TECHNICAL REPORT AND DESIGN GUIDANCE FOR THE USE OF H+H AIRCREE T VERTICAL ELEMENTS IN THE UK

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Materials Development • Testing • Assurance
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Lucideon is an internationally renowned centre for consultancy and testing in the materials world. Lucideon’s involvement in masonry materials dates back to its formation in the 1920’s. Initially from a manufacturing perspective and since the 1960’s it has been central to the generation and interpretation of data to support the development of British Standards and Codes of Practice and more recently their European counterparts. Through large testing programmes at their extensive laboratories in Stoke-on-Trent, information has been produced covering large areas of design eg lateral loading of masonry walls, reinforced and pre-stressed masonry, durability, compressive strength of walls and shear strength. In many cases, the sequence has been the development of test data, all of which has been published, and the development of design approaches which have been published as authoritative guides for practicing designers. These have then formed the basis for Code of Practice guidance.
Lucideon occupies a central role at the British Standards Institution (BSI) and the European Committee of Standardisation (CEN), providing Chairmen, leaders of delegations and conveners and is well placed to help in the development of guidance for storey height elements. Lucideon also provides project specific information for schemes, which because of their unique nature need bespoke assistance. Good examples are Glyndebourne Opera House, Portcullis House, Kelvingrove Museum and Art Gallery and La Poste, Marseilles.

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Key Properties
The guidance given in this Report is intended for use with Eurocode 6 (BS EN 1996-1-1). The Table below summarises the key properties of H+H storey height elements to be used with the provisions of EC6.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
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<tr>
<td>Dimensions</td>
<td>$t = 100\text{mm}$</td>
</tr>
<tr>
<td>Equivalent normalised block strength, $f_b$</td>
<td>$4 \text{ N/mm}^2$</td>
</tr>
<tr>
<td>Equivalent characteristic compressive strength of the masonry, $f_k$</td>
<td>$2.9 \text{ N/mm}^2$</td>
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<td>Characteristic flexural strength spanning vertically, $f_{x_1}$</td>
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Introduction
H+H aircrete vertical elements are supplied by H+H UK Limited and are intended for the construction of domestic houses of up to 3 storeys (although typically this would be 2 storeys or 2 storeys plus a room in the roof). In addition, they can be used for internal partitions. The essence of the system is to replace the blockwork to the inner leaf of external cavity walls, separating walls and internal partition walls with aircrete vertical elements. The aircrete vertical elements are manufactured from the same materials as sand based aircrete blocks.

The elements have a height equal to the storey height of the house and have a width of 600mm and a thickness of 100mm. The vertical joints are filled with a fast setting thin layer mortar which has been specially developed for use with elements. Since the material can be easily cut, the infill sections required between windows and openings and for lengths of wall that are not based on a 600mm module, cutting is carried out on site, with the length of cut elements being used generally limited to 150mm. The elements are lightly reinforced with 3 steel bars to facilitate handling and transportation without damaging the products.

Typically, timber floors are used in conjunction with the system and to maintain speed of build, cassette floors are generally included. Roofs are either standard truss construction with timber spandrel panels or cassette roof systems can be used. All components of the construction are lifted into position by crane or individual elements can be positioned using specialist equipment.

Where structural design shows that the elements are not suitable, or where it is more appropriate to choose otherwise, such as infilling around joist ends or at joist level, sections of the build can be of thin joint block masonry to replace the elements.

Aircrete vertical elements have a long history of use in mainland Europe (particularly in Scandinavia and the Benelux countries) and comply with the European Standard BS EN 12602. However, as vertical elements have not been used extensively in the UK and they are not covered by UK Codes of Practice, the aim of this Technical Report and Guide is to provide guidance so that H+H vertical elements may be designed in the UK with confidence that they meet regulatory requirements.

H+H vertical elements are used as a replacement for blockwork masonry and in conjunction with traditional masonry used as the external leaf of cavity walling. They are also used as internal partition walls. The European Standard for Autoclaved Aerated Concrete masonry units, BS EN 771-4, does not cover vertical elements and they comply with BS EN 12602. A recent review concluded that the basic structural properties of aircrete vertical elements exceeded those of Autoclaved Aerated Concrete blockwork masonry that meets the requirements of Approved Document A to the Building Regulations. Also that design of walls based upon BS EN 1996-1-1 can be applied to walls made using aircrete vertical elements.

Clearly as the elements are used as a replacement for some of the masonry in masonry houses the adoption of masonry Code provisions for the design is welcome. The purpose of this guide is to show how this might be achieved. Previous guidance has regarded elements as being able to resist vertical concentrated loads independently of the adjacent elements. Recent research has shown that walls constructed from elements behave compositely with the development of a series of strain contours in a
bulb shape beneath a concentrated load. The contours cross element boundaries and this behaviour extends to the point where failure occurs by local crushing at which point the vertical element joint fails in shear. Consequently, load sharing as allowed for in Eurocode 6 has been included. Similarly, lateral load testing has shown that lateral load is shared across vertical joints and that a panel consisting of multiple elements will behave very much like one which has been built using traditional blockwork masonry.

Section 1 - General

1.1 Scope
This Technical Report and Guide covers the use of H+H aircrète vertical elements for use as the inner skin of external cavity walls, for cavity separating walls and for internal partitions.

1.2 References
Roberts, J.J; The Design of 100mm Thick H+H ACC Storey Height Elements for the Inner Leaf of Cavity Walls and Partitions. Technical Innovation Consultancy Report for H+H UK Limited, February 2016

De Zuani; Determination of the Strain Distribution using Digital Image Correlation of Two Walls when Load is Applied at Various Points. Lucideon Report 162486 for H+H UK Limited, August 2016

Zar, K; Comparative Tests on Walls Constructed from Storey Height Celcon Elements and Celcon Concrete Blockwork. Lucideon Report 171638 for H+H UK Limited, September 2017

Zar, K; Design Resistance of Storey Height Panel with Side Loads from Windows. Lucideon Report 171819 for H+H UK Limited, September 2017

Kingston University; Experimental Testing of Walls made with Aerated Concrete Panels. Report for H+H UK Limited, August 2016

BS EN 12602 Prefabricated reinforced components of autoclaved aerated concrete
BS EN 678 Determination of the dry density of autoclaved aerated concrete
BS EN 679 Determination of the compressive strength of autoclaved aerated concrete
BS EN 680 Determination of the drying shrinkage of autoclaved aerated concrete
BS EN 771-4 Specification of masonry units:
Part 4: Autoclaved Aerated Concrete masonry units
BS EN 772-1 Methods of test for masonry units:
Part 1: Determination of compressive strength
BS EN 845-1 Specification for ancillary components for masonry Part 1: Wall ties, tension straps, hangers and brackets
BS EN 845-2 Specification for ancillary components for masonry Part 2: Lintels
BS EN 998-2 Specification for mortar for masonry:
Part 2: Masonry mortar
BS EN 1996-1-1 Eurocode 6 - Design of masonry structures:
BS EN 1996-1-2 Eurocode 6 - Design of masonry structures:
1.3 Definitions

**Notation**

- \( f_k \): characteristic compressive strength of masonry (N/mm\(^2\))
- \( f_{kk}, f_{kk1}, f_{kk2} \): characteristic flexural strength of masonry (N/mm\(^2\))
- \( f_v, f_{vk} \): characteristic shear strength of masonry (N/mm\(^2\))
- \( f_{vko} \): characteristic initial shear strength of masonry (N/mm\(^2\))
- \( U \): heat flow per unit area per degree temperature difference (W/m\(^2\)°K)
- \( \gamma_m \): partial safety factor for material
- \( \gamma_{mv} \): partial safety factor for the shear strength of material
- \( \gamma_f \): partial safety factor for loads
Section 2 - Materials

2.1 General
The materials and components used in walls constructed using H+H aircrete vertical elements should all meet the requirements of the relevant European and British Standards.

2.2 H+H Aircrete Vertical Elements
H+H aircrete vertical elements meet the requirements of BS EN 12602.

2.3 Element Mortar
H+H Element mortar (Dünnbettmörtel) is a premixed dry mortar and is declared as an M10 according to BS EN 998-2.

2.4 Damp Proof Courses
In most locations dpc's are embedded in mortar below the first element as required by the design for example at the base of a wall. Where there is a need for damp course membranes to form cavity trays above lintels, these are face fixed to the inner leaf within the cavity.

2.5 Wall Ties
The wall ties to be used with aircrete elements comply with the requirements of BS EN 845-1. The ties are those used in conjunction with thin layer aircrete masonry construction and are classified as Type 4 (for party walls) or Type 3 or 2 (for external walls) to PD 6697.

2.6 Tension Straps
Tension Straps shall comply with the requirements of BS EN 845-1.

2.7 Lintels
Lintels should comply with the requirements of BS EN 845-2.

Section 3 - Specification for Performance

Design Method and Values

3.1 General Structural Design
The structural design of aircrete vertical elements follows the general principles of masonry design. The recommendations in this Guide are based upon BS EN 1996-1-1.

3.2 Characteristic Compressive Strength of Aircrete Vertical Elements, \( f_{ck} \)
The characteristic compressive strengths for use in design are given in Clause 3.6 of BS EN 1996-1-1.

The characteristic compressive strength to be used in the design of walls made from aircrete vertical elements is 2.9 N/mm\(^2\) (see Annex A).

3.3 Modulus of Elasticity of Aircrete Vertical Elements
The modulus of elasticity to be used in calculating structural eccentricities using Annex G of BS EN 1996-1-1 is 2125 N/mm\(^2\), which is 727 \( f_{ck} \) (see Annex B).

3.4 Characteristic Flexural Strength of Aircrete Vertical Elements, \( f_{xk} \)
The flexural strengths for use in design are given in Clause 3.6.3 of BS EN 1996-1-1. The values which have been derived by testing indicate a significant increase in flexural strengths in both the vertical and horizontal direction compared to aircrete masonry. Until greater experience has been developed the characteristic flexural strength, \( f_{xk1} \), should be taken as 1.35 N/mm\(^2\) for vertically spanning elements.

Guidance on design for lateral load resistance is given in Section 5.3 of this document.
### 3.5 Characteristic Shear Strength of Aircrete Vertical Elements, $f_{vk}$

Table NA 5 of the UK National Annex indicates that for AAC masonry units laid with thin layer mortar the initial shear strength may be taken as 0.3 N/mm$^2$.

### Section 4 - Procedure, Loads, Factors of Safety etc

#### 4.1 Partial Safety Factors for Material Strength, $\gamma_m \gamma_{mv}$

**4.1.1 General**

The principle followed in BS EN 1996-1-1 is that the value of $\gamma_m$ to be used in design is related to the material selection and control over the execution on site.

#### 4.2 Quality Control

**4.2.1 Materials**

Aircrete elements meet the requirements of BS EN 12602. Under this Standard the system of assessment and verification of constancy of performance is $2^+$. This requires continuous surveillance, assessment and evaluation of factory production control by a notified production control certification body. This ensures that the degree of confidence in the declared material strength is consistent with that required in declaring Category 1 masonry units. The mortar is a factory made mortar and complies with BS EN 998-2.

**4.2.2 Execution Control**

Class 1 of execution control may be assumed if:

- The work is carried out following the recommendations in BS EN 1996-2, including appropriate supervision and inspection.

- The specification, supervision and control are compatible with the use of the partial factors in BS EN 1996-1-1.

Class 2 of execution control may be assumed if:

- The work is carried out following the recommendations of BS EN 1996-2 including appropriate supervision.

**4.2.3 Value of $\gamma_m$ and $\gamma_{mv}$ for Normal and Accidental Loads**

The value of $\gamma_m$ to be used in design are given in Table 4.1. These are based upon BS EN 1996-1-1 together with the considerations in 4.2.2.

<table>
<thead>
<tr>
<th>Category of Execution Control</th>
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<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression + Flexure</td>
<td>2.3</td>
<td>2.7</td>
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</table>

The value for the partial factor in shear should be 2.5.

The value for the partial factor to be applied to the strength of wall ties conforming to BS EN 845-1 should be 3.0.

For horizontal restraint straps unless otherwise specified the declared load capacity depends on there being a design compressive stress in the element of 0.4 N/mm$^2$. If a lower stress is acting, the manufacturer’s advice should be sought. A partial factor of 3.0 should be used.
When considering the effects of accident or misuse, the partial safety factor values would normally be taken as 1.0.

Section 5 - Design of Walls Subjected to Mainly Vertical and Wind Loads

5.1 General
The design of walls to resist vertical loads follows the principles and rules in Clause 6.1 of BS EN 1996-1-1 using the effective height and thickness derived from Clause 5.5. Where a wall is loaded uniformly along the length of the wall the design may be based upon the wall as a whole or as individual units.

Clause 6.1.2.1 of BS EN 1996-1-1 requires that where the cross-sectional area of a masonry wall is less than 0.1 m² the design compressive strength of the wall should be reduced by application of a small area reduction factor. This factor does not need to be applied to storey height aircrete panels.

5.2 Concentrated and Non-Uniformly Distributed Loads
The design to resist concentrated loads should follow Clause 6.1.3 of BS EN 1996-1-1. The stress caused by a concentrated load spreads out to form a bulb of pressure. This is idealised in the Code by a spreading at 60° to the vertical from the edges of the load and this point defines the loaded area at the mid height of the wall. Where this distribution includes a vertical joint between elements a check to ensure that the part of the load that is being transferred across the joint can be resisted by the shear resistance of the joint is required.

The vertical area taken to resist the shear force should not exceed in height the vertical distance from the load to the level at which the load distribution is assumed to cease ie $h_c/2$. Where a non-uniform distributed load is applied to the top of a wall the load spreading and shear checks at any vertical joints should follow the same principle as for concentrated loads which is shown in Figure 1.

![Figure 1](image-url)
The load to be transferred across the joint is that which acts at a depth of \( h_c/2 \) along the length \( l_s \). If \( P \) is the total load on the plate, and it can spread fully in both directions, the load, \( P_s \), acting on the length \( l_s \) is given by:

\[
P_s = \frac{hc - 2\sqrt{3} \, lj}{2\sqrt{3} \, l_b + 2hc} \cdot P
\]

Where:  
- \( h_c \) is the height of the wall to the level of the load.  
- \( l_b \) is the width of the concentrated load.  
- \( lj \) is the distance of the edge of the concentrated load to the joint.

Alternatively, and where full load spread in both directions is not possible, \( P_s \) may be determined by considering simple ratios of \((P_s / l_{efm})\) and \((P_s / l_s)\) such that

\[
P_s = \left( \frac{l_s}{l_{efm}} \right) \cdot P
\]

The area taken to resist the shear force at the joint is \( h_c/2 \) times the wall thickness. Clearly the pressure bulb does generate some force normal to the joint and hence there will be some 'frictional' component to the shear resistance. In practice this is relatively small due to the combination of the upper limit to the inclination of the force to the vertical of 30° and also the relatively low angle of internal friction. Consequently, for design purposes, the characteristic shear strength acting vertically at the joint \( f_v \) is taken to be \( f_{vk0} \).

The load spreading behaviour is described in Annex C.

### 5.3 Lateral load resistance

The design of walls to resist lateral loads follows the principles and rules in Clauses 5.5.5, 6.3 and 6.4 of BS EN 1996-1-1, with elements designed as vertically spanning. In the case of panels subject to additional lateral loading from adjacent openings, the benefit of limited load share into adjoining elements may be taken into consideration. Further guidance on the design of elements, including potential areas for load share, are given in Annex E.

Where elements cannot be justified in this way, the whole wall panel may be designed as consisting of 3.6N/mm² aircrete blocks in a traditional M4 mortar using relevant \( f_{xk1} \) and \( f_{xk2} \) values together with appropriate bending moment coefficients based on actual panel dimensions and restraint conditions. Recent testing has shown that walls consisting of multiple elements will perform at least as good under lateral loading as a similar wall built using 3.6N/mm² aircrete blocks in traditional M4 mortar (see Annex D).

### 5.4 Racking Resistance

There is relatively little data on the racking strength of walls made from aircrete vertical elements and the effect of vertical load on the racking strength is not conclusive. It is therefore proposed that as an interim measure the racking strength of such walls be determined using the characteristic initial shear stress, \( f_{vk0} \) only ie without a contribution from precompression.

### Section 6 - Other Design Considerations

#### 6.1 Sound Insulation

Part E of the Building Regulations requires that separating (party) walls and internal walls provide reasonable resistance to the transmission of sound between and within residential accommodation.

Site test experience has demonstrated that cavity separating walls of elements with a fully filled cavity, with aircrete element flanking walls can easily achieve the required levels of the Building Regulations Part E. This form of construction is now covered by Robust Detail E-WM-31 enabling compliance with the regulations without the need for further site testing, provided the dwellings are registered with Robust Details Limited.
Wall ties meeting the requirements for Type A (as defined Approved Document E) are generally provided at a density of 2.1 ties per m² and fixed as work proceeds. However, they may be omitted if structural calculations show that untied walls leaves are sufficient to resist lateral or compressive actions. Where wall ties are used they should be Type A (see manufacturer’s guidance).

6.2 Partition Walls
The H+H aircrete vertical elements can be used as internal partition walls. Their fire resistance and reaction to fire can be determined from tables given in BS EN 12602. However, their performance is as good as aircrete masonry used in the same situation. Where the walls are designed as loadbearing, the general principles for structural design given in this Guide apply. The head and ends of each panel constructed of vertical elements should be restrained as though it were designed as masonry. Guidance is given either in National Regulations and Standards or using the guidance given in BS EN 1996-3 in the case of non-loadbearing walls.

6.3 Movement
The Declaration of Performance for the elements shows that the movement characteristics of the elements are low with a value of 0.2 mm/m or less. (The test method BS EN 680 is based on measuring the change in length of material from a high moisture content of 30% to a value of 6% moisture content.) This low value can be attributed to the sand used in the production of the AAC and is lower than usually found for AAC products made in the UK. As the shrinkage of the H+H elements is low, experience to date shows that movement joints will not be required for most housing situations.

6.4 Air Leakage
Site testing has indicated that the aircrete elements can perform well with regards to airtightness and values of 3 m³/(hm²) have been achieved where the design has warranted such values (as opposed to the Regulatory limit of 10 m³/(hm²)).

6.5 Wall Ties
Wall ties should be specified as for traditional blockwork and in accordance with the tie manufacturer’s guidelines based on the diameter and exposure conditions. Wall ties should be evenly distributed and preferably staggered. The normal spacing of 2.5 ties/m² (900mm x 450mm) will generally be adequate in the UK, however, the density may need to be increased depending on exposure conditions and performance required. Additional wall ties will be needed at unbonded edges such as openings at a maximum spacing of 300mm, not more than 225mm from the opening.

Section 7 - Work on Site

7.1 General
The general requirements given in BS 8000-3 and PD 6697 apply to walling made with storey height aircrete elements as the inner leaf. Particular requirements for the H+H storey height concrete elements are given below and additional specific guidance on installation is available from H+H.

7.2 Preparation of Mortar
The mortar for use in bedding and filling the vertical joints between elements is supplied by H+H. Mixing instructions and working time are given on the packaging.

A plasterer’s whisk and suitable bucket are sufficient for mixing.

7.3 Installation of Elements
It is very important that storey height elements are placed on a level base. If the slab or foundation is more than ± 5mm from the datum level then a levelling course of general purpose mortar should be used. No point should be more than 10mm from the datum level. Where a dpc is required beneath the elements this should be placed between two layers of element mortar.
It is good practice to place a timber guide rail 20mm above the floor so that mortar can exude from either side of the element ensuring a full joint and it is a guide for installers.

All joints should be free of dust or other material that would affect the bond. The joints may be cleaned with a stiff brush then dampened if needed. The mortar should be applied with a suitable scoop to form a 3mm ± 2mm wide joint and excess mortar should be removed immediately. The element should be agitated vertically using a suitable lever to ensure the joint is fully filled.

Building will normally start at a corner where two mortared units are placed to form a corner. Corrugated nails are used as a temporary connection. One is placed vertically in the top of the wall and three up the height at 45°. The walls are propped temporarily. A permanent mechanical connection between the elements at the corners is formed by 220mm x 8mm Ø helical ties placed at a maximum of 300mm vertical centres. The remaining walls are built using the corner as a guide for locating the elements. Corrugated nails are used as detailed above across all subsequent joints to help stabilise the walls during the initial mortar set.

Internal partition walls are butt jointed against the inner leaf using mortar and tied using 220mm x 8mm Ø helical ties driven from the outside, through the inner leaf, at 300mm vertical centres. Where a tied connection is required between the elements and a section of traditional masonry, the elements should be built first and ties driven in at a maximum of 300mm vertical centres (and to suit the traditional mortar beds) allowing for a minimum embedment of 70mm into the aircrete element and 50mm into traditional mortar. Tied junctions between the elements and thin jointed blockwork are similarly formed except that the ties are driven at 45° downward angle through the bed of the thin jointed blocks and into the adjoining element as block laying proceeds.

7.4 Wall Ties
Wall ties are generally the helical type which are driven into the aircrete element using a support driver to prevent bending of the tie during insertion and to control the depth of penetration. The ties are usually placed as the external leaf is constructed.

7.5 Storage
Vertical elements should always be covered once the original packaging has been opened to avoid unwanted moisture uptake. Similarly element mortar and accessories should all be kept dry.

7.6 Winter Working
Vertical elements may be installed during the winter period but all surfaces must be free of ice prior to bonding. Do not use salt or thawing agents. Element mortar should only be used at air temperatures greater than 0°C.

7.7 Summer Working
At temperatures above 25°C whilst work can readily proceed the ‘bucket life’ of element mortar may be reduced and it should not be used if it has started to set.

7.8 Chasing
Chases should be limited to the general requirements for masonry:
- Vertical chases should not be deeper than 1/3 of the element thickness.
- Horizontal chases should not be deeper than 1/6 of the element thickness.

Section 8 - Design of Aircrete Element walls using ‘Simple Rules’

For low rise housing of up to 3 storeys the following documents are normally used to design masonry walls:
- BS 8103-2 Structural design of low-rise buildings. Part 2: Code of practice for masonry walls for housing
- The Building Regulations Approved Document A (Structure)
- The Scottish Building Regulations. Technical Handbooks. Section 1 Structure
Although these documents do not specifically cover aircrete vertical panels, evidence has shown the equivalence in performance of aircrete vertical panels to 3.6N/mm² aircrete blockwork in traditional M4 mortar. It can therefore be assumed that, provided the general requirements are met and the overall stability is achieved using lateral restraint straps etc, the elements can be used in the same locations. This will generally be two storey dwellings or the upper two storeys of 3 storey dwellings. However, it should be noted that although these documents may be used as a guide to suitability, Building Control authorities and/or Warranty providers may still require additional calculations from a qualified engineer for lateral and/or vertical loading conditions.

There may also be some situations where the resistance to concentrated loads may have to be calculated, such as under beams, directly supporting floors, or roofs.
ANNEX A

Characteristic Compressive Strength
The characteristic strength of autoclaved aerated concrete used in vertical elements is required to be declared in accordance with BS EN 12602. This value is 4 N/mm² and is measured on 100mm cubes in accordance with BS EN 679 (which is similar to BS EN 772-1). For the purpose of this guide the value is considered as an equivalent masonry unit strength to BS EN 771-4. BS EN 771-4 allows for compressive strength to be determined on cubes cut from units, for example in the case of large units, and the values derived are taken as the strength of the unit. The cutting scheme used in BS EN 12602 is identical to that in BS EN 771-4. The normalised compressive strength is 4 N/mm² as there is no correction for moisture content or unit shape. The characteristic compressive strength of equivalent masonry is derived using equation (3.3) of BS EN 1996-1-1 and is 2.9 N/mm². It is assumed that vertical elements, which include no horizontal joints, will perform at least as well as aircrete masonry made with thin layer mortar.

ANNEX B

Modulus of Elasticity
In the absence of testing the short term modulus of elasticity may be taken as $K_E f_k$ where $K_E$ is taken from the National Annex to BS EN 1996-1-1. The UK has recommended the use of 1000$f_k$. However, for vertical elements a more appropriate value is available from BS EN 12602. In this case, in the absence of test results, the modulus may be taken as:

$$E_{cm} = 5 (P_m - 150)$$

where $E_{cm}$ is the mean value of the modulus of elasticity in MPa and $P_m$ is the mean value of the dry density of the AAC in Kg/m³.

For H+H aircrete vertical elements the declared dry density measured according to BS EN 678 is 575 Kg/m³ and from B1 above the modulus of elasticity is 2125 N/mm² which is equivalent to 727 $f_k$.

ANNEX C

Testing to Examine Load Share Across Vertical Joints Beneath Concentrated Vertical Loads
In order to assess the degree of load spreading beneath concentrated loads two panels were built from aircrete vertical elements. The format of the panels is shown in Figure C1.

![Figure C1](image)
The two panels differed in that the jointing procedures were different but that did not become significant in relation to the results. The first panel was constructed using an old form of mortar applicator and the installation method was not properly carried out so that it could represent relatively poor workmanship on site. The second panel was constructed using the recommended applicator and with the approved method of installation. Three tests were carried out on each panel, one using a 100 mm x 100 mm load at point A, one at point B and subsequently to failure at point C.

The key factor in the investigation was the use of Digital Image Correlation, a technique which enables the presentation pictorially of the strain in the specimen under load. In this case the presentation of interest is of the maximum and minimum principle strains which are tensile and compressive respectively. A key finding is that at loads below these to cause failure (at load position C) the load distributes itself in a bulb shape as shown in Figure C2. This is the distribution of maximum principle compression strain at around 75% of ultimate failure load.

![Figure C2](image)

Beneath the loading plate is the maximum (purple) zone gradually reducing through the spectrum of colours until zero in the orange zone. This pattern of distribution continued until the point of failure. At that point shear failure of the vertical joints occurred. The principle tensile strains are shown in Figure C3.

![Figure C3](image)
The location of the cracks is very clear. The principal compressive strains are shown in Figure C4.

In this Figure the concentration of compressive strain is confined to the 150 mm made up unit beneath the loading plate. The directions of the principal strains are at 45° to the horizontal which indicates the shear strain is at a maximum in the vertical direction and the shear stress has caused the joint to fail.

In the tests where the loads were at positions A and B the tests did not go to failure and the ‘bulb’ of pressure was maintained until the maximum load.

A number of tests to destruction of walls made from vertical panels were carried out at Kingston University. Much of the work was related to test method development and some of the results were associated with local shear or rotational effects at the load position. However, where cracking of the joints occurred, it precipitated failure and the associated changes in strain, although measured at discrete locations, were consistent with the behaviour described above.

The consequence of this behaviour is that the distribution of stress beneath a concentrated load is a pressure bulb and this remains the case until either the wall fails in compression or a premature shear failure of the joint causes the behaviour of the wall to change from an assembly to that of the component panels in which case the loaded panel fails. Consequently, the principle in BS EN 1996-1-1 for designing to resist concentrated loads will be applicable to walls made from aircrète vertical elements provided there is a shear check on the joints and one or other situation will control the design.

ANNEX D

Testing to examine load share across vertical joints under lateral load

Two testing programmes were undertaken in order to assess the load share across vertical joints. As reported in Lucideon Test Report 171638, comparison tests between two identical (other than one was built of storey height aircrète elements and the other 3.6N/mm² aircrète blocks in a traditional M4 mortar) wall panels showed that the wall built of vertical elements performed better than the aircrète blockwork wall with an ultimate failure load some 21% higher. More importantly the failure mode for both was consistent with that predicted for masonry using yield line analysis, showing that the vertical elements behaved as would traditional bonded masonry. In each case maximum deflection (and first cracks) occurred in the central panel with horizontal cracks forming between the openings and diagonal cracks from the outer openings towards the supports (see Figure D1).
The pattern of cracks clearly showed that sufficient lateral load share had occurred across the vertical joints of the vertical elements prior to ultimate failure. The panels in these tests were subjected to increasing lateral load, applied via air bags, whilst sustaining an eccentric vertical line load designed to act in conjunction with the lateral load for bending. In practice this would represent a worst-case scenario as wind load may be acting against the bending caused by any floor loads.

Lucideon Test Report 171638 reports on additional testing carried out to examine load share across vertical joints. These tests consisted of a series of single and multiple element panels ranging from 440mm to 2 x 600mm wide. In each case lateral load was applied via air bags with a line load applied to one or both edges of the panels to simulate the effects of load transferred from an opening. The mode of failure in each case was a horizontal crack at mid height with the vertical joint, where present, having no influence on the mode of failure. This showed that adequate lateral load distribution across the joint had been achieved, even where the window load was applied to one edge only.
**ANNEX E**

**Guidance on the design of elements considering load share under lateral loading**

<table>
<thead>
<tr>
<th>Elements adjacent an opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  If P1 &lt; 600mm, then, for design purposes, assume a single width of panel adjacent window equal to the sum of P1 + P2, but not greater than 600mm.</td>
</tr>
<tr>
<td>2  If P1 = 600mm, then the design lateral load on P1 may be reduced by 10% to account for load share into element P2. In this case, the load on P2 will have increased by an amount equal to the reduction made to P1, but further checks will not be required if P1 is satisfactory.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two elements between openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>3  If P1 and P2 &lt; 600mm, then, for design purposes, assume a single width of panel between the windows equal to the sum of P1 + P2, but not greater than 600mm.</td>
</tr>
<tr>
<td>4  Where the difference between W1 and W2 is less than 10% of the largest opening width, assume width of panel between the windows to be equal to the sum of P1 + P2.</td>
</tr>
<tr>
<td>5  Where the difference between W1 and W2 is greater than 10% of the largest opening width, each element should be considered separately. Where one of the elements is 600mm wide and the other is less than 600mm, then the design lateral load on the larger element may be reduced by 10% to allow for load share into the adjacent element. In this case, the load on the other element will have increased by an amount equal to the reduction made to the 600mm wide element.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Three elements between openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>6  The design lateral load on P1 and P3 may be reduced by 10% respectively to account for load share into element P2. In this case, the load on P2 will have increased by an amount equal to the reduction made to P1 and P3, but further checks will not be required if P1 and P3 are satisfactory and the length of P2 is not greater than the length of P1 or of P3.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Whole panel design</th>
</tr>
</thead>
<tbody>
<tr>
<td>7  H+H Celcon elements may be used to form a panel where design calculations show that the whole panel may be built assuming the use of 3.6N/mm² aircrete blocks in a traditional M4 mortar.</td>
</tr>
</tbody>
</table>

Note: The above guidance is based on wall panels subject to a constant uniformly distributed lateral load and does not consider the influence of potential local actions or zone effects. Where local actions or zone effects are being considered then individual elements falling within different wind action zones should be checked independently.