these blocks, mainly for retaining walls, where vertical reinforcement is inserted to resist the large lateral loads.

This paper describes research and development work on walls without any infill concrete or reinforcement. The material and labour costs of infill concrete and insertion of even nominal reinforcement are considerable, and there is also a time penalty. Omitting the infill concrete will lead to substantial cost savings. The objective of the tests was to establish whether walls without infill could resist realistic lateral loading.

Previous Research Work on Filled and Unfilled Masonry

A considerable body of work has been carried out on the behaviour of infilled dry-stack masonry. The North American work described by (NCMA 1985) and (Drysdale 1986) shows that the compressive load coming on to the masonry is shared between the blocks and infill concrete. Similar tests have been carried out at the Institut fur Bautechnik in Berlin in regard to a German product (Kuthe 1986).

In regard to unfilled dry-stack masonry, a preliminary investigation has been carried out at Paisley (Oswald 1991). He showed that ordinary concrete blocks simply laid one on top of the other would carry vertical loads exceeding 60% of the load which would be carried when mortar was used to form the joints. Thus performance under light vertical loading such as arises in two to three storey construction is assured.

In regard to the general acceptability of dry-stack walling, Oswald had discussions with individual building control officers in Scotland; at least one expressed strong interest and indicated that he would give proposals to use unfilled walls serious consideration. Oswald recommended that further work be carried out, which has led to the pilot tests described below being carried out.

Pilot tests of dry-stack walls without infill concrete

Five tests have been carried out so far, all of which have been provided with vertical supports at the ends, but free to deform laterally at the top (see sketch in Fig. 2). The test load was applied through a loading rig which distributed a single applied load into 16 separate and equal loads, applied at points spread evenly across the wall surface. Loading rods passed through holes drilled through the blocks, with the load applied through a small plywood pad. This loading simulated a uniform wind load. The overall weight of the steel beams and rods used to spread the load was 200kg. A counterweight system ensured that only horizontal loading was applied to the wall.

All the test work and some of the actual building work has been carried out by undergraduate students, either engaged on final year project work or employed by the University in one of their industrial training periods (we have a 'co-op' degree program at Paisley).

Five tests have been carried out are as follows:

Test 1	4m long and 1.96m high - not bonded to supporting walls (see sketch in Fig. 2)
Test 2	4.7m long and 3.02m high - not bonded to supporting walls
Test 3	4m long and 2.17m high - not bonded to supporting walls
Test 4	4.25m long and 2.16m high - bonded to return walls (see Fig. 3 and Fig. 4)
Test 5	Reloading of test 4 after unloading (more extensive measurements of individual block movements were made in this test)

The tests were controlled by pumping the loading jacks until a previously selected top-centre deflection of the wall was reached. The load was recorded at this point, and a general inspection made of the overall response, before deforming the wall further. The maximum deflection was usually 100 mm (around 1/40 to 1/50 of the span). A deflection of this order can be considered as a total structural failure. We also wished to be certain of avoiding a complete collapse of the wall, which could have endangered personnel and caused damage to the loading rig and jacks.

At selected load stages, deformations in the x, y and z directions were recorded at various points on one face of the wall using a pair of high precision theodolites linked to a computer. The measuring points consisted of glass balls glued in position; intersection of the lines of sight from the two theodolites is assured to high accuracy since it is easy to focus on the centre of the balls. A total of around 100 points were located on each wall, with a few adjacent blocks having four points applied, one close to each corner. The computer software checks the accuracy of intersection of the lines of sight, enabling an accuracy of around 0.2 mm to be assured. At maximum deflection, the gaps which had opened up between blocks were measured using a rule, estimating to the nearest mm.

General behaviour observed

Perhaps the most surprising result is that the walls, despite being loaded by 16 point loads, behaved as flexurally connected walls. We expected some tendency for the blocks loaded with the plywood pads to 'pull out' of the wall. This only happened with test five, and was considered to be due to the large 'push-out' which had developed in the topmost courses under the previous test four.

The load deflection plots for the five tests are shown in Fig. 2. The graphs indicate some reserve of strength beyond the point of maximum deformation. There is a substantial recovery of deflection that takes place when the load is removed. While no unloading was carried out at earlier stages, it can be inferred that the residual deflection after unloading from a service loading of say 2/3 of ultimate would be a matter of only a few mm. Of particular interest is the high initial stiffness displayed in test 4, considered to be due to the end fixity caused by bonding into the return walls.

Design adequacy

The maximum resistance at the end of the tests for the three approximately 4 x 2m walls ranges from 1.1 to 1.3 kN/mm^2 which is equivalent to a substantial wind loading. It means that the wall would be structurally safe against extreme wind loading in many locations in the UK. The recovery under load also means that the deformations under service loading would be satisfactory.

We therefore conclude that we have a viable structural system. In the remainder of the paper an attempt is made to explain the detailed mechanisms observed, and some theoretical approaches are suggested.

Local deformations established from precision theodolite measurements

Where blocks had four measuring stations applied the overall relative movements between adjacent blocks could be established. A three dimensional model of some of these relative movements has been built up using Autocad. It is not practicable to present results in the paper, since they can only really be understood and studied usefully using the viewing and zoom facilities in Autocad itself (it is hoped in the conference to present some results in this way). Considerable effort has been devoted to studying the local deformations, enabling the mechanisms of resistance in the next section to be worked out.

The mechanisms of resistance

An obvious contributor to resisting lateral load is the simple effort required to overturn the wall. For the 2.1 metre height of this wall, and the weight of 23.5 kg per 290 mm wide unit, the overturning pressure works out at 0.33 kN/m^2, less than one third of the ultimate loading recorded. A substantial resistance has to be due to other causes, some of which are explored below.

The deformations of the wall 5 at maximum deflection are shown in Fig. 3 and Fig. 4 (these have been adapted from photographs). Figure 3 shows the deflected profile along the top row of blocks, where it can be seen that there is a virtually straight central section (blocks 4, 5 and 6). Figure 4 shows the top-right rear face (viewed from the unloaded side with the loading rig elements removed for clarity. Those vertical joints which have opened up significantly are indicated by a thick vertical line. A yield line pattern can be seen, made up of a central trapezoid which does not deform flexurally, but simply tilts about the base, with two outer triangles,

This behaviour can be idealised as in Fig. 5. It is clear that the two outer triangles are subjected to double the uplift that the central trapezoid experiences. However, calculations show that the minimum load capacity for this yield line pattern occurs with the angle ß equal to a right angle, in other words a return to simple overturning. Why then does the yield line pattern in our tests give a ß value of around 60 degrees? The answer, I believe, is that energy is also absorbed in flexural deformations in the stretcher bond interlock in the masonry.

Consider a plan view on A-A of the bed joint between block 17 and blocks 11 and 12 above it (Fig. 4). An exaggerated view of the deformation pattern is shown in Fig. 6(a). It will be seen that block 12 rotates and moves outwards over the surface of block 17. The outward movement results in a small tilt being induced in the return wall involving energy absorption, which in turn produces a lateral thrust in the wall. Looking now at the relative deformations in the vertical joint between blocks 11 and 12 (see Fig. 6(b)), again a relative rotation is in evidence which because of the longitudinal thrust now present will result in some absorption of energy. Additional energy absorption, possibly the most significant of all, occurs in 'tooth' formations where blocks are gripped in the trapezoid of the yield line pattern on the one hand and in the triangle on the other (see block 22, Fig. 4). Where the wall panel is bonded to a return (or to an adjacent panel), this tooth pattern will apply for the whole height of the wall.

A theoretical approach is being developed which assumes simple frictional movement between blocks, with the average stress on each bed joint assessed from the dead load above it. The lateral thrust also has to be estimated. This will be dependent on how 'tight' the vertical joints are when laid, on subsequent shrinkage, and on the lateral restraints which are present. These lateral restraints will be substantial for internal where a panel has similar panels adjacent to which it is bonded.

Other aspects to be considered

It is clear that wind and weather tightness will have to be established by other means, although for simple storage structures the walls might be adequate, provided there was an overhang or other shelter against wind-driven rain. Many of the supplementary cladding systems used with other structural materials to achieve wind and weather tightness, will be equally applicable to this type of wall.

Conclusions

1. Tests confirm that dri-stacked masonry walls, made up from concrete blocks are capable of resisting significant structural loading.

2. The precision theodolites used to measure the movements of the individual blocks in the wall, should enable the mechanisms of the behaviour to be determined.
3. Progress has been made in developing an understanding of how the loads are resisted.
4. Further work is required to develop a theory to predict the behaviour.
5. Further tests are required to confirm any theory developed over a wider practical range. We hope to gain European Community funding for a collaborative project involving partners from several EC countries. We will be happy to collaborate with organisations from outside the EC.

Acknowledgements

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4. Oswald W M *'Dry-Stack Masonry - an Investigation'* Project Report No 7, MSc Course in Engineering Design of Buildings, University of Paisley, Apr 1991,

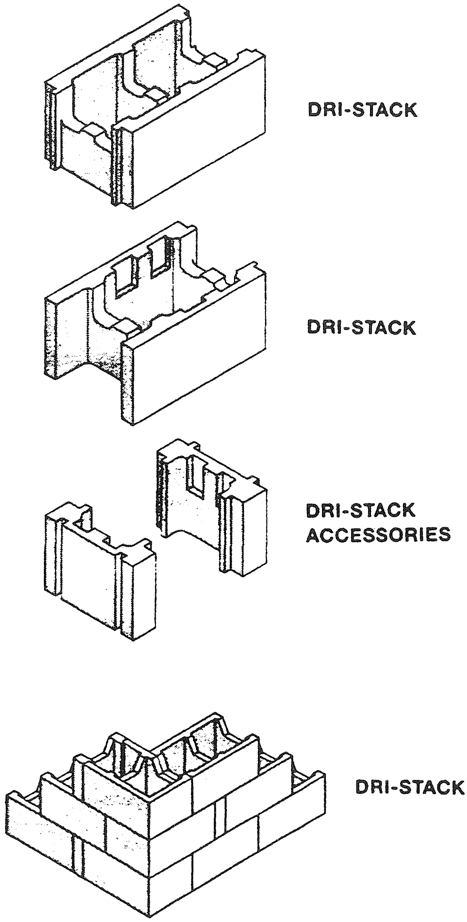


Figure 1 - Block details

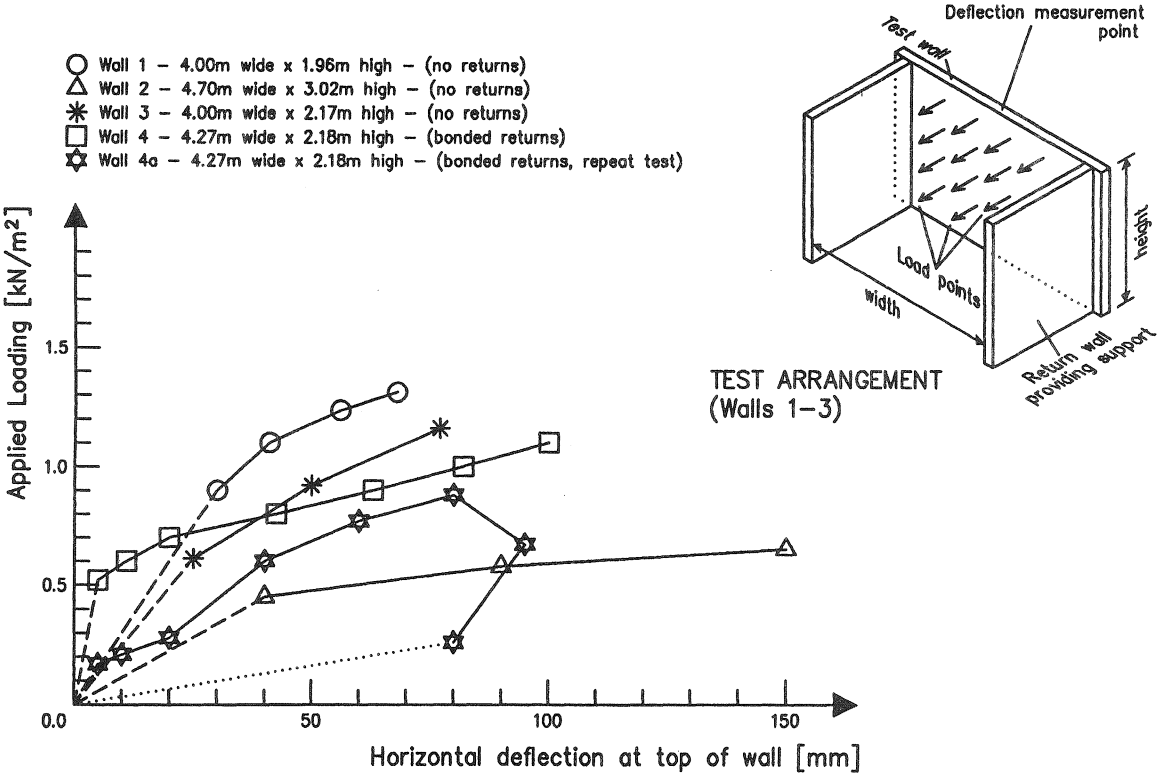


Figure 2 - Load /deflection graphs

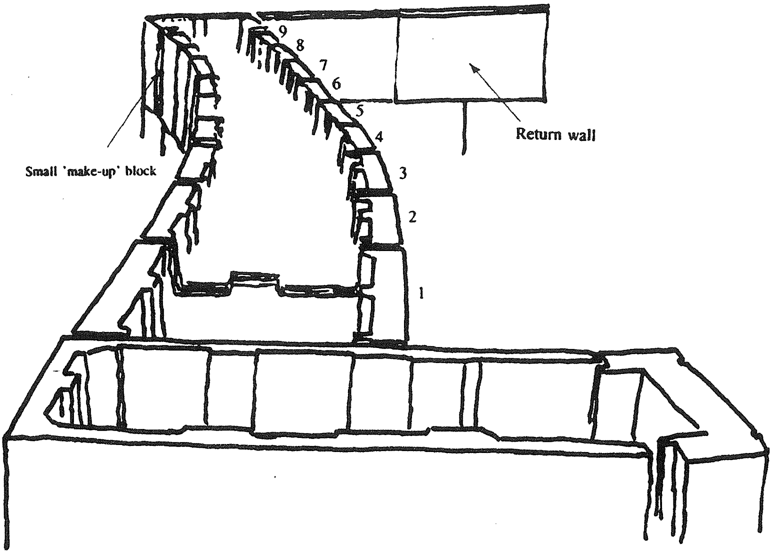
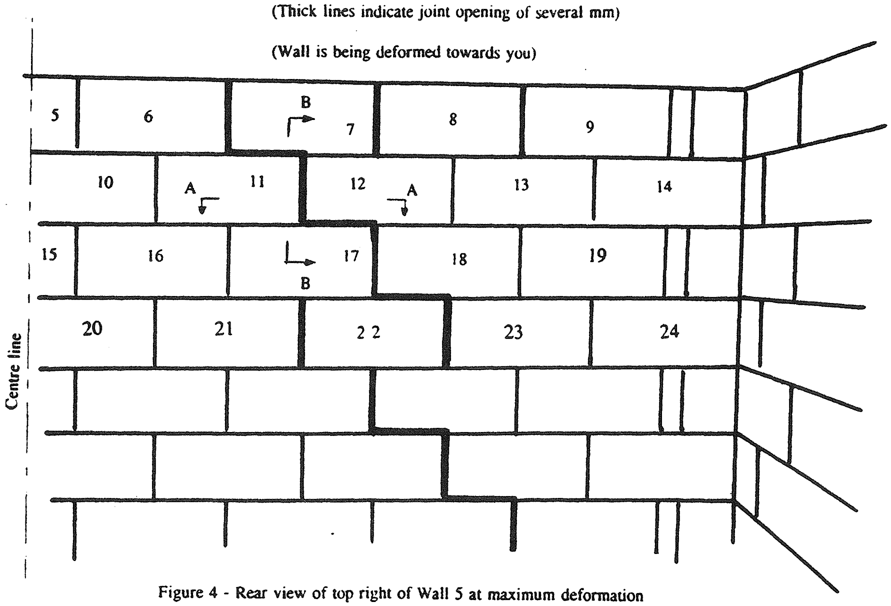


Figure 3 - View along top of Wall 5 at maximum deformation (adapted from photograph)


(Thick lines indicate joint opening of several mm)

(Wall is being deformed towards you)

Figure 4 - Rear view of top right of Wall 5 at maximum deformation

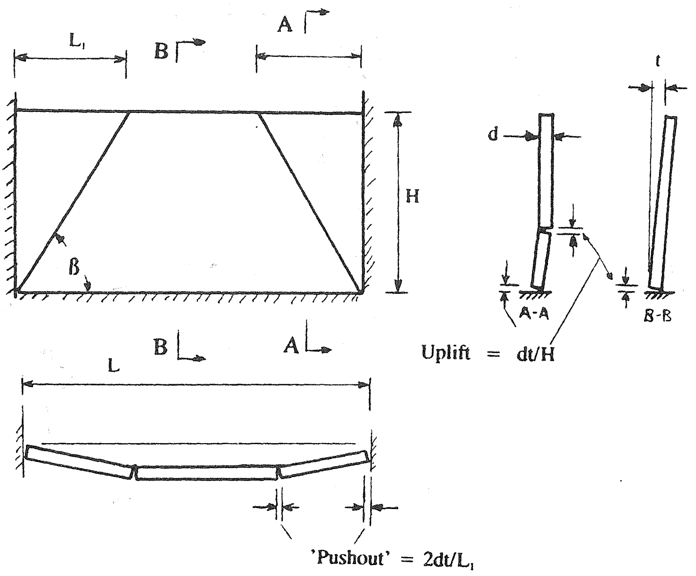
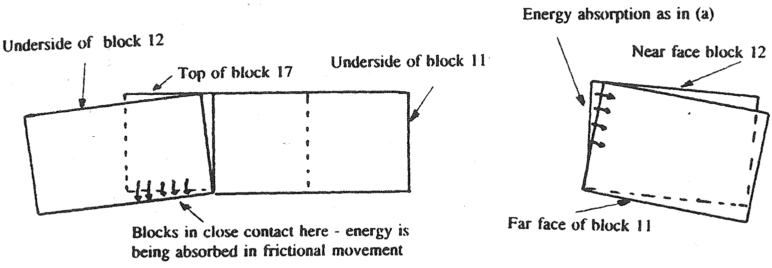


Figure 5 - Idealized yield-line behaviour



(a) View on A-A in Fig 4

(b) View on B-B in Fig. 4

Figure 6 - Relative movements of blocks - schematic and exaggerated