CONCENTRATED LOADS ON AIRCRETE THIN JOINT BLOCKWORK

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SUMMARY

The effects of some limited forms of concentrated loading on low density Aircrete (Autoclaved Aerated Concrete)(AAC) thin joint blockwork were examined using non destructive testing to measure the load spreads. The results are compared with the spreads given in BS 5628 (British Standards 2005) and EC6 (CEN Standards 2005).

INTRODUCTION

Aircrete, the lightest form of concrete masonry, was introduced into the UK in the 1950's. It is used extensively, especially to construct walls of low rise dwellings. Today's material has become progressively lighter than the material produced 50 years ago and the ratio of compressive strength to density has improved.

The two principal drivers for lowering density are manufacturing economy, by reduced raw material consumption, and improvements to the thermal insulation properties of the material. Reducing density tends to produce lower strengths and reduce robustness, durability and resistance to chemical attack. As Aircrete has become progressively lighter, modified construction methods have also been introduced including thin joint construction.

Behaviour under concentrated loads

Stresses induced by concentrated loads on walls can be more critical than those from the general run of vertical loads which are taken to be uniformly distributed. For masonry materials at the lower end of the compressive strength range, behaviour under concentrated loads is central to their suitability for economic application in construction. Codes and regulations regarding the ability of walls to support concentrated loads have been developed on the basis of the strength and behavioural properties of masonry materials which were stronger and denser than the lighter forms of Aircrete (Page and Hendry 1988).

Eurocode 6

Eurocode 6 Design of masonry structures - Part 1-1 (EC6) (CEN Standard 2005) will eventually replace BS 5628 (British Standard 2005) for the design of masonry structures in the UK, although there will be residual British Standards for matters not covered by the European Standards.

By eliminating the effect of slenderness and factors of safety, the strength of masonry subjected to a vertical concentrated load can be calculated according to both BS5628 and EC6.

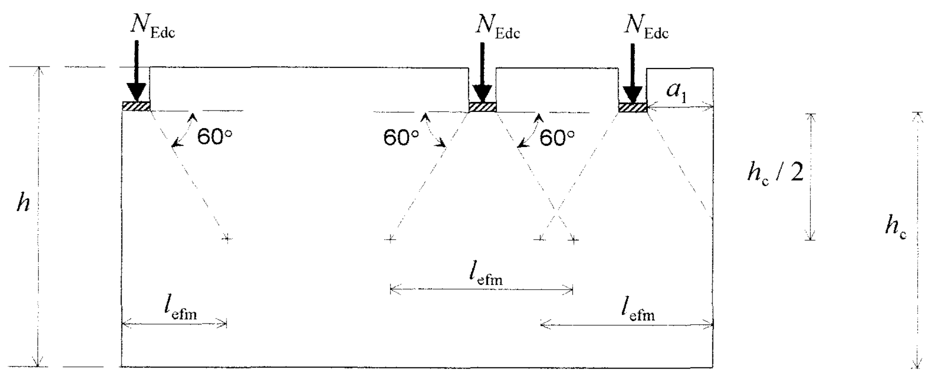

Figure 1: Walls subjected to Concentrated Loads

According to EC6, when a wall, built with Group 1 masonry units with fully filled mortar joints (all Aircrete blocks are classified as Group 1 units) detailed in accordance with EC6, see Figure 1, is subjected to a concentrated load, the design value of the vertical concentrated load resistance of the wall is given by:

$$N_{Rdc} = \beta \, A_b \, f_d \qquad (1)$$

where:

f_d is the design compressive strength of the masonry

$$\beta = \left(1 + 0{,}3\,\frac{\alpha_1}{h_c}\right)\left(1{,}5 - 1{,}1\,\frac{A_b}{A_{ef}}\right)$$

which should not be less than 1,0 nor taken to be greater than:
$1.25 + a_1/2h_c$ or 1,5 whichever is the lesser

where:
β is an enhancement factor for concentrated loads;
a_1 is the distance from the end of the wall to the nearer edge of the loaded area;
h_c is the height of the wall to the level of the load;
A_b is the loaded area;
A_{ef} is the effective area of bearing, i.e. $l_{efm}.t$;
l_{efm} is the effective length of the bearing as determined at the mid height of the wall or pier, obtained from a 30^0 spread from the direction of loading, (or the width of the wall if that is less)

t is the thickness of the wall, taking into account the depth of recesses in joints greater than 5 mm.

A_b/A_{ef} is not to be taken greater as 0,45.

e.g. for Test 1(b), β =(1+ 0.3x880/2000)(1.5 – 1.1x15000/279000) = (1.132)(1.5-0.059) = 1.63* or (1+0.3x880 b) = 1.25 + a1/2h_c = 1.47** which is the lesser. See Table 1 where the two right hand columns contain the results of the various calculations to find the maximum enhancement allowed.

EC 6 states the design value of a concentrated vertical load,
N_{Sdc}, applied to a masonry wall, shall be less than or equal to the design value of the vertical concentrated load resistance of the wall, N_{Rdc},

such that $N_{Sdc} \leq N_{Rdc}$.

The concentrated load should bear on solid material of length equal to the required bearing length plus a length on each side of the bearing based on a 60° maximum spread of load to the base of the solid material; for an end bearing the additional length is required on one side only.
For the load to be able to spread at least 60^0 to mid height, the minimum width of wall = 1.155h + bearing width to obtain maximum enhancement for a concentrated load which can spread in both directions and 0.58h + bearing width for an end load (which can only spread in one direction).

Calculations according to EC 6 are summarised in Table 1 for a wall of 2.0m high (h) x 1.86 m long (l_2) x 150 mm thick (t) in thin layer mortar where the test wall height of 1.0 m is taken as representing half the storey height. The concentrated load is applied across the full thickness of the wall through a bearing plate 150 mm x 100 mm. The spread is taken to be 30^0 from the line of action of the load both ways along the length of the wall. BS5628 gives the spread as 45^0 and the enhancement as 1.5 (or 1.25 for concentrated loads at or near the end of the wall) for simple concentrated loads of limited area.

Wall strength calculation to Eurocode 6

The characteristic compressive strength of Aircrete masonry (f_k) in general purpose mortar may be calculated as:

$$f_k = K f_b^{\alpha} f_m^{\beta} \quad (2)$$

where:
f_k is the characteristic compressive strength of the masonry, in N/mm^2
K is a constant
α, β are constants, normally 0.7 and 0.3
f_b is the normalised mean compressive strength of the units, in the direction of the applied action effect, in N/mm^2
f_m is the compressive strength of the mortar, in N/mm^2
K is 0.8
But the characteristic compressive strength of Aircrete masonry in thin bed mortar 0.5 mm to 3 mm thick may be calculated as:

$$f_k = 0.8 f_b^{0.85} \quad (3)$$

Thus for the Aircrete masonry units used in this research f_k = 1.44 N/mm^2 for the 2.0 N/mm^2 compressive strength blocks and 1.92 N/mm^2 for the 2.8 N/mm^2 compressive strength blocks.
In calculating the vertical resistance of masonry walls, it may be assumed that plane sections remain plane and the tensile strength of masonry perpendicular to bed joints is zero.
The calculated vertical resistance of a single leaf wall per unit length:

$$= \Phi t f_k \quad (4)$$

where:
Φ is the capacity reduction factor, Φi, at the top or bottom of the wall, or Φm, in the middle of the wall, as appropriate, allowing for the effects of slenderness and eccentricity of loading,
t is the thickness of the wall
As we are considering the bearing stress at the top of the wall, Φi is appropriate.
At the top or bottom of the wall
$\Phi i = 1 - 2e_e/t$

where:
e_e is equal to the initial eccentricity at the top of the wall
where e_i is the initial eccentricity
e_i, is assumed to be $h_{ef}/450$, where h_{ef} is the effective height of the wall which in the case of the walls in these tests is taken as 0.75h/450
t is the thickness of the wall.

Thus the calculated vertical resistance per unit length is:
$\Phi t f_k = (1 – (2(0.75.2000/450/150))).150.1.44 = 211.2N/mm$

Table 1: Maximum enhancements according to EC 6-Part 1-1

	a_1, mm	h_c, mm	A_b, mm^2	A_{ef}, mm^2	t, mm	Conc load width, mm	β^* (see Note below table)	β^{**}= the lesser of $1{,}25 + \frac{\alpha_1}{2h_c}$ or 1.5
Concentrated load at the centre of the wall i.e. Test 1(b)	880	2000	15,000	279,000	150	100	1.63*	1.47** (less than 1.63 in the previous column, therefore this is the limiting value)
Concentrated load at the end of the wall i.e. Test 1(c)	0	2000	15,000	279,000	150	100	1.44	1.25 (less than 1.44 in the previous column, therefore this is the limiting value)

Note: $\beta^* = \left(1 + 0{,}3\frac{\alpha_1}{h_c}\right)\left(1{,}5 - 1{,}1\frac{A_b}{A_{ef}}\right)$

Table 2: Comparison between maximum enhancements and spreads for concentrated loads according to EC6 and BS5628 for the test wall

	Concentrated load within the length of the wall – Test 1(b)		Concentrated load at the end of the wall – Test 1(c)	
	Maximum Enhancement	Degrees Spread from vertical	Maximum Enhancement	Degrees Spread (one way) from vertical
European Standard EC6	**1.47**	**30**	**1.25**	**30**
British Standard BS 5628	**1.50**	**45**	**1.50**[a]	**45**

a - For concentrated load from beam spanning in the plane of the wall (bearing type 2) but 1.25 for concentrated load at end of the wall from beam spanning perpendicular to the wall (bearing type 1)

TEST PROGRAMME

Three half storey height test walls were built by a skilled craftsman in the laboratory, four courses high and three blocks long for the initial part of a much larger test programme. The internal dimensions of the test frame limited the maximum size of wall to approximately 1.0 m high (taken to be ½ storey height for the purposes of the tests and calculations) x 1.86m long in thin layer mortar.

In the design of masonry walls subjected to concentrated loads there are two limiting criteria. The overstress immediately below the bearing is limited and the stress at the mid height of the wall must not exceed the maximum distributed stress at that level (when taken together with the stress from any other loads. This enabled the maximum spread to be measured in the test wall to be treated as the spread at mid height. The Aircrete blocks used were 620mm long x 250mm high x 150mm thick low density Aircrete with a compressive strength of 2.0 N/mm^2 and a nominal density of 350 kg/m^3. The thin layer mortar (1 to 3mm thick) compressive strength was nominally 10 N/mm^2 at 28 days and was supplied in 22 kg bags.

The walls were carefully lifted into position in the steel testing frame and the base bedded on a single 10mm layer of general purpose mortar (1:6 cement:sand with a plasticizer) laid on the steel joist forming the base of the test frame. Under normal site conditions the base course of a thin joint wall is similarly laid on a single course of general purpose mortar bed. The purpose is to enable the base course to be laid as accurately as possible providing it with a level horizontal top surface. This is essential in practice to enable the second and subsequent courses to be laid accurately. It also reduces the risk of premature failure being caused by high local stresses from any high spots at the base.

Strains were measured using 150mm Demec gauges strategically arranged on the faces of the walls. The distribution of the Demec strain gauges is shown in Figure 2 with the concentrated load positioned centrally as in Tests 1(a) and 1(b).

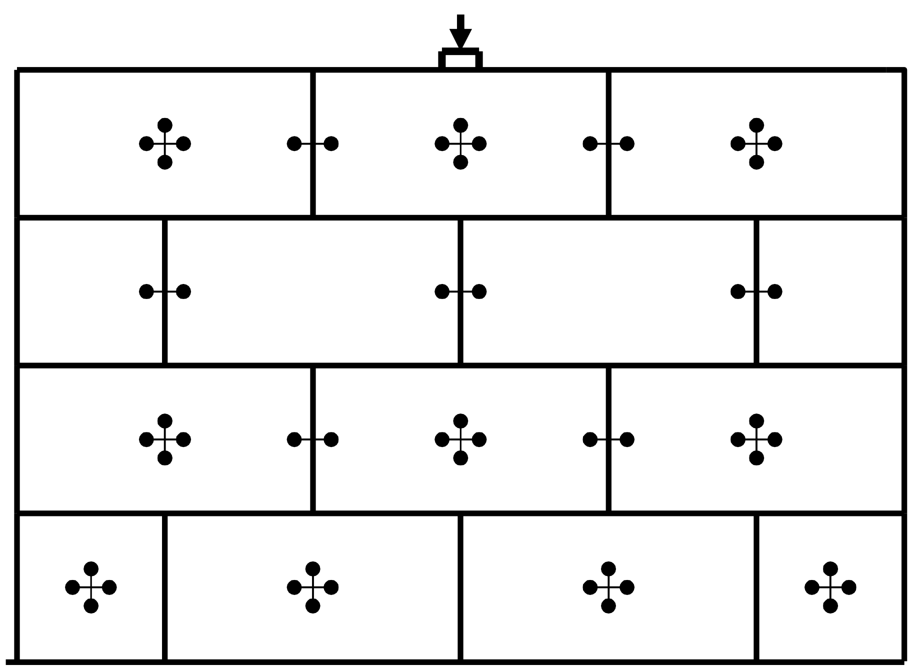

Figure 2: 150 mm Demec Strain Gauge Arrangement

There were three loading conditions:
Test 1(a) Central load through 100mm x 100mm bearing plate
Test 1(b) Central load through 100mm x 150mm bearing plate
Test 1(c) End load through 100mm x 150mm bearing plate

The loading was applied to the walls through bearing plates which were 15 mm thick mild steel at a bearing stress ranging from zero up to approximately 1.2 N/mm^2 in steps of 0.1 N/mm^2. In all three cases, when looking at the face of the wall, the dimension of the steel bearing plate was 100 mm.

RESULTS

Table 3: Test 1(a) - 100mm x 100mm central concentrated load measured vertical strains

Vertical Location (Proportion of height down)	Horizontal Location (Proportion of wall length from left)						
	0.083	0.167	0.333	0.500	0.667	0.833	0.917
0.125		**-9.1**		**-637.1**		**-8.1**	
0.375							
0.625		**-119.1**		**-200.3**		**-65.0**	
0.875	**-48.1**		**-29.9**		**-46.0**		**-17.2**
Vertical Strains (με) at 1.22 N/mm^2 compressive stress under central concentrated load							
Compressive vertical strains shown bold							

Table 4: Test 1(b) - 100mm x 150mm central concentrated load vertical strains

Vertical Location (Proportion of height down)	Horizontal Location (Proportion of wall length from left)						
	0.083	0.167	0.333	0.500	0.667	0.833	0.917
0.125		5.7		**-302.7**		1.0	
0.375							
0.625		**-54.6**		**-86.1**		**-133.9**	
0.875	**-23.9**		**-18.3**		**-20.8**		**-131.4**
Vertical Strains at 1.18 N/mm^2 compressive stress under central concentrated load							
Compressive vertical strains shown bold							

The vertical compressive stress (applied by the central concentrated load) / strain (as measured by the demec strain gauges) relationship remained remarkably linear over the range in each of the tests. Because the bearing plate through which the concentrated load was applied was 50% larger in area in Test 1(b) than in Test 1(a), the applied load was also larger to obtain a similar bearing stress.
The load in Test 1(b) was applied over the full 150mm thickness of the wall. Therefore it could only spread in one direction along the length of the wall. On the other hand, the load in

Test 1(a) was only applied across the centre 100 mm of the thickness. It could therefore spread in both directions i.e. along the length of the wall and across the width of the wall. Based on a 45^0 spread, at 25mm below the top surface the load in Test 1(a) is spread over 22,500 mm^2 and the load in Test 1(b) is also spread over 22,500 mm^2. The stress in Test 1(b) at 25mm below would be 18000/(150 x 150) N/mm^2 compared with Test 1(a) which is 12000/(150 x 150) N/mm^2 i.e. the stress in the wall from the concentrated load in Test 1(b) increases from approximately equal directly under the bearing to 50% higher 25 mm below. However, the vertical compressive strains in Test 1(b) were seen to be up to double those in Test 1(a). The Demec strain measurements confirmed the proposition that the load in Test 1(a) spread in both directions.

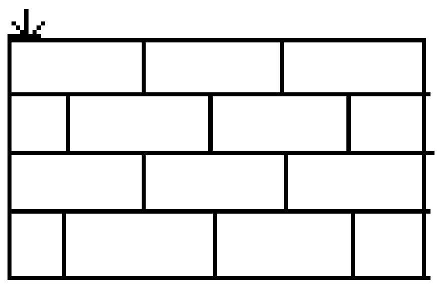

Figure 3 Concentrated load position Test 1(c)

Table 5: Test 1(c) - 100 x 150 mm end concentrated load vertical strains

Vertical Location (Fraction of height down)	Horizontal Location (Fraction of wall length from left)						
	0.083	0.167	0.333	0.500	0.667	0.833	0.917
0.125		**-27.1**		6.7		6.3	
0.375							
0.625		**-73.4**		43.2		6.7	
0.875	38.7		1.8		**-5.6**		37.2
Vertical Strains (με) at 1.22 N/mm^2 compressive stress under end concentrated load *Compressive vertical strains shown bold*							

Test 1(c), shown diagrammatically in Figure 3, was not very satisfactory. As the wall was loaded at one end only, there was a tendency for the wall to rotate downwards at the loaded end. This prevented the concentrated load from fully spreading across the wall length and the strains in the bottom course make no sense because of the rotation along the length of the wall. The position of the nearest vertical strain Demec gauge was 250mm away horizontally from the vertical centre line of the concentrated load at mid height of the top course. The vertical compressive strain gauge readings were so low that they could not be taken as a very useful indication of the spread of strain from under the load. In later work in the test programme, the subject of a further paper, improved testing techniques were used to overcome the problem of tilting.

CONCLUSIONS AND DISCUSSION

The work reported in this paper allows the conclusion that vertical concentrated loads on low density Aircrete masonry (in thin joint mortar) spread at an angle of 45^0 or greater to the vertical although the assumption in EC6 is that spread is only 30^0.

A further paper will report on later work in the programme, including testing walls and wallettes to destruction, which enables limiting levels of local overstress to be proposed.

REFERENCES

British Standard BS 5628 Code of Practice for the Use of Masonry – Part 1 – Structural Use of Unreinforced Masonry, BritishStandards, 2005, 72 pp

European Standard EN 1996-1-1 Eurocode 6. Design of masonry structures. Part 1-1. General rules for reinforced and unreinforced masonry structures, European Committee for Standardization, 2005, 123 pp

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