Strength tests of shell bedded autoclaved aerated concrete

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Lund University, 2006

Report TVBK -5142

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Hållfasthetstester av stötfogsfri strängmurad lättbetong

Marcus Björk and Daniel Johanson

2006

Abstract

In this master thesis, the properties of shell bedded autoclaved aerated concrete (AAC) are investigated. There are reasons to believe that the values for flexural, compressive and shear strength in the Swedish regulations are on the low side.

The work within this master thesis consists of determining the characteristic values based on experimental tests. The test results indicate that the values in the Swedish code BKR 2003, at least for the flexural strength might be on the low side. Regarding shear and compressive strength, which had values close to Swedish regulations, further tests are necessary to draw any conclusions.

Keywords: Cross joint, bed joint, autoclaved aerated concrete, AAC, flexural strength, compressive strength, shear strength, BKR, experimental tests, characteristic values

Rapport TVBK 5142
ISSN 0349-4969
ISRN: LUTVDG/TVBK-06/5142+92p

Master Thesis
Supervisor: Tord Isaksson
May 2006

Acknowledgements

This master thesis was carried out during the spring of 2006 at the division of Structural Engineering at Lund University, Sweden.

We would first like to express our sincere gratitude to our supervisor Dr. Tord Isaksson for guidance and support. We are also grateful to Mr. Per-Olof Rosenkvist for indispensable assistance during the experimental testing, Mr. Rolf Ekefjärd at H+H Celcon for important views, Mr. Klaus Hansen at LIP in Denmark for useful help during the shear tests and also the rest of the staff at the division of Structural Engineering for helping us out during the work of this thesis.

Lund, May 2006

Marcus Björk Daniel Johanson

Sammanfattning

H+H Celcon är norra Europas största producent av lättbetong. Examensarbetet omfattar en experimentell undersökning av hållfasthetsvärden för fullskaliga provkroppar av lättbetong som är utförda med stötfogsfri strängmurning. Man tror sig kunna göra ekonomiska vinster samt spara tid med denna metod. Information saknas gällande denna murningsteknik. Tryck-, skjuv- samt böjdraghållfastheten i två riktningar skall testas och jämföras med befintliga värden i BKR som tros vara för låga.

För varje test tillverkas sex provkroppar som får härda i minst 28 dygn innan försöken genomförs. Den utbredda last som är nödvändig för bestämning av böjdraghållfastheten genereras av en luftkudde. Trycktesterna genomförs med en hydraulisk press och skjuvproverna i en maskin speciellt avsedd för detta ändamål.

Testerna för böjdraghållfastheten visar att de erhållna värdena är högre än de som finns angivna i BKR för fullfogsmurning. Detta gör att några reduktioner för stötfogsfri strängmurning av lättbetong, likt de reduktioner som görs för lättklinkerblock, inte behövs.

Vad gäller tryckhållfastheten, uppvisades värden strax under de som finns angivna i BKR.

Testerna av skjuvhållfastheten visade värden som är lägre än de angivna i BKR.

Sammantaget visar dessa tester att stötfogsfri strängmurning har potential att ersätta det traditionella sättet att tunnfogsmura på. Dock krävs ytterligare tester för att verifiera en del av resultaten. Ytterligare tester kan också leda till en förändring av de värden som ges i BKR, vilket i sin tur kan effektivisera utförandet ute på byggarbetsplatsen.

Utförandet är viktigt för resultaten. I de fall där bruket inte har blivit tillräckligt utjämnat har brottet skett i fogen i stället för i blocket, med lägre hållfasthet som följd.

Summary

H+H Celcon is the largest manufacturer of autoclaved aerated concrete in northern Europe. This report presents an experimental investigation of strength properties of full scale specimens of shell bedded autoclaved aerated concrete (AAC). There are reasons to believe that there is a potential to save both time and money using this method. However, there is a lack of information about material properties using this technique. Shear, compressive and flexural strength in two directions will be tested and compared with the existing values in the Swedish code BKR, which are believed to be on the lower side.

For each tested property, six specimens are made and cured for at least 28 days before the test is carried out. The distributed load that is necessary for the tests regarding the flexural strength is generated by an air cushion. The compressive strength test is carried out with a hydraulic pressure machine and the shear strength is tested in a machine especially designed for this purpose.

The flexural strength tests show higher characteristic values than the ones given in BKR for mortar in all joints. Consequently, no reduction for shell bedded AAC is necessary.

The compressive strength showed a characteristic value slightly lower than the value in BKR.

The tests of the shear strength showed values lower than BKR.

These tests show that shell bedded masonry has potential to replace the traditional way of building with blocks of autoclaved aerated concrete. However, further tests are necessary to verify some of the results. Further tests can also lead to a change of the Swedish code, which thereby will make the work on the building site more efficient.

The way the test specimens are assembled is very important for the results. In those cases where the mortar was not properly levelled out, the failure occurred in the joints instead of in the bricks with a lower strength as a result.

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1 Introduction

Shell bedded autoclaved aerated concrete has potential to be an attractive alternative to conventional brick-laying. With no mortar in the cross joints, increased construction efficiency is gained. The heat isolation of the masonry will most likely increase due to the higher amount of stationary air within the masonry.

On the long term, this technique can help lowering the costs and promote autoclaved aerated concrete as an alternative to other structural systems.

1.1 Background

H+H Celcon AB is a part of the Danish concern listed on the stock market as H+H Celcon A/S. They are the largest manufacturer of autoclaved aerated concrete in northern Europe. The core activity is manufacturing and sales of autoclaved aerated concrete. Products are sold in the shape of blocks, beams and elements for interior and exterior walls, floor structures and roofs.

H+H Celcon A/S in Denmark has together with the Danish mortar manufacturer LIP bygningartikler A/S developed a mortar which has worked well with blocks from H+H Celcon.

When it comes to bricklaying of autoclaved aerated concrete, the Swedish technique differs from most other countries in Europe. Outside Sweden it is common to perform the masonry with no mortar in the cross joints, and with mortar placed in two strings in the bed joints. With this procedure, you save both time and material, and gain efficiency on the building site.

In Sweden however, the masonry is performed with mortar filled cross joints and bed joints. There are factors as shown above making it interesting to change this procedure, especially if this can be done without a significant strength reduction. The problem is the lack of research in Sweden in this area.

1.2 Purpose

The main purpose with this report is to determine characteristic strength values for shell bedded autoclaved aerated concrete. The values are determined using full-scale test specimens. In a greater perspective, this report is a first step to introduce less conservative code values for shell bedded masonry.

The masonry will be tested for flexural, compressive and shear strength. In connection with the compressive strength test the modulus of elasticity will be determined. The moisture content by mass will be determined for each specimen.

The flexural strength is tested both parallel and perpendicular to the bed joints.

The obtained values are compared to the values given in the Swedish code (BKR).

1.3 Methodology

For each property to be tested, six specimens are made on pallets covered with plywood or plastic film on plasterboard in order to reduce friction. In total 28 specimens are tested. The densities of three representative blocks are measured before assembling the specimens. Directly after assembling the blocks, a plastic bag is used to cover the specimens to prevent them from drying out. When the specimens have cured 28 days the tests begin. This period of curing is chosen on the basis that the curve of strength for the mortar will be levelled after this time.

The characteristic strength value is evaluated from the test results.

A moisture profile for each specimen is determined after the tests.

The flexural strength is tested according to the European Standard with some modifications. The tests are made both parallel and perpendicular to bed joints. An air cushion combined with an abutment wall is used to generate a distributed load against the masonry. The masonry is supported with two line supports.

Compressive strength and modulus of elasticity is tested according to the European standard with a uniform load until failure.

Shear strength is tested according to the European standard.

1.4 Focus and limitations

The tests specimens are built up by blocks with a nominal density of 375 kg/m^3. The specimens are all built with no mortar in the cross joints, and with mortar in two strings of 150 mm width, covering 80 % of the surface, in the bed joints.

Tests concerning long-term load and fatigue are not represented in this report.

1.5 Definitions

Flexural strength parallel to bed joints means that there is a horizontal moment vector and that the failure surface is parallel to the bed joints.

Flexural strength perpendicular to bed joints means that there is a vertical moment vector and that the failure surface is perpendicular to the bed joints.

If nothing else is stated, a block or a masonry unit has the following dimensions:

- Length 500 mm
- Width 365 mm
- Height 200 mm

BKR is the Swedish regulations for structural design published by the Swedish national board of housing, building and planning - Boverket.

When N.I is stated, no information is available.

Autoclaved aerated concrete abbreviates AAC.

Lightweight aggregate concrete abbreviates LAC.

2 Theory

2.1 General

Dr. Axel Eriksson invented lightweight concrete in Sweden in the 1920: s[1]. The development of lightweight concrete originates in a desire to create a material that is not only load bearing, but also thermal insulating. There are similarities between lightweight concrete and common concrete. They both consist of a binding agent mixed with water and filler material. The big difference is the density, which is significantly lower for lightweight concrete. Another big difference is that the lightweight concrete is always manufactured in a factory.

AAC is the dominating type of lightweight concrete and usually when you speak about lightweight concrete, you mean this type.

AAC is a fine-grained and porous material, where a gas generates the noticeable pore system during the manufacturing process (fermentation).

Since 1975, AAC has been manufactured using fine sand, cement and lime. Earlier on, some manufacturers of AAC used alum shale as one component.[2] This rock contains a great deal of the radioactive metal uranium, which makes it unsuitable as building material. When the uranium disintegrates other radioactive materials are formed. One is the gas radon which besides smoking is the most common cause to lung cancer in Sweden.[3]

2.2 Properties

As a building material, AAC has a very low density which gives it excellent insulation against heat at the expense of the load bearing capacity. AAC is usually manufactured in four different quality groups, based on the density. The different groups are 400, 450, 500 and 550 kg/m^3.[4] The relationship between density and compressive strength is nearly linear as shown in figure 1 below.

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[1] Lättbetongmaterialet, Yxhult AB, page 6
[2] www.ssi.se 25/10 - 05
[3] www.ssi.se 15/11 - 05
[4] Burström, Per Gunnar, Byggnadsmaterial 2001, page 276

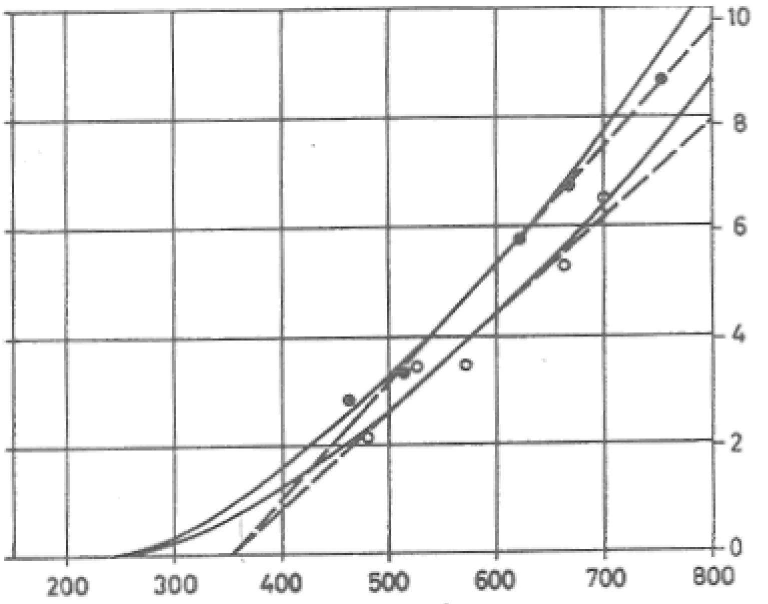


Figure 1. Compressive strength as a function of density.[5]

AAC is a non combustible material, which can withstand high temperatures and is therefore a good protection against fire. If the AAC is reinforced for example in a floor structure the fire resistance is reduced. This is because the coefficient of thermal expansion in the reinforcement bars differs from the one in the AAC and thereby generates unwanted stresses in the material. The temperature in the steel is highly affected by the thickness of the cover of reinforcement. If the cover is increased the fire resistance will become significantly higher.

Due to the lower density, the sound isolation for AAC is worse than regular concrete. It is of importance that, if AAC is used in a cavity wall, no contact occurs between the walls.

2.3 Masonry

2.3.1 General

Structures are in general designed according to the theory of elasticity and/or the theory of plasticity. In many cases the masonry is behaving neither elastic nor plastic.

Often the durability, deformations or the quality of the performance are of greater importance than the strength of a structure.[6]

[5] Burström, Per Gunnar, Byggnadsmaterial 2001, page 273

[6] Burström, Per Gunnar, Byggnadsmaterial 2001, page 3

Masonry is in Sweden mostly used as veneer wall outside a bearing framework of stud walls, or outside walls of concrete. The main purpose with that kind of wall is to be climate protective and aesthetical attractive, but it can also resist wind load. Masonry made of AAC is usually used as bearing external walls. Because of the significant heat insulation capacity, no extra insulation is necessary and that makes the masonry very efficient as building material.

The strength properties for masonry are important, not only the compressive strength, but also shear and flexural strength. These strength properties depend on which type of block is used, quality of the mortar and the workmanship.[7]

2.3.2 Dry stacked masonry

Tests have been made on dry-stacked masonry, which show a vertical load carrying capacity nearly as high as traditional masonry with mortar joints.

For bending stresses, the resistance of the joints is depending on the vertical pre-stressing force. For low values of the pre-stressing force, the failure occurs in the joints. In addition, vice versa, a high value of the pre stressing force generates a failure in the block.

For compressive strength, observations show that the overall compressive strength of mortarless masonry was at most 15 % lower than that of thin mortar layer masonry. The modulus of elasticity is reduced in the same way.[8]

2.4 Cracking

The magnitude of the energy absorption nearby the cracking zone is determining how brittle the fracture of the material is. The value of the energy absorption is highly affected by witch obstacles a crack is facing as it grows. For concrete, the obstacles consist of the aggregate particles because they are stronger than the cement paste. For AAC, the particles are weaker than the cement paste which results in lower energy absorption, and a straighter cracking.[9]

2.5 Fracture mechanics

When AAC is exposed to an increasing load, a maximum stress will be reached. After this maximum, the stress will decrease with an increasing deformation. The reason for the decrease is that there will be a spot in the masonry where a weakening occurs,

[7] Sentler, Lars, Strength tests of Swedish masonry, 1994, page 1

[8] Marzahn, Gero A, Investigation on the Initial Settlement of Dry-Stacked Masonry under Compression, 1999, page 257

[9] Nilsson, Lars-Olof, Byggnadsmaterialvetenskap, 2004, chapter 11, page 39

where the ability to transmit the stress is reduced. For AAC, the deformation will be of minor importance due to the brittleness of the material.[10]

2.6 Modulus of elasticity

The modulus of elasticity can be determined from a stress-strain curve. When the relation between stress and deformation shows a non-linear relationship, you either determine the modulus of elasticity as a secant modulus or a tangent modulus. The modulus of secant is applicable when the purpose is to find out how much the material will be deformed, when an earlier unloaded material will be loaded.

Concerning brittle materials, the modulus of elasticity is normally stated as the secant modulus evaluated at one third of the ultimate compressive strength.[11]

2.7 Thin layer mortar

Thin layer mortar is a pre-mixed cement-based product that only requires adding of water to make an easily applied mortar. It differs from general mortar in that it sets far more rapidly, thus giving early stability to the construction.

It provides an alternative to traditional sand/cement mortar and allows the depth of the mortar to be reduced from at least 10 mm to 3 mm or less.[12]

2.8 Confidence interval

There is a transitional stage where characteristic properties are evaluated using a 95 % confidence interval in advantage for the 75 % confidence interval. In the Swedish regulations, calculations are made according to a 75 % confidence interval.[13]

2.9 Characteristic values according to BKR

According to Swedish design code (BKR) the characteristic value for the flexural strength shall be reduced with a factor 0.75 when using shell bedded masonry. This is valid for the flexural strength when LAC is used. No information about AAC is available but it is assumed to be the same as the materials are similar. This results in a characteristic value, for the flexural strength, of 0,075 MPa in both directions for the lowest quality class.

The compressive strength should be reduced to 2/3 if more than 1/6 of the surface in the bed joints is left without mortar. This is valid for LAC.

[10] Nilsson, Lars-Olof, Byggnadsmaterialvetenskap, 2004, chapter 11, page 1
[11] Burström, Per Gunnar, Byggnadsmaterial 2001, page 132
[12] http://www.aircrete.co.uk/output/construction1.htm, 27/2- 06
[13] Boverket, byggavdelningen, Dimensionering genom provning, 1994, page 19

3 Experimental tests

Initially pallets are prepared to serve as platforms for the different tests specimens. The specimens are built on the pallets with the technique of placing the mortar in two strings with a width of 150 millimetres in the bed joints only. The overlapping is always half a block as shown in figure 2. After the specimens are built, they are immediately covered with plastic foil in order to prevent drying out and high moisture variation over the cross section.

The relative humidity and the temperature during the curing period are measured with a climate indicator. The indicator is placed inside the plastic foil of one specimen. The measurement is assumed valid for all specimens.

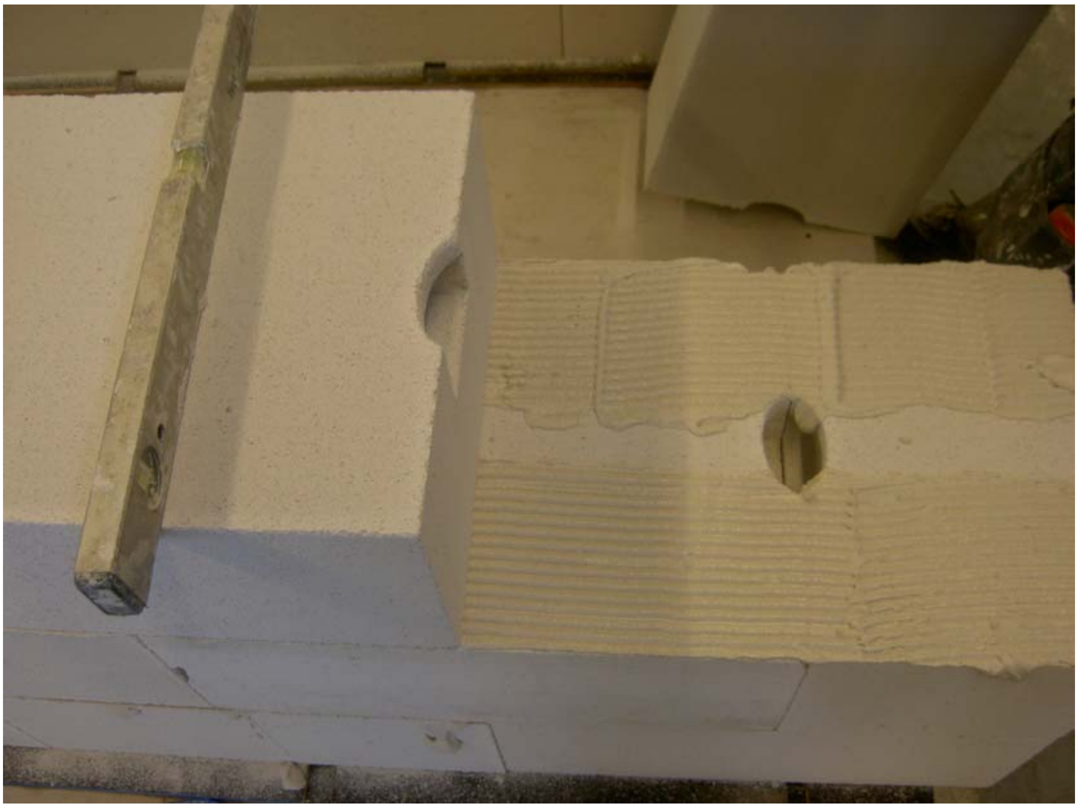


Figure 2. Mortar in strings of 150 millimetres with a half blocks displacement.

3.1 Material characteristics of the blocks

Three material characteristics for the blocks are to be determined. The tests are performed on blocks that have been covered with plastic foil standing in the laboratory.

3.1.1 Density

The net dry and the gross dry density tests are made according to European standard EN 772-13. Three blocks are used and three representative portions are taken from each block. The whole block is first weighed. Then the portions are weighed as a group before being dried. They are carefully measured with a digital slide gauge and weighed again individually. The moisture content of each portion group is also determined.

The net dry density is calculated for each one of the dried individual portions and the value for the block is obtained as the mean value of these three. The net dry density is then obtained as the mean value of the three blocks.

The gross dry density is calculated by using the whole block volume and a corresponding dry mass that is obtained by using the moisture content of the three different portions. The volume of the block is measured and a reduction for the two handles is made. This is done with a plastic bag containing water filling the hole. The gross dry density is then obtained as the mean value of the three blocks.

The net dry density and the gross dry density are assumed valid for the entire shipment of blocks.

3.1.2 Moisture content by mass

The moisture content is determined according to the standard EN 772-10. A total of six representative samples are taken from three blocks. They are weighed, dried and weighed again. The moisture content is obtained by calculating the mean value from the samples.

3.1.3 Compressive strength of masonry units

The compressive strength is determined for six cubes taken from three blocks with each cube measuring 100 mm. They are loaded until failure in a hydraulic press with surfaces of steel. Tests are made according to European standard EN 772-1.

Six additional tests are performed because of unsatisfactory results. The cubes are taken from one block and each one measuring 100 mm.

3.2 Flexural strength of masonry

The flexural strength is tested in two directions, parallel with bed joints and perpendicular to bed joints. Tests are made according to the European standard EN 1052-2. The test set-ups are shown in figure 3 and 4 below.

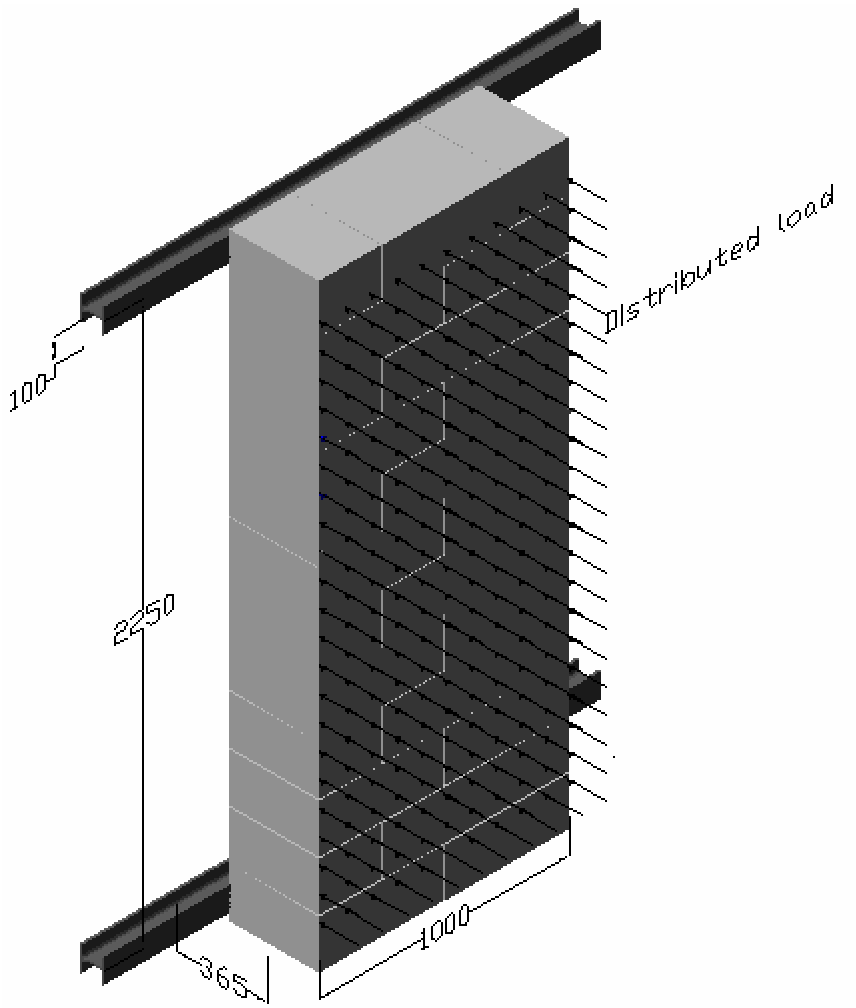


Figure 3. Principle of the test parallel to bed joints.

According to the standard two line loads are used to generate a bending moment. In reality, a vertical wall is exposed to a distributed load such as wind or earth pressure. Considering that, the wall is loaded by a distributed load using an air cushion. The air cushion is pressed against the specimen in assistance of a non deformable wall which is placed approximately 200 mm behind the specimen. The non deformable wall is fixed to big columns in the laboratory with struts. The air cushion is linked to a gauge that will register the pressure from start to failure.

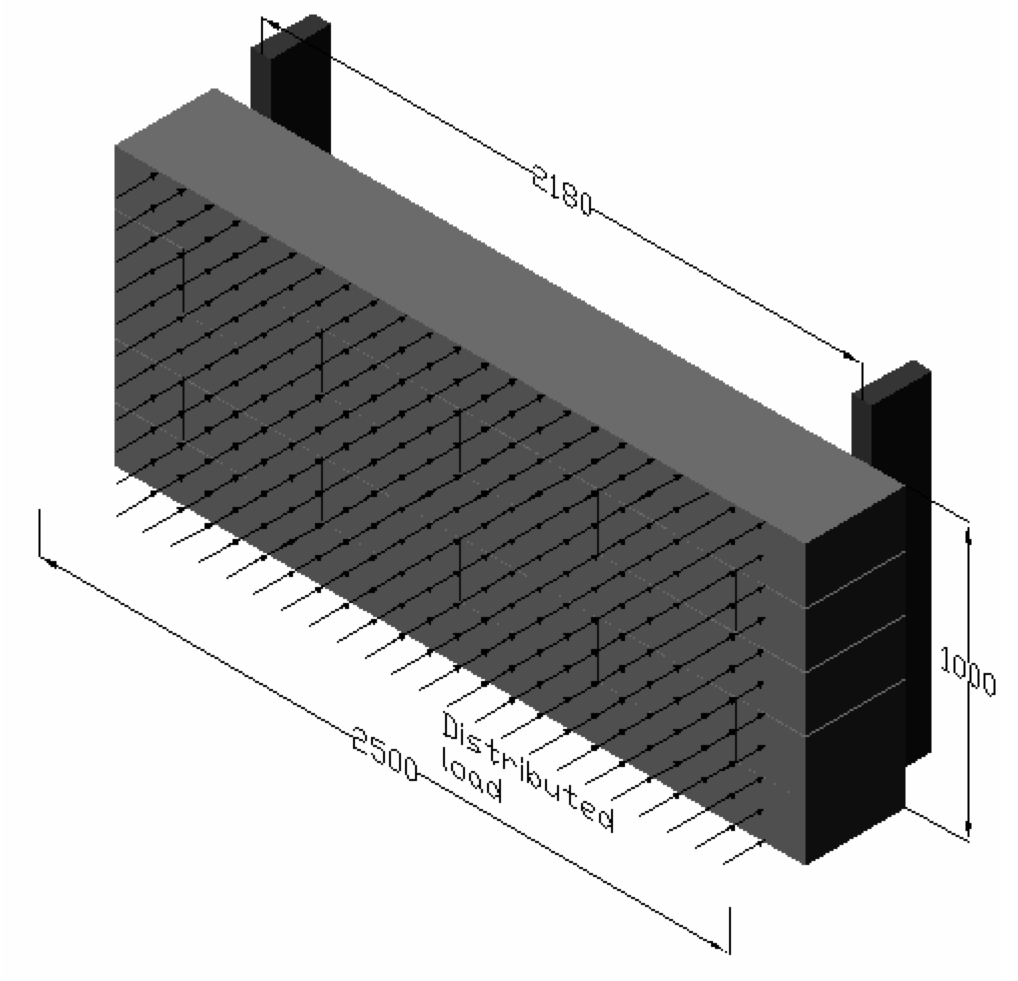


Figure 4. Principle of the test perpendicular to bed joints.

To make sure that the entire load from the air cushion reaches the load indicators, the friction between the abutment wall and the pallet must be eliminated. To achieve that, an overhead travelling crane is used to lift the abutment wall just above the pallet.

For the test perpendicular to the bed joints, it is of great importance that the friction between the pallet and the specimen is reduced. To achieve this, two layers of smooth plywood is used with hydraulic oil in between. The upper layer of plywood is made in pieces in order to secure frictionless bending of the specimen, as shown in figure 5. The pallets for the test perpendicular to the bed joints are assembled with strong studs and are moved to the test site with two fork-lift trucks.

Figure 5. Plywood with oil in between in order to reduce friction.

Dimensions for specimens tested parallel to bed joints:

- Height 2400 mm
- Width 1000 mm
- Thickness 365 mm

Dimensions for specimens tested perpendicular to bed joints:

- Height 1000 mm
- Width 2500 mm
- Thickness 365 mm

The specimens that will be tested perpendicular to bed joints were made 2500 mm wide. This is because the joining will be optimized with half a blocks displacement between the cross joints. The failure occurs in a section with three cross joints, i.e. only two blocks contribute to the bending capacity. The blocks interact in pairs and in this case, the fifth course does not contribute to the overall strength. Consequently the strength is calculated for a height of the cross section of 800 mm, i.e. over four courses instead of five. Calculations using five courses are shown in appendix C.

Another thing that will be taken into consideration is that the air cushion, when inflated, will rise up from the pallet, and therefore it will not be able to press on the entire specimen. This needs to be accounted for in the test of flexural strength perpendicular to bed joints.

3.2.1 Abutment wall

The abutment wall is used as a support for the air cushion. It is designed to resist the maximum failure load of the masonry. The studs in the wall are of dimensions 45x145 mm, and a distance between centres of 300 mm is used.
To distribute the load to the studs a 12 mm thick plywood board is used.

The wall has the dimensions 2500x1200 mm^2.

3.2.2 Air Cushion

To generate a distributed load over the specimen an air cushion made of plastic-coated fabric is used. It is placed between the abutment wall and the specimen as shown in figure 6 below. The air cushion is filled with air and the maximum pressure will not exceed 10 kPa. The size of the cushion is 2150x1000 mm.

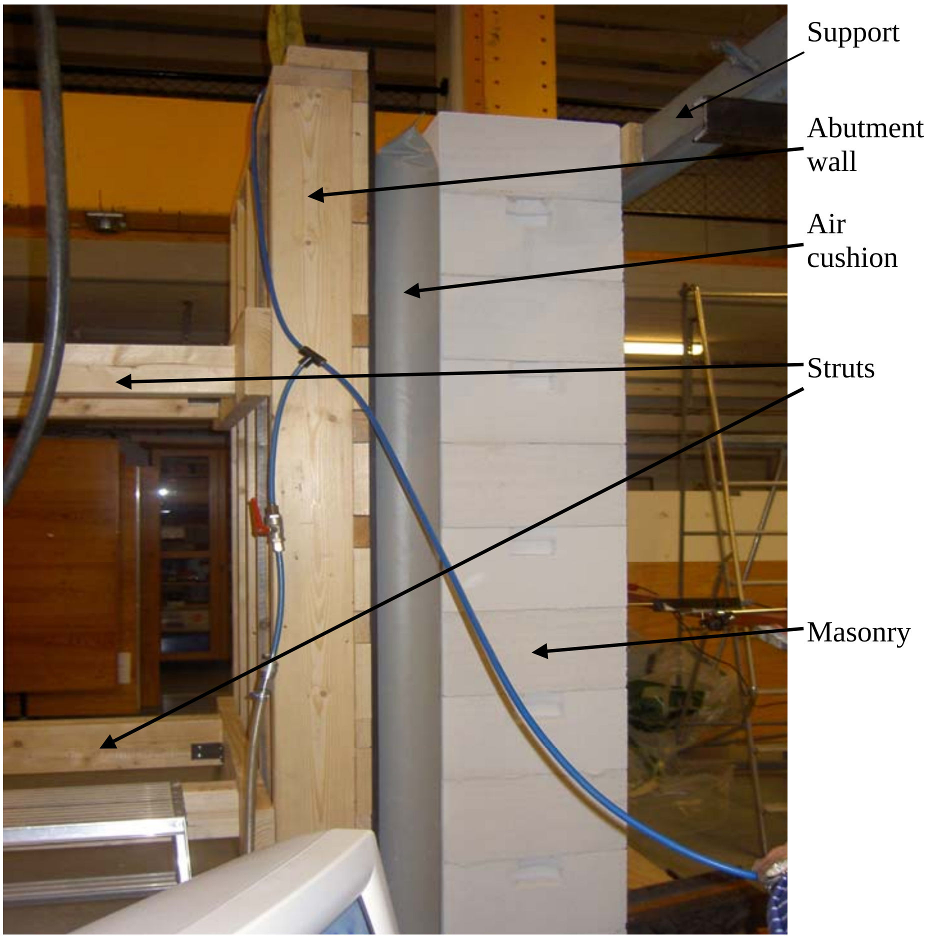


Figure 6. Resisting wall, air cushion and the specimen.

3.2.3 Supports

Steel beams, type HEA 100, are used as supports for the specimens tested parallel to the bed joints. The flange width is 100 mm and that is more than enough to prevent the support to punch through the masonry. The supports are fixed to non deformable columns in the laboratory as shown in figure 6 above. Fibre boards are attached between the supports and the masonry, in order to uniformly distribute the load. Calculations show that the supports will have a maximum deflection of 2,5 mm and this will not affect the failure load. This deformation is measured during the test and is taken into consideration when the deformation of the specimen is to be determined.

Two 70x220 planed timber beams are used as supports for the specimens tested perpendicular to the bed joints. The reason for choosing a smaller support than above is due to the position of the existing columns. These supports will not have any deflection because they rest on the existing columns. They will be pressed because of the fibreboards that are placed between the supports and the masonry.

3.2.4 Struts

To secure the abutment wall, struts are necessary and will be fitted to the wall and to beams that are attached to the non deformable columns in the laboratory, see figure 7.

Calculations show that four wooden struts with dimensions 90x120 mm^2 are sufficient. Eight Struts with dimensions 45x120 mm^2 are nailed in pairs so that only four gauges are required. Beams are attached to the existing columns in order to support the struts as shown in figure 7 below. The length of a strut is 1750 mm.

Figure 7. Struts attached to the resisting wall.

3.2.5 Gauges

Load indicators, capable of measuring forces up to 35 kN are fitted between the beams and the end of the struts in order to determine the total load that is applied on the specimen. This is shown in figure 8.


Figure 8. Load indicators between strut and beam.

Deflection gauges are attached to the masonry where the deformation reaches its maximum, nearby and onto the supports. This is shown in figure 9 below. This makes it possible to obtain the deformation of the specimen only. All gauges are connected to a computer that records the data each second.

Figure 9. Deflection gauges fitted on the masonry- flexural strength.

3.2.6 Method of calculation for the flexural strength

The failure load is given by the sum of the reaction forces of the 4 load cells divided by the loaded area of the cushion. This value is compared with the pressure in the cushion at failure. The measuring of air pressure is not accurate enough to be used for determining the failure load. This is due to the measuring gauge being affected by the injection of air into the cushion

According to the standard, the rate at which the flexural stress is to be increased is between 0,03 N/mm^2/min and 0,3 N/mm^2/min. Due to the low strength of the masonry to be tested, the lower rate is chosen.

The specimen is modelled as a beam as shown in figure 10.

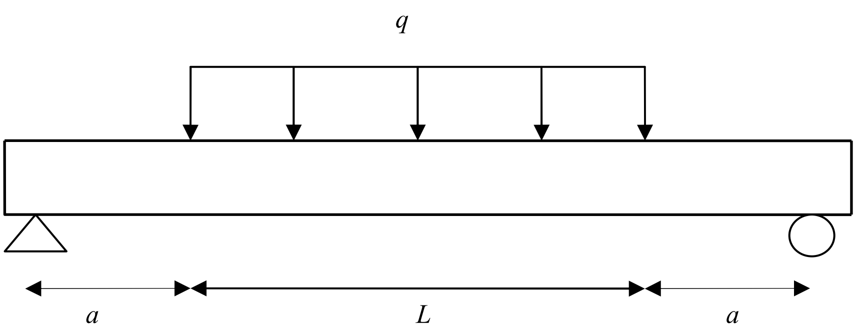


Figure 10. The specimen modelled as a beam.

The maximum bending moment can be determined with the formula

$$M = \frac{qL}{2}\left(a + \frac{L}{4}\right)$$

where q is the distributed load in N/m, L is the length of the load and a is the distance from the support to where the load begins.

After this, the strength, f can be determined from the formula

$$M = W \cdot f$$

where W is the section modulus of the specimen given by

$$W = \frac{bh^2}{6}$$

where b and h are the width and height of the cross section respectively.

In the case where four courses are used, b is chosen in accordance to that and the distributed load is concentrated over the smaller width.

The strength f, is calculated for each specimen, and the mean value f_m of the six specimens is determined. If nothing unexpected occurs, six specimens are used to determine the characteristic value. According to the standard the characteristic value, f_k is determined as the 5 % fractile based on a confidence level of 75 or 95 % using the log-normal distribution.

If five specimens are used, the characteristic value is determined as $f_k=f_m/1{,}5$, according to the European standard.

3.2.7 Evaluation of tests parallel to bed joints

Before performing the tests, various preparations had to be made. Some of these preparations could not be made with the plastic foil covering the specimen. As a result, the specimens were allowed to dry for approximately one hour.

Initially, the load gauges were placed between the supporting beams and the existing columns. The friction between the specimen and the pallet means that part of the load applied by the cushion is not registered by the load gauges but transferred to ground via friction. After specimen number one was tested, the load gauges were moved to a position at the end of the struts supporting the abutment wall. By lifting the abutment wall when testing, no friction has to be taken into consideration and the gauges registered the total force.

Only two deflection gauges were fitted to the specimen when the first couple of tests were carried out. One was placed at centre of the specimen and the other measured the deformation on one of the supporting beams. For the following tests, six gauges were used in order to measure the deformation properly. They were placed at each support, one on the specimen close to the support and two at the centre of the span. This is necessary in order to exclude the deformation of the soft fibreboard at the supports.

3.2.8 Evaluation of tests perpendicular to bed joints

The specimens were moved to the test site with two fork lifted trucks. The plywood boards with the oil in between worked in a satisfactory way. A small change was made to the load gauges. Instead of being fitted to the beams crossing the existing columns they were attached to the struts because of the previous difficulty of fitting the struts exactly onto the gauges. In these tests wooden supports were used and that was for two reasons. First, there was no need for steel supports for any load bearing reasons since they were supported throughout their whole length by the existing columns. Secondly, the wooden supports were significantly easier to attach to the existing columns. The span for the bending test was adjusted to fit to the existing steel columns in the laboratory. The span had to be made slightly smaller than for the wall tested parallel to bed joints.

3.3 Compressive strength

The compressive strength is tested perpendicular to bed joints according to the European standard SS-EN 1052-1. The compressive strength is determined without consideration to the effects of loading restraint, slenderness or eccentricity of loading. The same test includes determining the compression modulus of elasticity.

Two specimens are manufactured on each pallet. They are moved one at a time into the hydraulic press before the testing procedure. The hydraulic press in the original state only allowed a specimen with a size up to 800 mm. This is modified with two strong steel beams and a solid steel plate with dimensions 1000 x 1000 x 20 mm^3 at each end of the specimen, as shown in figure 11. This makes the specimen fit without getting any significant deformations in the testing machinery. The self-weight of the plates and beams is added when calculating the compressive strength.
In total six specimens are available for the test.

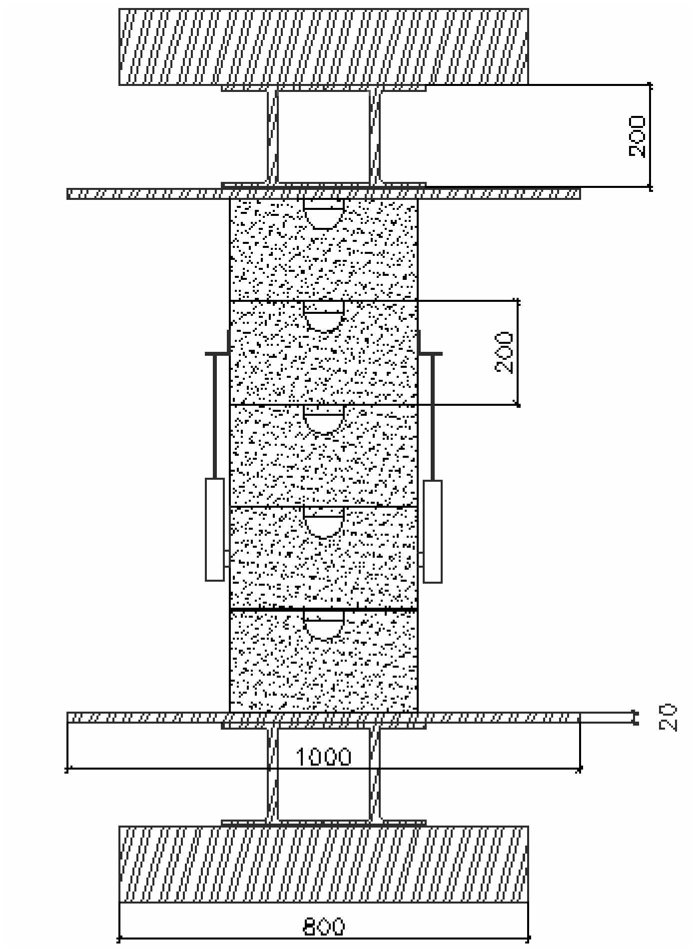


Figure 11. Principle of the compressive strength test.

The specimens have the following dimensions:

- Height: 1000 mm
- Width: 1000 mm
- Thickness: 365 mm

The load will be applied uniformly. The load will be increased uniformly so that failure is reached after 15 minutes to 30 minutes. Because of the difficulty of determining the initial rate, the first specimen tested will be a guide to the other specimens concerning the required rate of the loading.

The modulus of elasticity is measured using deflection gauges fitted to the masonry. Four gauges are used, two on each side as shown in figure 11 and 12. The measuring length is 400 mm.

Figure 12. Deflection gauges attached to the masonry- compressive strength.

3.3.1 Measurements

According to the standard above, the following is recorded:

- The dimensions of the loaded cross-section of the specimen with an accuracy of 1 mm.
- The maximum load $F_{i,max}$ to the nearest kN.
- The load at which visible cracks occur
- The time from the start of loading until the maximum load is reached.

The compressive strength f is determined as:

$$f = \frac{F}{A}$$

Where

- f is the compressive strength
- F is the failure load
- A is the cross sectional area

The area is the same for all specimens and equal to 1000x365 mm^2.

The thickness of the joints is measured in 25 different places. A precision feeler gauge is used.

3.3.2 Evaluation of tests

As for the test of flexural strength, numerous preparations were made after the plastic foil had been taken off. The specimens suffered minor damage when they were moved from the pallet to the testing platform. Small pieces of the brittle material came loose. This could have been prevented if the pallet had been covered with plywood instead of plasterboard.

As mentioned earlier, steel plates were used at the top and bottom of the specimen. In the standard however, gypsum wallboard or appropriate mortar are suggested as a compensating layer to level any irregularity in the specimen surface. In this case the surfaces were assumed to be even and parallel and no additional layer was used between specimen and steel plate.

Two of the deflection gauges attached at the specimens in order to determine the modulus of elasticity had to be extended, see figure 11. The deformation should be measured over two joints in order to reach satisfactory values. Only two deflection gauges had sufficient length, therefore an extension stick was glued on to two of the original shorter gauges.

3.4 Shear strength

The shear strength is tested according to the European standard EN 1739: 2005. The specimens consist of two parts sawed by hand from a block. The jointed surfaces are not sawed and the cross section is a square with the side 150 millimetres. The parts are 200 and 100 millimetres long respectively, as shown in figure 13 below.

Figure 13. The two blocks joined with mortar.

After the specimens are joined with mortar, they are stored in the laboratory covered with a plastic sheet in the same way as the other specimens.

The specimens are fitted into a certain shear strength testing machine as shown in figure 14 below.

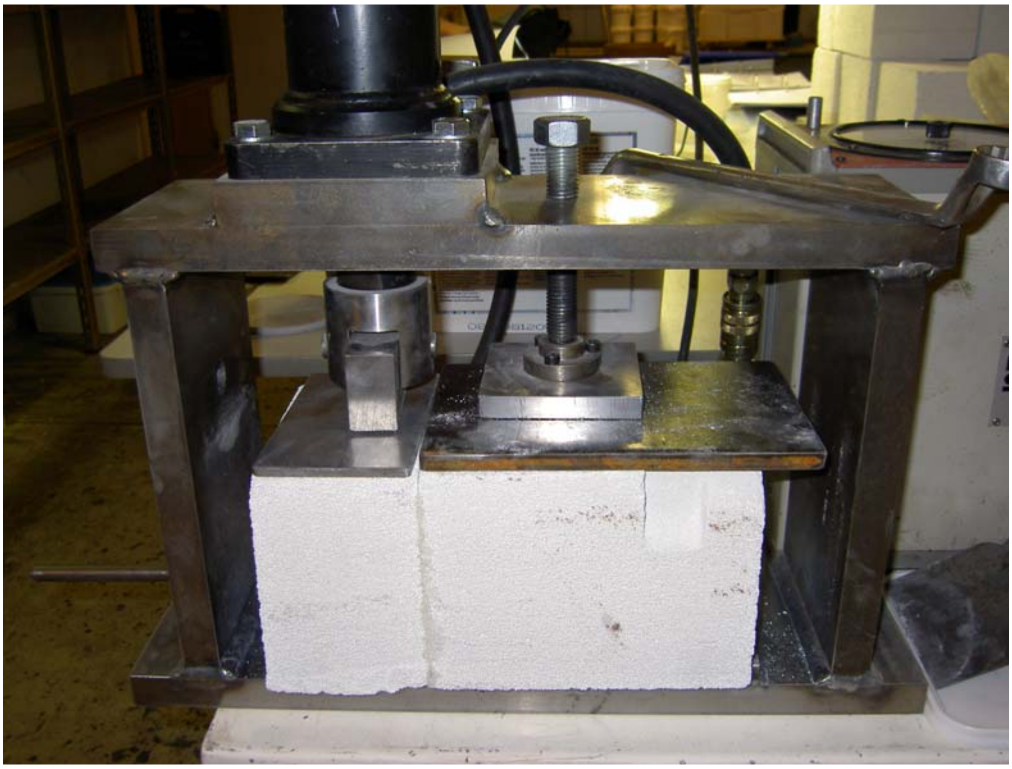


Figure 14. Test set-up for shear strength.

Steel plates are placed both below and above the longer block of the specimen in order to distribute the load. The shorter block is also fitted with a steel plate, distributing the load. The load is increased so that the failure will occur after approximately ten minutes. After the tests, the shear strength can be expressed as a stress, τ (MPa).

$$\tau = \frac{F}{h \cdot w}$$

where:

- F is the force measured at failure
- h is the height of the tested specimen
- w is the width of the tested specimen

3.4.1 Evaluation of tests

The specimens were tested in a device specifically designed for testing shear strength. The surfaces fitted into the device were neither perfectly smooth nor parallel. To verify that this does not influence the results, two specimens were sawed in the laboratory with a very precise saw just before the tests. The results showed no significant difference.

3.5 Test results

The Characteristic values are determined in accordance to Bayesian procedures, which lead to a result similar to the conventional 75 % confidence interval. The latter are available in appendix.

3.5.1 Material characteristics

The six additional tests were performed because of the suspiciously low values in the original six tests.

Specimen no.	Compressive strength of masonry units, original tests (MPa)	Compressive strength of masonry units, additional tests (MPa)
1	1,501	2,177
2	1,492	1,758
3	1,615	2,353
4	1,277	2,078
5	1,517	2,541
6	1,544	2,566
Net dry density (kg/m^3)	365	N.I
Gross dry density (kg/m^3)	355	N.I
Mean strength (MPa)	1,491	2,245
Characteristic strength (MPa)	1,250	1,632
Coefficient of variation (%)	7,6*	13,7

3.5.2 Flexural strength

Specimen no.	Flexural strength // bed joints (MPa)	Moisture content (%)	Flexural strength ⊥ bed joints (MPa)	Moisture content (%)
1	0,251	42,35	0,176	38,70
2	0,225	39,11	0,202	42,71
3	0,184	40,64	0,181	40,47
4	0,164	39,86	0,201	40,61
5	0,105	39,14	0,195	37,61
6	0,207	41,29	0,176	40,43
Net dry density (kg/m^3)	365		365	
Gross dry density (kg/m^3)	355		355	
Mean strength (MPa)	0,206*		0,188**	
Characteristic strength (MPa)	0,138*		0,163**	
Coefficient of variation (%)	16,5*		6,49**	
Mean deflection at failure (mm)	N.I		0,422	

* Excluding specimen # 5
** Based on four courses

3.5.3 Compressive and shear strength

Specimen no.	Compressive strength (MPa)	Moisture content (%)	Shear strength (MPa)
1	1,156	41,76	0,318
2	1,437	40,25	0,498
3	1,086	44,17	0,255
4	1,182	41,78	0,423
5	1,130	40,97	0,261
6	1,182	43,50	0,388
7			0,486
8			0,264
9			0,327
Mean thickness of joints (mm)	1,40		N.I
Net dry density (kg/m^3)	365		365
Gross dry density (kg/m^3)	355		355
Mean strength (MPa)	1,196		0,358
Characteristic strength (MPa)	0,953		0,207
Coefficient of variation (%)	10,3		26,6

4 Evaluation of results

The evaluation is based on the characteristic values from the Bayesian procedures.

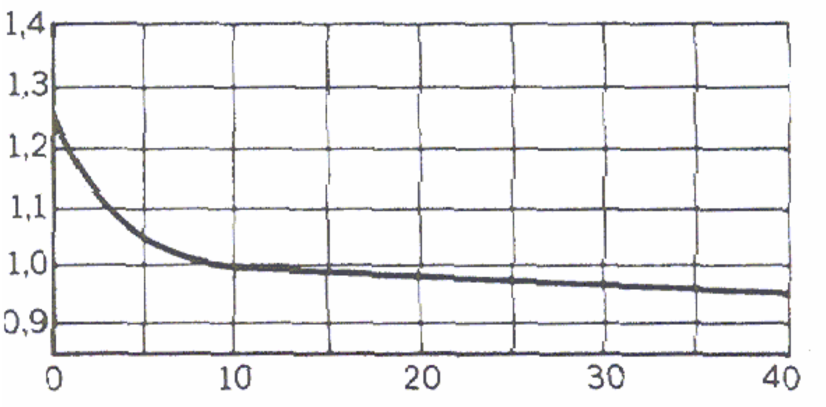
4.1 Material characteristics

The net and gross density is 365 and 355 kg/m^3 respectively; i.e. there is a difference in density of 10 kg/m^3. It is thought to be the gross dry density that has the largest margin of error. The volume of the two handles in the block was accounted for when determining the gross volume. The margin of error from measuring the volume of these is not enough to generate the difference between the two densities. The difference could have its origin in the assumption that the moisture content calculated from the three portions is constant throughout the block. Any irregularities will affect the corresponding dry mass and thereby the gross dry density. Even though the moisture content have been relatively constant, small differences within the block is enough to generate this distinction between the two densities. The volume used was 365x200x500 mm^3 and any small divergence from this is another possible source of error.

The moisture content is determined for three different blocks with two portions taken from each block. The results show that the moisture content is close to 40 %. The variation can be due to where in the block the portion is taken. Further, the moisture content profile is measured for every individual specimen. There is no obvious trend that the moisture content is higher in the centre of the block compared the surface of the block. Consequently, the plastic cover of the specimens has prevented extensive drying out.

The compressive strength of the AAC was tested and the values were all close to 1,5 MPa. In the technical data provided from H+H Celcon the mean compressive strength should be around 2,5 MPa at a moisture content of 6 % ± 2%. According to Swedish standard SS 137304, blocks with a density of 400 kg/m^3 have a nominal compressive strength of 1,7 MPa. Interesting in the context is that these blocks had a moisture content of 10 %, when tested. In this report, the units had a moisture content of 40 % and that alone should not be able explain the lower values. In the six additional tests that were made because of the suspiciously low values the moisture content was around 3,5%. The results were significantly higher with a mean value of 2,25 MPa. It is hard to find a satisfactory explanation for this. The fact that the moisture content was much lower should not be enough. How the compressive strength differs with the moisture content is shown in figure 15 below.

Relative Compressive Strength



Moisture content (%)

Figure 15. Relative compressive strength as a function of moisture content.[14]

4.2 Flexural strength parallel to bed joints

The characteristic value for bending parallel to bed joints of AAC with mortar in all joints is 0,1 MPa according to the Swedish code. This value should be reduced with a factor of 0.75 to account for no mortar in cross joints and two strings of mortar in bed joints. Thus, the test results should be compared to a code value of 0.075 MPa.

If specimen number five is excluded, the characteristic strength for the masonry tested is 0,138 MPa which is significantly higher than 0,075 MPa. If specimen number five is included the strength is 0,093 MPa, which is still higher than 0,075 MPa. One reason for the high values can be that the cross joints does not contribute to the flexural strength in this direction. This is an assumption that seems reasonable. Another reason is that the strength is mostly dependent on the mortar being placed near the edges of the blocks, i.e. mortar in the centre of the joint does not contribute significantly to the strength. This however, does not explain that the strength obtained in the tests is even higher than the values given in BKR, which applies for masonry with all joints filled with mortar. Interesting is the fact that the moisture content for the tested specimen is around 40 %. If the specimens would have been able to dry out, an even higher value would be probable.

4.3 Flexural strength perpendicular to bed joints

The strength perpendicular to bed joints is the same as for parallel to bed joints, according to the Swedish code. The characteristic value is consequently 0,075 MPa.

[14] Burström, Per Gunnar, Byggnadsmaterial 2001, page 277

The specimens show very similar values when tested. The coefficient of variation for the six specimens is only 6,49 %.

The characteristic value is based on four contributing courses and the value is 0,163 MPa. The value is higher than the code. If the characteristic value is based on the assumption that five courses are contributing to the strength, the value is 0,117 MPa. Still, this value is higher than given in the code. There is no obvious explanation to the high test values. The moisture content was the same as above.

4.4 Compressive strength

The results showed little variation, except for specimen number two that had a significantly higher value. The characteristic value based on the test results is 0,953 MPa. It is a bit lower than 1,1 MPa given in BKR. However, the strings of mortar are 150 mm wide and according to BKR one should reduce the strength to 2/3 if more than 1/6 of the block is left unfilled. The masonry in this investigation is bricked with two strings of mortar leaving 18 % of the bed joint without mortar. This should make this rule apply by a narrow margin. The reduction to 2/3 according to BKR is here valid for LAC but assumed to be valid for AAC as well. The value according to the code is then reduced to 0.73 MPa, i.e. the test results show a higher strength.

The higher moisture content should be taken into consideration when the values are compared to the Swedish code.

When measuring the secant modulus of elasticity two of the gauges were modified so the deflection could be measured over two bed joints. It was noted that these two gauges by some reason showed a slightly smaller deflection throughout the tests than the other two. The modulus of elasticity had a quite large scatter with a coefficient of variation of 26 %. Notable is that the highest modulus of 2500 MPa was not measured for the specimen with a significantly high compression strength. The characteristic value based on the test results is 964 MPa which can be compared with 1260 MPa according to the manufacturer. This comparison is not entirely correct because the latter value is valid for a single block unit only. Still the comparison indicates that the measurement give a reasonable value even though the difficulties of measuring the modulus of elasticity are known.

In the Swedish code, the modulus of elasticity for AAC performed with thin joint mortar is E_k=700f_{ck}. Since f_{ck}, according to the code, is 1,1 MPa the comparable value is then 770 MPa.

4.5 Shear strength

The mean shear strength of the nine specimens is 0,358 MPa and the characteristic value is 0,207 MPa with a coefficient of variation of 26,6 %. If the masonry is performed with mortar in strings and with no mortar in cross joints or in a traditional way does not affect the shear strength in this test. The characteristic value for pure shear strength given in BKR is 0.25 MPa. This value can be increased if there is normal stress as well. The test results show a lower characteristic value compared to the code. It is hard to find any particular explanation for this other than the higher moisture content. This alone though should not be enough to cause the difference. All failures occurred in the AAC and not in the mortar.

4.6 Comments to the results

The load in the flexural strength test is generated with an air cushion instead of two line loads as described in standard EN 1052-2. This might have a positive effect on the strength and could to some degree explain the higher values. The air cushion gives a more gentle form of pressure and can adapt to the surface of the wall in a different way. However this way of generating the load gives a more realistic view of reality and the results should be considered legitimate.

5 Conclusions

The conclusions of this master thesis are focused on the flexural strength tests. These tests showed values that are higher than the code values for masonry with mortar filled joints. Thus, a reduction of strength due to the masonry being shell bedded is not necessary. This combined with the time and material winning factor should make this building technique competitive. It is therefore recommended that the reduction of 0,75 is removed from the regulations.

The accuracy when building the test specimens is very important for performance and strength of the masonry. It was clear that specimens carried out in a poor way, had a much lower strength. For example, if the mortar string is not properly levelled out when placing the block, the joint between blocks will have a low strength. This leads to failure in the joints.

It is difficult to draw any conclusions from the compressive strength tests. The obtained value was slightly lower than the one in the code for all joints filled. If the reduction to 2/3 is applied, the test value is higher. Therefore, it is recommended that the reduction according to the code should be decreased.

Based on the test results it can be concluded that the reduction of flexural strength for shell bedded masonry is not necessary. Further, the tests indicate that the reduction of compressive strength according to the code when using shell bedded masonry is too high.

6 Bibliography

6.1 Literature

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Appendix A
Material characteristics

Determination of net and gross dry density of masonry units

Products

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Test report

The following test report is established according to the standard EN 772-13.

1) Standard	EN 772-13
Date of issue	1999-06-03

2) Tested at Lund institute of technology, division of structural engineering.

3) Date of Receipt	2005-11-20
4) Date of testing the specimens.	2006-02-08

5) All representative portions of a whole unit specimen were sawed in sizes of 70x70x70 mm^3. Three portions were taken from each one of the three blocks that were used.

6) Net dry density, individual value and gross dry density for the specimens and portions below.

Block (No)	Portion (No)	Net dry density (kg/m^3)	Block density (kg/m^3)	Gross dry density (kg/m^3)
	1	362,9		
1	2	363,6	364.3	355,7
	3	366,4		
	1	368,8		
2	2	367,1	367,5	359,4
	3	366,5		
	1	377,6		
3	2	363,1	368,9	355,4
	3	366,1		

7) Net dry density mean value 365 kg/m3

8) Gross dry density mean value 355 kg/m3

Determination of moisture content of masonry units

Product

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Test report

The following test report is established according to the standard EN 772-10.

1) Standard	EN 772-10
Date of issue	1999-08-20

2) Tested at Lund institute of technology, division of structural engineering.

3) Date of testing the specimens. 2006-02-06

4) Individual moisture content for each portion.

Specimen (No)	Portion (No)	Moisture content (%)
1	1	41,0
	2	41,0
2	1	31,0
	2	37,0
3	1	44,5
	2	41,0

5) Mean moisture content: 39,5 %

Determination of compressive strength for masonry units

Product

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Test report

The following test report is established according to the standard EN 772-1.

1) Standard EN 772-1
Date of issue 1999-06-03

2) Tested at Lund institute of technology, division of structural engineering.

3) Date of testing the specimens. 2006-02-06

4) All of the cubes were sawed with a band saw in sizes of 100x100x100 mm^3. The loaded area is the same for all blocks, 0,01 m^2.

Two cubes were taken from each one of the three blocks that were used. Smooth steel plates constituted the contact surfaces.

5) No moisture content was measured.

6) Individual failure load and compressive strength for each specimen.

Specimen	Failure load (kN)	Compressive strength (MPa)
1	15,02	1,5
2	15,04	1,5
3	16,23	1,6
4	12,84	1,3
5	15,34	1,5
6	15,53	1,5

7) Mean compressive strength:	1,491 MPa
Coefficient of variation:	7,6 %
Characteristic compressive strength:	1,250 MPa (95 % confidence interval)

Vertical compressive strength, masonry units

Bayesian ~ 75 % confidence interval

compressive strength f1 (MPa)	1,501
compressive strength f2 (MPa)	1,492
compressive strength f3 (MPa)	1,615
compressive strength f4 (MPa)	1,277
compressive strength f5 (MPa)	1,517
compressive strength f6 (MPa)	1,544
mean compressive strength f_m (MPa)	1,491
Standard deviation	0,114
Coefficient of variation	7,6%
n (number of specimen)	6
k (function of n)	2,180
log f1	0,176
log f2	0,174
log f3	0,208
log f4	0,106
log f5	0,181
log f6	0,189
log f_m	0,172
Standard deviation log-normal	0,035
logarithmic characteristic value	0,097
Characteristic strength f_c (Mpa)	**1,250**

75 % confidence interval

k (function of n)	2,330
logarithmic characteristic strength	0,092
Characteristic strength f_c (Mpa)	**1,235**

Additional tests

compressive strength f1 (MPa)	2,177
compressive strength f2 (MPa)	1,758
compressive strength f3 (MPa)	2,353
compressive strength f4 (MPa)	2,078
compressive strength f5 (MPa)	2,541

compressive strength f6 (MPa)	2,566
mean compressive strength f_m (MPa)	**2,2455**

Appendix B
Flexural strength parallel to bed joints

Determination of flexural strength parallel to bed joints

Products

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Thin bed mortar, H+H Celcon

Test report

The following test report is established according to the standard DS/EN 1052-2.

1) Standard	DS/EN 1052-2
Edition	Second edition
Date of issue	2001-11-20

2) Tested at Lund institute of technology, division of structural engineering.

3) Number of specimens 6 specimens

4) Date of building the specimens 2005-11-23

5) The temperature varied between 12,40 and 17,20 ° C during the curing period. The relative humidity was constant close to 99 %.

6) Date of testing the specimens.	No.1	2006-01-11
	No.2	2006-01-16
	No.3	2006-01-17
	No.4	2006-01-18
	No.5	2006-01-24
	No.6	2006-01-24

7) All specimens were built up by 12 courses with a customary half block displacement between the cross joints as shown in figure 2. The specimens had the following size:

- Width 1000 mm
- Height 2400 mm
- Thickness 365 mm

8) For description of the masonry units and its properties, see section 2.2. No tests concerning the mortar were made.

9) No non-autoclaved units are available.

10) Mean moisture content for the current specimens is shown in the table below.

Specimen	**moisture content (%)**
1	42.35%
2	39.11%
3	40.64%
4	39.86%
5	39.14%
6	41.29%

11) Individual failure load and flexural strength for each specimen and the time to failure and in which joint, counted from the bottom, which failure occurred.

Specimen (No)	Failure load (kN)	Time to failure (min.)	Failure in joint no.	Flexural strength (MPa)
1	17,54	5.14	8	0,251
2	15,65	15.58	6-7	0,225
3	12,64	5.46	5-7	0,184
4	11,54	5.40	6	0,164
5	7,31	8.40	5-7	0,105
6	14,69	6.43	4	0,207

12) Mean flexural strength: 0.206 MPa (excluding # 5)
Coefficient of variation: 16,5 % (excluding # 5)
Characteristic flexural strength: 0,138 (f_k=f/1,5, 95 % confidence interval)

13) No visible cracks occurred before the specimens broke.

14) Remarks:

1) For specimen number one the failure load is determined from the air pressure, instead of the load gauges. This is because the resisting wall was not raised above the pallet and therefore the friction between the resisting wall and the ground interfered with the load gauges.
2) There are two main reasons to not include specimen number five when the characteristic strength is to be determined:

   - The air cushion was punctured during the test and therefore the specimen was exposed to a load twice.
   - The performance of the brick-laying was very poor. This wall had a inclination that was significantly larger than the others and during the building process compensation for this was made with extra mortar in some areas of the bed joints. Because of this, failure occurred in the joints instead of in the AAC unit.

3) Calculations that exclude specimen number one and five are shown below, as well as calculations including all specimens.

Flexural strength parallel to bed joints

Bayesian ~ 75 % confidence interval

flexural strength, f1 (MPa)	0,251
flexural strength, f2 (MPa)	0,225
flexural strength, f3 (MPa)	0,184
flexural strength, f4 (MPa)	0,164
flexural strength, f5 (MPa)	0,105
flexural strength, f6 (MPa)	0,207
Mean flexural strength fm (MPa)	0,189
Standard deviation	0,051
Coefficient of variation	27,1%
n (number of specimen)	6
k (function of n)	2,180
log f1	-0,600
log f2	-0,648
log f3	-0,735
log f4	-0,785
log f5	-0,979
log f6	-0,684
log f_m	-0,738
Standard deviation log-normal	0,134
logarithmic characteristic strength	-1,031
Characteristic strength including all specimens	**0,093**

Excluding specimen # 5

Mean flexural strength	0,206
Standard deviation	0,034
Coefficient of variation	16,5%
Characteristic strength excluding specimen # 5	**0,138**

Excluding specimen # 1

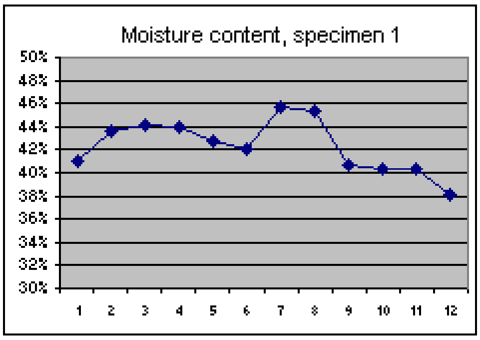
Mean flexural strength	0,177
Standard deviation	0,046
Coefficient of variation	26,2%
Characteristic strength	**0,118**

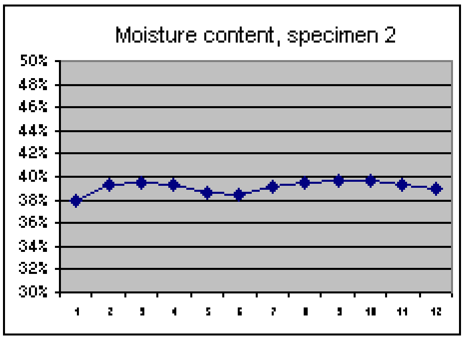
Loaded area		
Specimen #1	1,956	(estimated)
Specimen #2	1,945	
Specimen #3	1,910	
Specimen #4	1,976	
Specimen #5	1,947	
Specimen #6	2,000	
Mean	**1,956**	

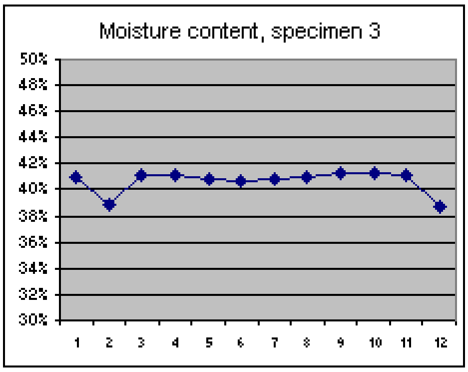
75 % confidence interval

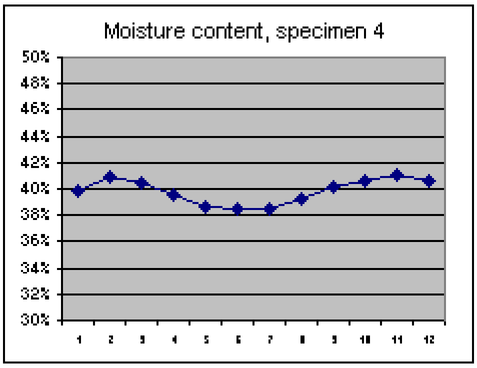
k (function of n)	2,330
logarithmic characteristic strength, y_c	-1,051
Characteristic strength including all specimens	**0,089**

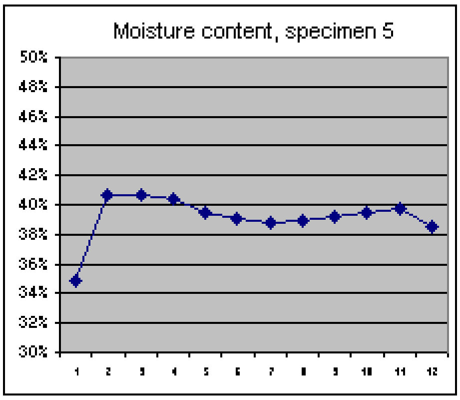
Moisture content, flexural strength parallel to bed joints

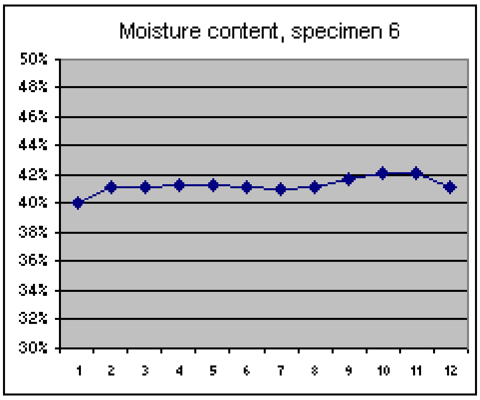










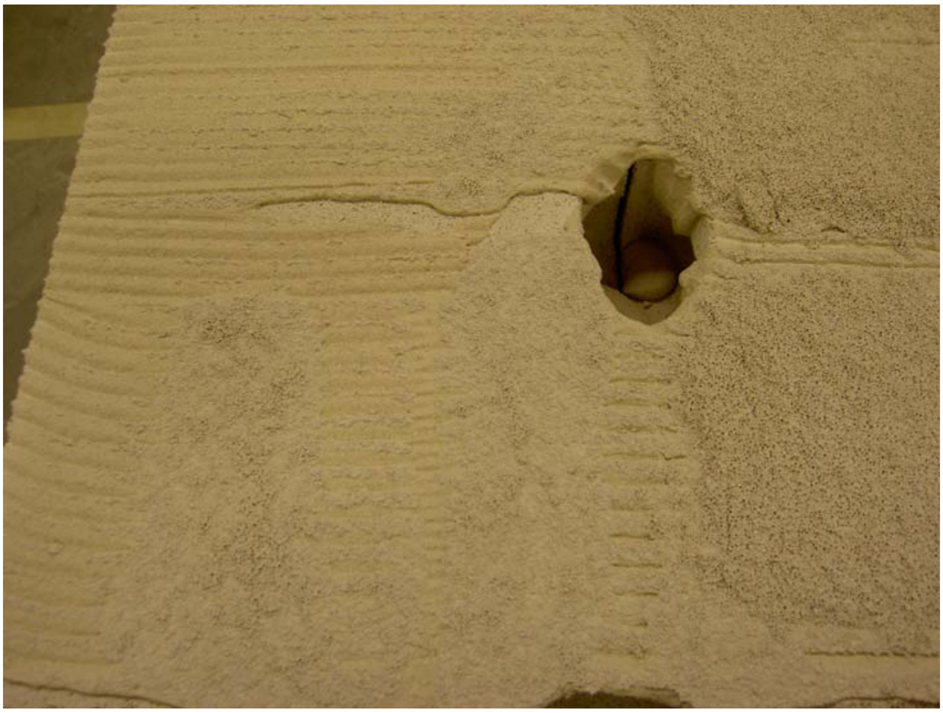


Pictures of failure, parallel to bed joints

Specimen 1

Specimen 2

Specimen 3



Specimen 4

Specimen 5

Specimen 6

Appendix C
Flexural strength perpendicular to bed joints

Determination of flexural strength perpendicular to bed joints

Products

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Thin bed mortar, H+H Celcon

Test report

The following test report is established according to the standard DS/EN 1052-2.

1) Standard	DS/EN 1052-2
Edition	Second edition
Date of issue	2001-11-20

2) Tested at Lund institute of technology, division of structural engineering.

3) Number of specimens	6 specimens

4) Date of building the specimens	2005-11-23

5) The temperature varied between 12,40 and 17,20 ° C during the curing period. The relative humidity was constant close to 99 %.

6) Date of testing the specimens.	No.1	2006-01-25
	No.2	2006-01-26
	No.3	2006-01-27
	No.4	2006-01-27
	No.5	2006-01-30
	No.6	2006-01-31

7) All specimens were built up by 5 courses with a customary half block displacement between the cross joints as shown in figure 2. The specimens had the following size:

- Width 2500 mm
- Height 1000 mm
- Thickness 365 mm

8) For description of the masonry units and its properties, see section 2.2. No tests concerning the mortar were made.

9) No non-autoclaved units are of current interest.

10) Mean moisture content for the current specimens is shown in the table below.

Specimen	**moisture content (%)**
1	38,70%
2	42,71%
3	40,47%
4	40,61%
5	37,61%
6	40,43%

11) Individual failure load and flexural strength for each specimen and the time to failure and in which joint, in which failure occurred.

Specimen (No)	Failure load (kN)	Time to failure (min)	Failure in joint no.	Flexural strength (MPa)
1	9,035	4,7	2	0,176
2	9,529	5,23	3	0,202
3	9,265	4,10	3	0,181
4	10,070	6,17	3	0,201
5	9,706	4,56	3	0,195
6	8,668	7,40	3	0,176

12) Mean flexural strength: 0,188 MPa
Coefficient of variation: 6,49 %
Characteristic flexural strength: 0,163 MPa (95 % confidence interval)

13) No visible cracks occurred before the specimens broke.

14) Remarks:

1) Calculations above are based on four load carrying courses. The case with five load carrying courses is shown below.
2) Data regarding deformations is shown below.

Flexural strength perpendicular to bed joints

Bayesian ~ 75 % confidence interval

Calculations based on 4 courses

flexural strength, f1 (MPa)	0,176
flexural strength, f2 (MPa)	0,202
flexural strength, f3 (MPa)	0,181
flexural strength, f4 (MPa)	0,201
flexural strength, f5 (MPa)	0,195
flexural strength, f6 (MPa)	0,176
Mean flexural strength f_m (MPa)	0,188
Standard deviation	0,012
Coefficient of variation	6,49%
n (number of specimen)	6
k (function of n)	2,18
log f1	-0,754
log f2	-0,696
log f3	-0,743
log f4	-0,696
log f5	-0,710
log f6	-0,755
log f_m	-0,726
Standard deviation log-normal	0,028
logarithmic characteristic strength	-0,787
Characteristic strength f_k log-normal distribution	**0,163**

Calculations based on 5 courses

flexural strength, f1 (MPa)	0,126
flexural strength, f2 (MPa)	0,145
flexural strength, f3 (MPa)	0,130
flexural strength, f4 (MPa)	0,145
flexural strength, f5 (MPa)	0,140
flexural strength, f6 (MPa)	0,126
Mean flexural strength f_m (MPa)	0,135
Standard deviation	0,009
Coefficient of variation	6,49%
n (number of specimen)	6

k (function of n)	2,18
log f1	-0,898
log f2	-0,839
log f3	-0,887
log f4	-0,840
log f5	-0,853
log f6	-0,898
log f_m	-0,869
Standard deviation log-normal	0,028
logarithmic characteristic strength	-0,931
Characteristic strength f_k log-normal distribution	**0,117**

75 % confidence interval

Calculations based on 4 courses

k (function of n)	2,330
logarithmic characteristic strength	-0,791
Characteristic strength f_k log-normal distribution	**0,162**

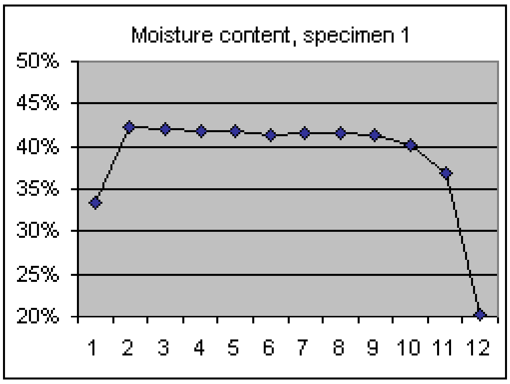
Calculations based on 5 courses

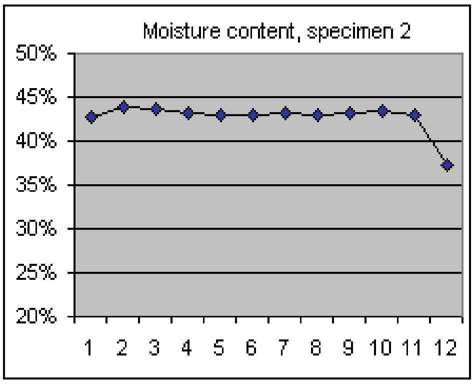
k (function of n)	2,330
logarithmic characteristic strength	-0,935
Characteristic strength f_k log-normal distribution	**0,116**

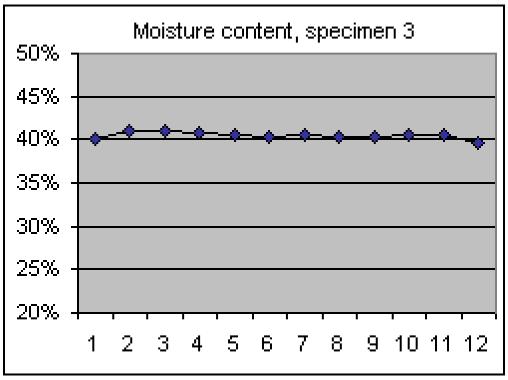
Deflection

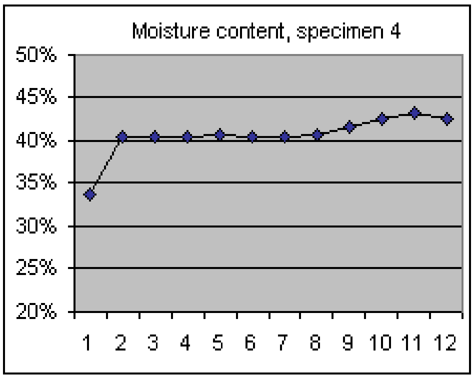
Deflection specimen #1 (mm)	N.I.
Deflection specimen #2 (mm)	0,433
Deflection specimen #3 (mm)	0,358
Deflection specimen #4 (mm)	0,299
Deflection specimen #5 (mm)	0,517
Deflection specimen #6 (mm)	0,501
Mean deflection (mm)	**0,422**

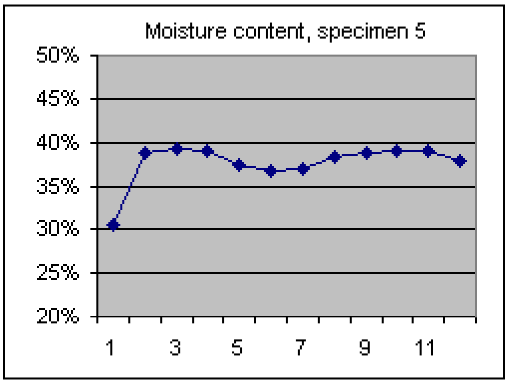
Moisture content, bending perpendicular to bed joints

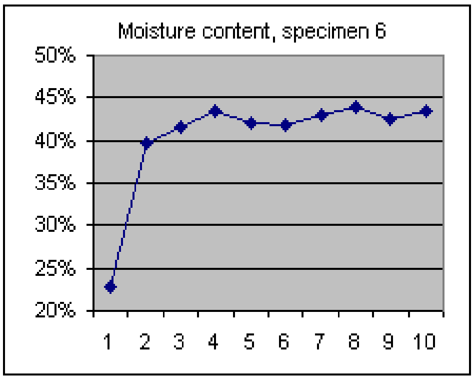












Pictures of failure, perpendicular to bed joints

Specimen 1

Specimen 2

Specimen 3

Specimen 4

Specimen 5

Specimen 6

Appendix D
Determination of compressive strength and modulus of elasticity

Determination of compressive strength and modulus of elasticity

Products

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Thin bed mortar, H+H Celcon

Test report

The following test report is established according to the standard SS-EN 1052-1.

1) Standard	SS-EN 1052-1
Edition	first edition
Date of issue	1999-02-12

2) Tested at Lund institute of technology, division of structural engineering.

3) Number of specimens	6 specimens

4) Date of building the specimens	2005-11-23

5) The temperature varied between 12,40 and 17,20 ° C during the curing period. The relative humidity was constant close to 99 %.

6) Date of testing the specimens.	No.1	2006-02-13
	No.2	2006-02-14
	No.3	2006-02-14
	No.4	2006-02-15
	No.5	2006-02-15
	No.6	2006-02-16

7) All specimens were built up by 5 courses with a customary half block displacement between the cross joints as shown in figure 2. The specimens had the following size:

- Width 1000 mm
- Height 1000 mm
- Thickness 365 mm

The loaded cross sectional areas are consequently 0,365 m^2. Due to the lack of mortar in the cross joints, the loaded cross sectional areas are equal for all specimens.

8) For description of the masonry units and its properties, see section 2.2 For description concerning the mortar, see section 2.7 No tests concerning the mortar were made.

9) No non-autoclaved units are of current interest.

10) Mean moisture content for the current specimens is shown in the table below.

Specimen	moisture content (%)
1	41.76%
2	40.25%
3	44.17%
4	41.78%
5	40.97%
6	43.50%

11) Individual failure load, compressive strength for each specimen, the time to failure, ultimate strain and the modulus of elasticity.

Specimen (No)	Failure load (kN)	Time to failure (min)	Compressive strength (MPa)	Ultimate strain (‰)	Modulus of Elasticity (GPa)
1	391	23,30	1,148	2,46	1,5
2	487	18,0	1.428	1,07	1,5
3	368	14,18	1.075	1,59	2,5
4	400	15,18	1.182	1,30	1,4
5	382	14,18	1.118	1,27	1,3
6	400	14,54	1.172	2,29	1,9

12) Mean compressive strength: 1,196 MPa
Coefficient of variation: 10,3 %
Characteristic compressive strength: 0,953 MPa (95 % confidence interval)

13) Load at which the first visible crack occurred.

Specimen (No)	Visible Crack (kN)	Failure load (kN)
1	N.I.	419
2	N.I.	521
3	366	392
4	417	431
5	257	408
6	306	428

14) The modulus of elasticity is determined as a secant modulus.

Mean modulus of elasticity: 1,70 GPa

Coefficient of variation: 26,7 %

15) Remarks:

1) The fluctuations of the values regarding the modulus of elasticity were large Therefore the characteristic value of the modulus of elasticity will decrease due to the high standard deviation.

2) For the first two specimens, no information regarding the visible crack was recorded.

Thickness of joints

The thickness of the joints is determined as a mean value from 25 randomly measured joints. Mean thickness: 1,40 mm.

Compressive strength

Bayesian ~ 75 % confidence interval

compressive strength f1 (MPa)	1,148
compressive strength f2 (MPa)	1,428
compressive strength f3 (MPa)	1,075
compressive strength f4 (MPa)	1,182
compressive strength f5 (MPa)	1,118
compressive strength f6 (MPa)	1,172
Mean compressive strength f_m (MPa)	1,187
Standard deviation	0,124
Coefficient of variation	10,5%
n (number of specimen)	6,000
k (function of n)	2,180
log f1	0,060
log f2	0,155
log f3	0,031
log f4	0,073
log f5	0,049
log f6	0,069
log f_m	0,073
Standard deviation log-normal	0,043
logarithmic characteristic strength	-0,021
Characteristic strength f_c (Mpa)	**0,953**

modulus of elasticity

modulus of elasticity, secant #1 (Mpa)	1543,782
modulus of elasticity, secant #2 (Mpa)	1534,907
modulus of elasticity, secant #3 (Mpa)	2509,818
modulus of elasticity, secant #4 (Mpa)	1430,221
modulus of elasticity, secant #5 (Mpa)	1250,484
modulus of elasticity, secant #6 (Mpa)	1920,445

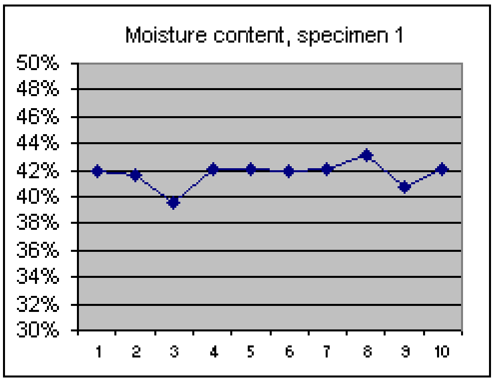
Mean modulus of elasticity f_m (MPa)	1698,276
Standard deviation	454,068
Coefficient of variation	26,7%
log #1	3,189
log #2	3,186
log #3	3,400
log #4	3,155
log #5	3,097
log #6	3,283
log f_m	3,218
Standard deviation log-normal	0,107
logarithmic modulus of elasticity	2,984
Characteristic modulus of elasticity (Mpa)	**964,253**

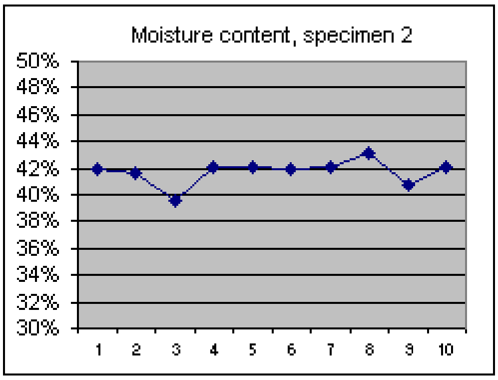
75 % confidence interval

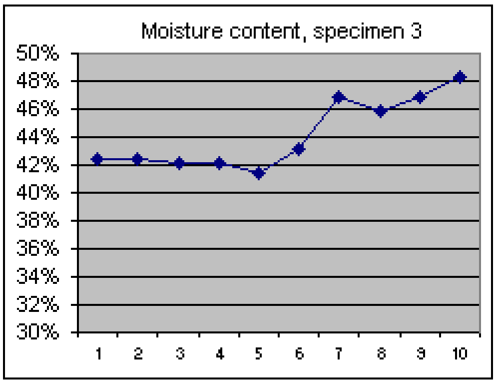
k (function of n)	2,330
logarithmic characteristic strength	-0,027
Characteristic strength including all specimens (Mpa)	**0,939**

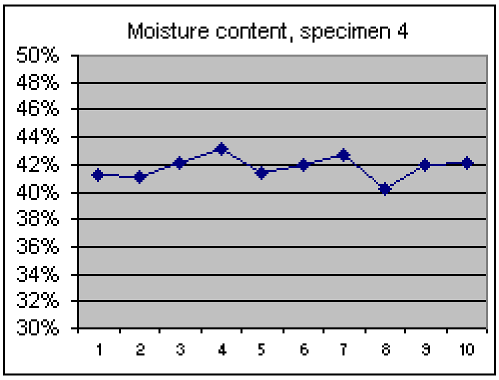
logarithmic modulus of elasticity	2,968
Characteristic modulus of elasticity (Mpa)	**929,133**

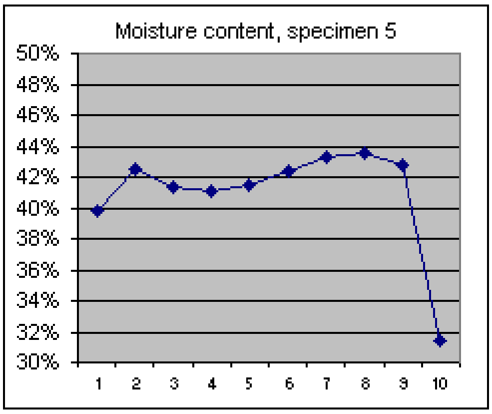
Moisture content, compressive strength

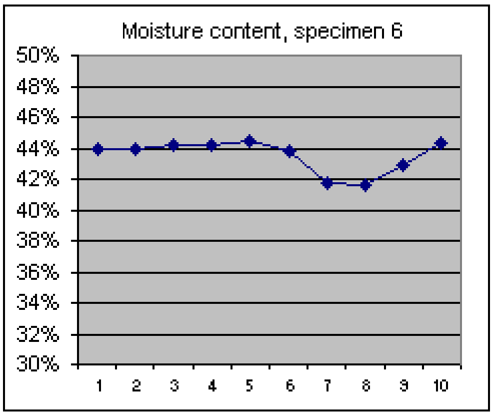






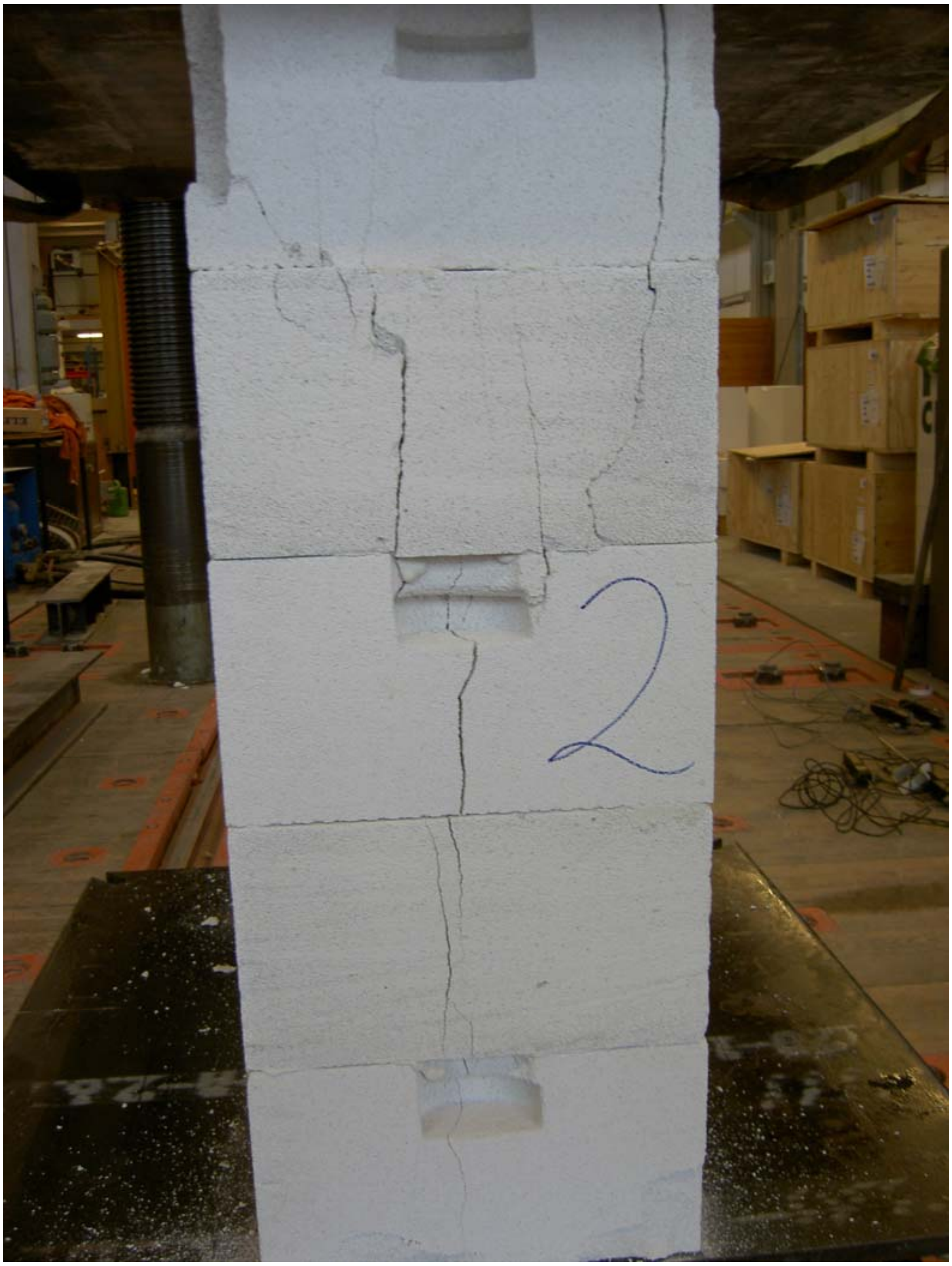






Pictures of failure, compressive strength

Specimen 1



Specimen 2

Specimen 3

Specimen 4

Specimen 5

Specimen 6

Appendix E
Determination of shear strength

Determination of shear strength

Products

AAC, H+H Celcon, 500 x 365 x 200 mm^3.

Thin bed mortar, H+H Celcon

Test report

The following test report is established according to the standard prEN 1739.

1) Standard	prEN 1739
Version	2.2
Date of issue	2005-02

2) Tested at LIP BYGNINGSARTIKLER A/S
Industrivej 16
5580 Nr. Åby
Denmark

3) Number of specimens	9 specimens
4) Date of building the specimens	2005-11-23

5) The temperature varied between 12,40 and 17, 20 ° C during the curing period. The relative humidity was constant close to 99 %.

6) Date of testing the specimens. 2006-03-01

7) The specimens consist of two compounded parts of AAC. The joint area is 150x150 mm^2. The length of each part is 100 mm and 200 mm respectively. The total length of the specimen is thereby 300 millimetres.

8) For description of the masonry units and its properties, see chapter 2.2. For description concerning the mortar, see part 2.7. No tests concerning the mortar were made.

9) Individual failure load, shear strength for each specimen and the time to failure.

Specimen (Nr)	Failure load (kN)	Time to failure (min)	Area (m^2)	Shear strength (MPa)
1	7.11	4	0.0223	0,318
2	11,3	10	0.0227	0,498
3	5,64	8	0.0221	0,254
4	8.34	8	0.0197	0,422
5	5.39	8	0.0207	0,261
6	8.58	7	0.0221	0,388
7	10.8	8	0.0222	0,486
8	5.88	5	0.0223	0,264
9	7.36	7	0.0225	0,327

10) Mean shear strength: 0,358 MPa
Coefficient of variation: 26,6 %
Characteristic shear strength: 0,207 MPa (95 % confidence interval)

11) Remarks:

Originally, ten specimens were manufactured but one of them was damaged during the testing procedure and is therefore excluded in the test report.

Shear strength

Bayesian ~ 75 % confidence interval

Specimen no		Failure Load (kN)	Area (mm2)	Shear strength (MPa)
	f1	7.11	22344	0.318
	f2	11.28	22650	0.498
	f3	5.64	22127	0.255
	f4	8.34	19728	0.423
	f5	5.39	20675	0.261
	f6	8.58	22122	0.388
	f7	10.79	22184	0.486
	f8	5.88	22290	0.264
	f9	7.36	22485	0.327

Mean flexural strength f_m (MPa)	0.358
n (number of specimen)	9
k (function of n)	1.96
log f1	-0.497
log f2	-0.303
log f3	-0.594
log f4	-0.374
log f5	-0.584
log f6	-0.411
log f7	-0.313
log f8	-0.578
log f9	-0.485
log f_m	-0.460
Standard deviation	0.095
Standard deviation log-normal	0.115
Coefficient of variation	26.61%
logarithmic characteristic strength	-0.685
Characteristic strength f_k	**0.207**

75 % confidence interval

k (function of n)	2.140
logarithmic characteristic strength	-0.705
Characteristic strength f_k	**0.197**

Pictures of failure, shear strength

Specimen 1

Specimen 2